User's Guide

GoldSim

Probabilistic Simulation Environment

GoldSim
TECHNOLOGY GROUP

Version 14.0 (October 2021)

GoldSim Technology Group
255 S. King Street, Suite 800
Seattle, Washington 98104
USA

Visit us at our web site: www.goldsim.com
Email us at: software@goldsim.com

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Chapter 1: Welcome to GoldSim!

> If a man will begin with certainties, he shall end in doubts, but if he will be content to begin with doubts, he shall end in certainties.
>
> Francis Bacon, *The Advancement of Learning*

Chapter Overview

GoldSim is a user-friendly, highly graphical program for carrying out dynamic, probabilistic simulations to support management and decision-making in business, engineering and science.

This User's Guide provides a complete description of the features and capabilities of GoldSim.

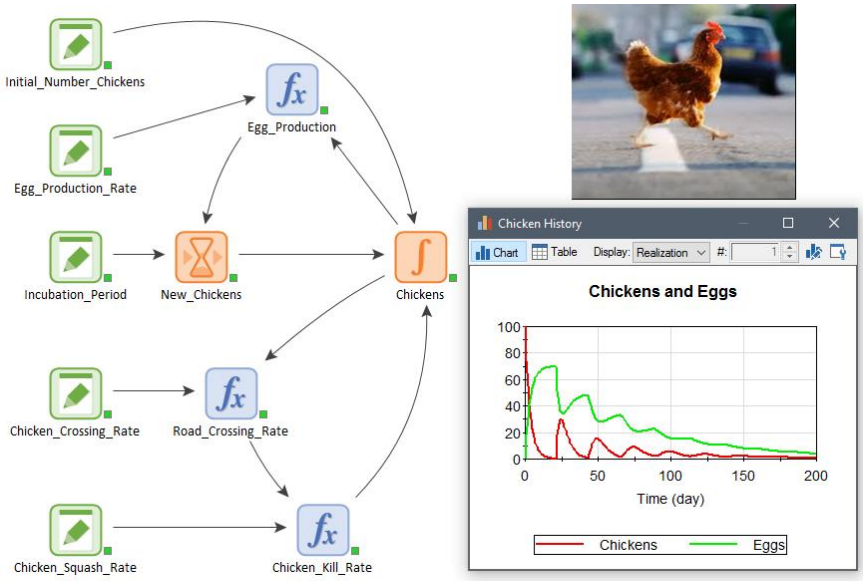
In this Chapter

This introductory chapter discusses the following topics:

- What is GoldSim?
- How to Use this Manual
- Conventions Used in this Manual
- Installing and Activating GoldSim
- Learning to Use GoldSim
- Using Help and the GoldSim Tutorial
- Getting Technical Support

What is GoldSim?

GoldSim is a highly graphical, object-oriented computer program for carrying out dynamic, probabilistic simulations. In a sense, GoldSim is like a "visual spreadsheet" allowing you to *visually* create and manipulate data and equations.



What Can I Do With GoldSim?

GoldSim is a simulation program. As used here, *simulation* is defined as the process of creating a model (i.e., an abstract representation or facsimile) of an existing or proposed *system* (e.g., a business, a mine, a watershed, a forest, the organs in your body, the atmosphere) in order to identify and understand those factors which control the system and/or to predict (forecast) the future behavior of the system. Almost any system which can be quantitatively described using equations and/or rules can be simulated.

Simulation is an important tool because it provides a way in which alternative designs, plans and/or policies can be evaluated without having to experiment on a real system, which may be prohibitively costly, time-consuming, or simply impractical to do. That is, simulation allows you to ask "What if?" questions about a system without having to experiment on the actual system itself (and hence incur the costs and delays associated with field tests, prototypes, etc.).

What Kind of Problems Can I Apply It To?

Because GoldSim was designed with flexibility in mind, you can use it to simulate almost any kind of system. Illustrative examples from the fields of business, science and engineering include the following:

Strategic Planning: You could simulate the implementation of a complex undertaking (e.g., design, manufacture and marketing of a new product) by describing the tasks involved, any precedent requirements (i.e., what must be done before a particular task can begin or end), task durations and costs, and events which could impact the process. The output of such a simulation might be the probability of successfully completing the undertaking (in a certain timeframe, or at a certain level of profitability). You could use the results to identify potential problems that might arise and design contingency plans. On a larger scale, such a tool could be then used to evaluate and manage portfolios of projects and investments.

Ecology: The growth of a group of animals could be simulated by describing in mathematical terms the initial number of animals, the birth

rate, the death rate, the rate at which animals migrate to or away from the group, possible catastrophic events, etc. The output of this simulation would then be the number of animals in the group as a function of time (e.g., one year from now, ten years from now, etc.). You could use the results to better manage the system in order to stabilize or increase the population (e.g., by limiting hunting, or introducing predators).

Environment: You could simulate the performance of a hazardous waste site by describing the initial conditions (e.g., the geometry of the system, the amount of contaminants in the system) and the processes acting on the system (e.g., degradation of the drums containing the waste, migration of contaminants through the environment). The output of this kind of simulation would be contaminant concentrations around the site as a function of time. You could use the results to design remediation measures which would minimize the environmental impacts at the site.

Reliability Engineering: The reliability of a proposed satellite system could be simulated by describing the components of the system and the processes and events which could compromise the system's integrity and lead to failure or downtime. The outputs of this kind of simulation would include the predicted reliability of the system and the probability and consequences of different types of failures. You could use the results to modify the design so as to maximize the reliability and minimize the probability and/or consequences of a failure.

Manufacturing: You could simulate the coupled dynamics of a manufacturing supply chain by defining the "links" in the chain (Retailer, Distributor, Manufacturer, Tier 1 supplier(s), Tier 2 suppliers, etc.) and how these organizations interact with each other. The model would simulate the movement of materials (parts to finished product) through the supply chain, and could be used to identify ways in which the system could be modified (e.g., via technology or improved decision rules) to operate more efficiently.

What Makes GoldSim Unique?

GoldSim is user-friendly and highly graphical, such that you can literally draw and subsequently present a picture (or *influence diagram*) of the system you wish to model in an intuitive way without having to learn a great deal of symbols, notation and functions.

Because simulation can be such a powerful tool for understanding and managing complex systems, a variety of graphical simulation tools currently exist. The following combination of features, however, makes the GoldSim approach unique:

GoldSim was specifically designed to quantitatively address the inherent uncertainty which is present in real-world systems. GoldSim provides powerful tools for representing uncertainty in processes, parameters and future events, and for evaluating such systems in a computationally efficient manner.

GoldSim provides powerful capabilities for superimposing the occurrence and consequences of discrete events onto continuously varying systems. This allows for the realistic simulation of discrete events such as financial transactions, accidents, system failures, storms, labor strikes, and lawsuits.

GoldSim was designed to facilitate the construction of large, complex models. You can build a model of your system in a hierarchical, modular manner, such that the model can readily evolve and add detail as more knowledge regarding the system is obtained. Other powerful features, such

as the ability to manipulate arrays, the ability to "localize" parts of your model, and the ability to assign version numbers to a model which is constantly being modified and improved, further facilitate the construction and management of large models.

GoldSim is dimensionally-aware. GoldSim has an extensive internal database of units and conversion factors. You can enter data and display results in any units. You can even define your own customized units. GoldSim ensures dimensional consistency in your models and carries out all of the unit conversions internally. As a result, when you use GoldSim, it is never necessary for you to carry out (error-prone) unit conversions.

GoldSim is highly extensible. You can dynamically link external programs or spreadsheets directly into your GoldSim model. In addition, GoldSim was specifically designed to support the addition of customized modules (program extensions) to address specialized applications.

GoldSim allows you to create compelling presentations of your model. A model that cannot be easily explained is a model that will not be used or believed. GoldSim was specifically designed to allow you to effectively document, explain and present your model. You can add graphics, explanatory text, notes and hyperlinks to your model, and organize it in a hierarchical manner such that it can be presented at an appropriate level of detail to multiple target audiences.

What Do I Need to Use GoldSim?

The program runs on personal computers using Microsoft Windows® 10 (Version 1903 or higher) . If you are linking GoldSim to Microsoft Excel, you must Excel 2010 or later (2016 or later recommended). You must have Administrative Privileges on the system during the installation and and a minimum of 500 MB disk space.

Because GoldSim is very powerful and flexible, it is relatively complex. Nevertheless, the software can be readily mastered by anyone familiar with the basic functions of a personal computer and the Windows operating system. Since a GoldSim model is built by describing functional relationships (equations) between the components of your system, however, you must be comfortable with the basics of quantitative analysis. This does not mean you must be a mathematician or a numerical modeler. As a rule of thumb, if you are comfortable using a spreadsheet you can learn to build a model in GoldSim.

Finally, although GoldSim can be run in a deterministic manner (i.e., with no uncertainty specified in the input parameters), one of the key features of the program is its ability to explicitly represent such uncertainty through the use of probability distributions. In order to do so, you must have at least a basic understanding of the representation and propagation of uncertainty. Appendix A provides a brief primer on this topic, along with suggestions for further reading.

How to Use this Manual

One way to learn a new program is to read the user's guide (if it exists and is well-written) from front to back, while simultaneously experimenting with the program. Although a few people may prefer this method, we realize that most software users (including ourselves!) rarely have the time or patience to do this. Instead, most of us prefer to read some introductory material (or take a training course), and then "dive in", referring to the documentation when we are stuck or need to learn a new feature. Therefore, this document is designed primarily to be used in this way, as a reference document.

Note: As will be discussed at the end of this chapter, because it can be time-consuming and inefficient to learn how to use a new software tool by only referring to detailed reference documentation, a number of other resources are available that complement this document and are specifically intended to help beginners learn to use GoldSim.

Read more: Learning to Use GoldSim (page 19)*.*

The document is heavily cross-referenced, such that each chapter and each major section can stand alone. To facilitate the use of these cross-references, whenever they appear in the manual, they are set off from the text and always proceeded by "Read More:"), as shown above.

This allows the document to be readily used as a reference guide, with the user accessing topics and features via the cross-references, the table of contents and/or the index on an as-needed basis. Furthermore, as will be discussed later in this introduction, nearly all of the information available in the printed documentation can also be accessed via an extensive help system.

Note: Although this manual is written primarily so that it can be used as a reference document, it is highly recommended that all users read Chapters 2 and 3 before starting to use GoldSim.

Example Models

Starting with Chapter 3, the manual references a number of examples that are relevant to features being discussed. When you install GoldSim, a number of examples are installed with the program. These example model files are mentioned in the text, and provide an excellent way to begin to experiment with GoldSim. Each example is internally documented with comments regarding the way the model was implemented.

Note: You can quickly access these files by selecting **File|Open Example…** from the main GoldSim menu.

Note: These examples are read-only files. If you wish to modify them, you will need to Save As.

Note: Additional (and generally more detailed) example models are available in the Model Library on the GoldSim web site.

How this Manual is Organized

This document is organized into ten chapters:

Chapter 1: Welcome to GoldSim! The remainder of this chapter discusses the information required for you to get started using GoldSim, including conventions used in the manual, installing the program, using online help, and obtaining technical support.

All users should read Chapters 2 and 3! These two chapters will provide you with enough information to start using GoldSim.

Chapter 2: GoldSim in a Nutshell. This chapter provides a broad overview of the features and capabilities of GoldSim. It is strongly recommended that you read this chapter, as it will tell you what the program is capable of doing, and direct you to those portions of the manual where you can obtain further information.

Chapter 3: Building a Model in GoldSim. This chapter describes the GoldSim user interface, and presents all of the techniques required for creating, editing, and navigating a GoldSim model. Before trying to experiment with GoldSim, it is highly recommended that you read this chapter in order to familiarize yourself with these basic techniques.

Chapter 4: Using the GoldSim Elements. GoldSim models are built using a wide variety of model objects (referred to as *elements*). This chapter describes the details of using the basic elements in GoldSim.

Chapter 5: Simulating Discrete Events. In many systems, processes occur that are discrete as opposed to continuous. These discrete occurrences are referred to within GoldSim as *events*. This chapter describes the GoldSim elements that you can use to simulate the occurrence and consequences of discrete events.

Chapter 6: Customizing the Interface. This chapter provides instructions for customizing the appearance of the user interface to meet your specific needs.

Chapter 7: Running a Model. After you have created a model, you need to run the model in order to produce results. This chapter describes the details of how to control your simulation (e.g., specify its duration), specify the types of results you wish to save, and run the model.

Chapter 8: Displaying Results in GoldSim. This chapter describes how you can view (via charts and tables), analyze, and present model results.

Chapter 9: Documenting and Presenting Your Model. GoldSim was specifically designed to allow you to effectively document, explain and present your model. This chapter describes how you can add graphics, explanatory text, notes and hyperlinks to your model, and organize it in a hierarchical manner such that it can be presented at an appropriate level of detail to multiple target audiences.

Chapter 10: Advanced Modeling Concepts. This chapter describes advanced and powerful capabilities of GoldSim that you will want to take advantage of once you become comfortable with the program, including using and manipulating arrays (vectors and matrices) in your models, simulating discrete events, and linking GoldSim to a database.

This manual also includes six appendices.

Appendix A: Introduction to Probabilistic Simulation. This appendix provides an introduction to basic concepts of probabilistic simulation, and provides suggestions for further reading.

Appendix B: Probabilistic Simulation Details. This appendix describes the mathematical details of the manner in which uncertainty is represented, propagated, and displayed in GoldSim.

Appendix C: Implementing External (DLL) Elements. This appendix provides instructions for users who wish to directly link external programs into a GoldSim model.

Appendix D: GoldSim Units Database. As mentioned above, GoldSim is dimensionally aware and carries out all unit conversions internally. This appendix lists all of the internal units and conversion factors provided by GoldSim.

Appendix E: Database Input File Formats. GoldSim allows data to be imported from an ODBC-compliant database directly into GoldSim. This appendix describes the required database structures and formats to facilitate such a data transfer.

Appendix F: Integration Methods and Timestepping Algorithm. This appendix describes the methods used by GoldSim to numerically integrate differential equations. It also discusses the unique timestepping algorithm GoldSim uses to accurately represent discrete events.

The manual also includes a Glossary of Terms and an Index.

Conventions Used in this Manual

The following conventions are used in this manual:

Convention	Description
Important Terms	New and important terms are presented in *bold italics*. These terms all appear in the Glossary of Terms at the end of the document.
File | Open…	Menus and menu selections are separated by a vertical bar. File | Open… means "Access the File menu and choose Open"
CTRL+C	Key combinations are shown using a "+" sign.. CTRL+C means press the Control and C keys simultaneously.
	**Warning**: This means watch out! Warnings typically alert you to potential pitfalls and problems that may occur if you perform (or fail to perform) a certain action.
	**Note**: Notes highlight important information about a particular concept, topic or procedure, such as limitations on how a particular feature can be used, or alternative ways of carrying out an action.

In describing various mouse actions, the following conventions are used:

Mouse Action	Definition
Click	Press and release the left mouse button once.
Double-click	Press and release the left mouse button twice in rapid succession.
Right-click	Press and release the right mouse button once.
Drag	Press the left mouse button, and while keeping it depressed, move the cursor to another location, then release the button.

Installing and Activating GoldSim

To install GoldSim, double-click the GoldSim installation file and follow the directions on the screen. The installation file for the latest version of GoldSim (as well as previous versions) is available on the GoldSim web site.

Note: In order to install GoldSim, you must have Administrator privileges on the computer.

During the installation process, the GoldSim License Agreement will be displayed in a dialog.

You can press the **Print…** button to print the document at this time to obtain a hardcopy version of the License Agreement. You must select "I accept the terms in the license agreement" to continue with the installation.

Note: After completing the installation of GoldSim, you can access the License Agreement at any time by selecting **Help|About GoldSim** from the main menu and pressing the **User License Agreement** link on that dialog.

Once the program is installed, GoldSim can be used by either activating a ***Standalone license*** on your computer, or by accessing a ***Network license*** that has been activated on a License Server.

Standalone licenses are activated on a single computer and, once they are activated, do not require connection to the internet (the license resides on the computer). Network licenses reside on a License Server, and in order to use the license, your computer must be persistently connected to the License Server (although as will be discussed below, licenses can be "borrowed" from the License Server so that they temporarily reside on your computer and a connection to the License Server is no longer necessary).

If you are unsure of what type of license you have, refer to the email you received from the GoldSim Technology Group when the license was provided (this may have been sent to a License Administrator).

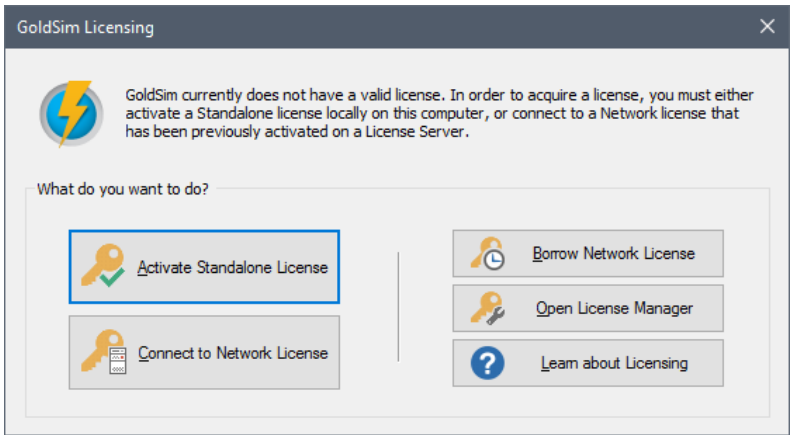
Using a Standalone License

There are two types of ***Standalone licenses***: Desktop Standalone licenses, and Enterprise Standalone licenses. The licenses are identical in all respects with one exception: Desktop Standalone licenses limit the number of license transfers (to 6 per year). Enterprise Standalone licenses allow an unlimited number of transfers.

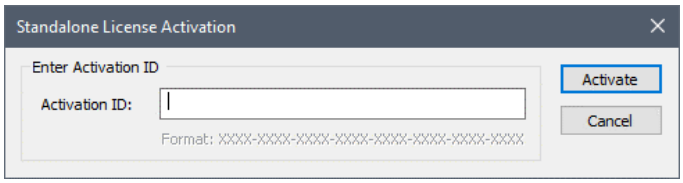
Activating a Standalone License

This section describes how to activate a GoldSim ***Standalone License*** (Desktop or Enterprise). The instructions below assume that you have an internet connection on the computer where you have installed GoldSim. If you do not have an internet connection, contact your License Administrator or GoldSim Technology Group for instructions on how to activate the license manually.

When you open an unlicensed copy of GoldSim, you will see the following dialog:

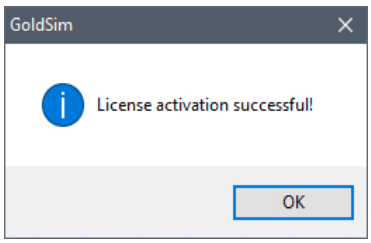


To activate a Standalone license, press the **Activate Standalone License** button. The following dialog will then be displayed:



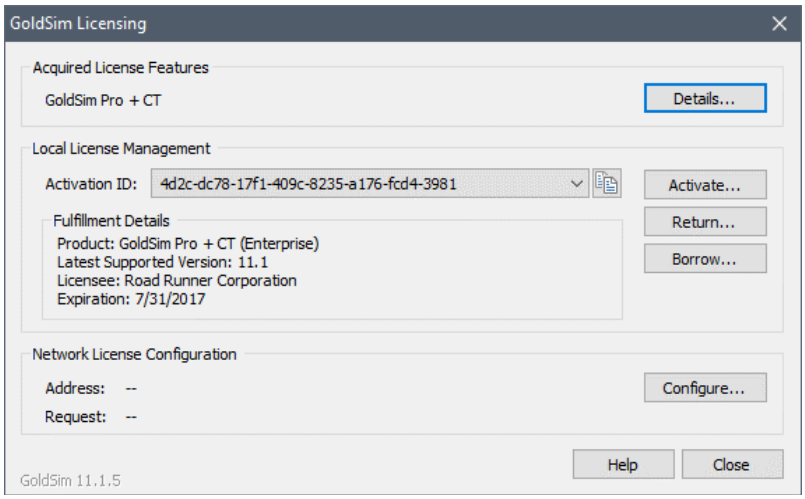
An ***Activation ID*** should have been provided to you (or your License Administrator) via email. The Activation ID is a 32-digit code (8 groups of 4 digits each, separated by hyphens) that is used to activate your license. To avoid errors, rather than typing the Activation ID in by hand, it is suggested that you copy your Activation ID (highlight it and press **Ctrl+C**) from the email that you received and paste it (**Ctrl+V**) into the **Activation ID** field.

After doing so, click the **Activate** button. You will momentarily see a progress dialog while GoldSim carries out the activation. If your license activation was successful, you will see the following message dialog:



When you click **OK**, GoldSim should open.

After successful activation, you can view your license details by selecting **Help|Licensing…** from the main GoldSim menu. This will open the GoldSim License Manager:

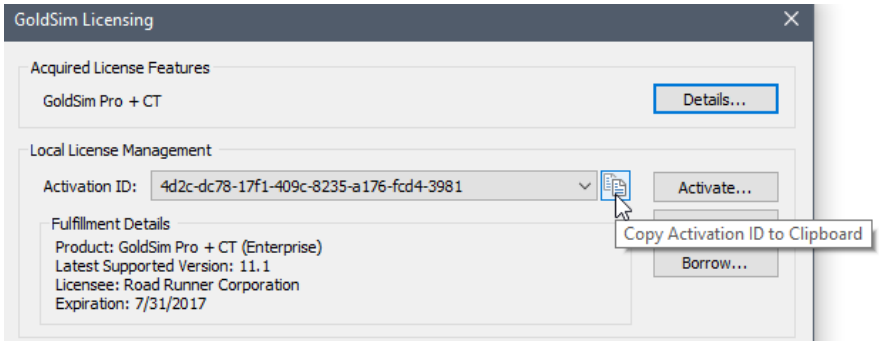


In this dialog, you can see details about your license. The middle section, *Local License Management*, displays your **Activation ID**, the **Product** name, the **Latest Supported Version**, the **Licensee** organization and the **Expiration** date of the license.

You can use any version of GoldSim including and prior to the **Latest Supported Version** with your GoldSim license. Note, however, that the current licensing system only supports GoldSim 10.5 (released in 2010) and later. If you need to use a very old version of GoldSim (previous to 10.5), contact the GoldSim Technology Group.

Although GoldSim licenses are perpetual, they still expire (typically after one year) and must be re-activated annually (at no charge). GoldSim will send reminders to your License Administrator several months prior to the **Expiration** date listed in the dialog.

If you ever need to provide your Activation ID to GoldSim Technology Group or to someone within your organization, you can copy the Activation ID to the clipboard using the copy button in the GoldSim License Manager dialog located to the immediate right of the Activation ID:



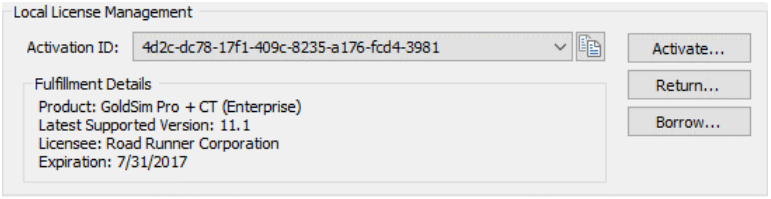
Returning (Deactivating) and Transferring a Standalone License

If you have already activated GoldSim on a computer and you wish to transfer the license to another computer, you can return (i.e. deactivate) the license and then activate it on another computer. This can be done very quickly without having to contact GoldSim Technology Group. This allows you to easily share your license with others.

Be aware, however, that if you are using a Desktop Standalone license, you are limited in the number of times you can transfer your license (6 times per year). If you plan to frequently move a Standalone license between computers and you

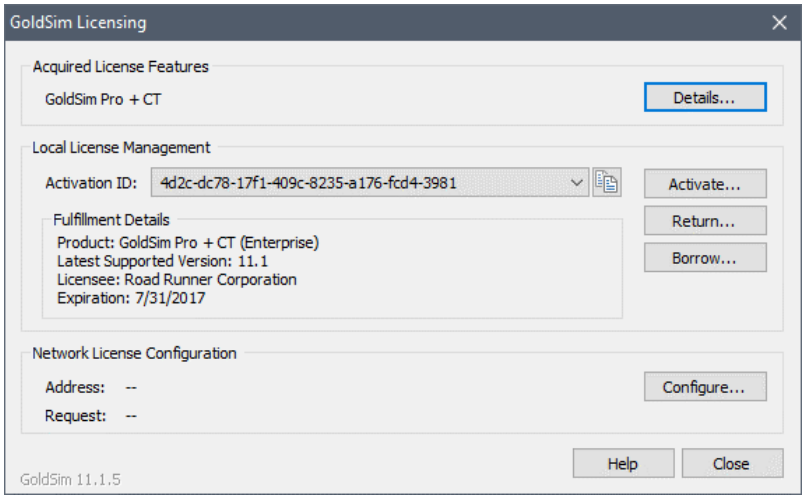
have a Desktop Standalone license, you can upgrade to an Enterprise Standalone license, which allows an unlimited number of transfers. This is useful in the case where you are frequently sharing the license with other users.

If you are unsure what type of license you have (Desktop or Enterprise), open GoldSim and from the main menu select **Help|Licensing…** to open the License Manager. In *the Local License Management* section, you can see information about your license. The license type is shown in parentheses in the **Product** line:



The instructions below for returning a license assume that you have an internet connection on the computer where you have installed GoldSim. If you do not have an internet connection, contact your License Administrator or GoldSim Technology Group for instructions on how to deactivate the license manually.

To return (deactivate) a Standalone license, open GoldSim and from the main menu select **Help|Licensing…** to open the License Manager:

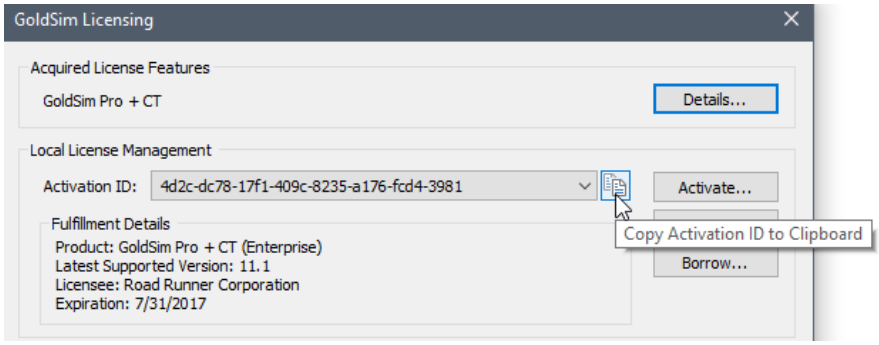


From the drop-list in the *Local License Management* section, select the **Activation ID** for the license that you want to return (in most cases, there will only be one in the list).

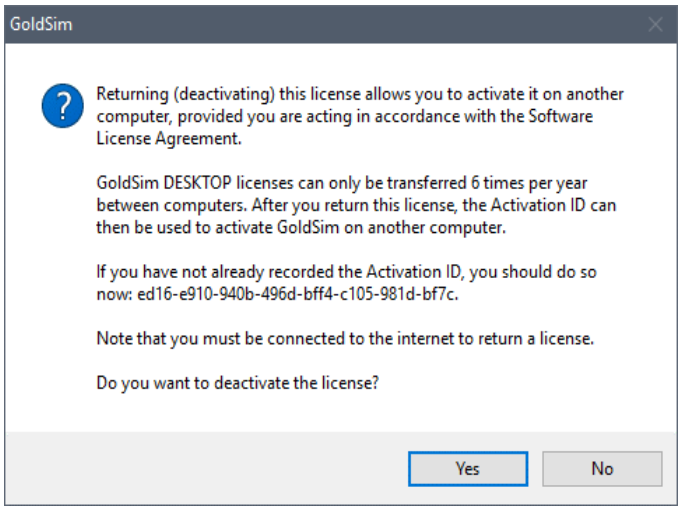
Note: The **Activation ID** is a drop-list, since under some license use scenarios, you could have multiple activations on your computer (e.g., if you temporarily needed to borrow a license with additional modules that was available on a Network license server, but not on your Standalone license). In most situations, however, there will only be a single Activation ID in the list. The *Fulfillment Details* refer to the selected Activation ID, so you can easily understand what each ID represents.

After you return a license, in most cases, you will want to communicate to others in your organization (e.g., your License Administrator, a colleague who wants to use the license) which Activation ID you have returned. Therefore,

before you return the license, you should copy the **Activation ID** to the clipboard so you can easily paste it into an email. You can do so by pressing the copy button to the right of the Activation ID:



Once the the Activation ID has been selected (and copied), click the **Return…** button. You will see a dialog asking you to confirm whether or not you want to proceed with the return. Note that his message indicates what type of Standalone license you have (Desktop or Enterprise):



It also prompts you to record the Activation ID (if you have not already done so). You cannot highlight and copy text in this dialog. Hence, if you have not already copied the Activation ID (as described above), the easiest thing to do is press **No** in this dialog, which will return you to the License Manager dialog. You can then copy the Activation ID using the copy button to the right of the Activation ID, and proceed again with the return.

If the return was successful, you will be notified. Once a license has been returned, it will no longer be used on the computer from which you returned the license. This means that you can activate that license on a different computer using the same Activation ID.

Reactivating or Upgrading a Standalone License

In addition to initially activating your Standalone license, there are three instances in which you will need to reactivate the license (provide a new Activation ID):

- Although GoldSim licenses are perpetual, they still expire (typically after one year) and must be re-activated annually (at no charge). GoldSim will send reminders to your License Administrator several months prior to the **Expiration** date (listed in the GoldSim License Manager dialog).

- When a new version of GoldSim is released that you are eligible to use (i.e., your license is under active maintenance).
- In some cases, you may decide to upgrade your license (e.g., add a specialized extension module, or convert from a Desktop to an Enterprise Standalone).

  Read more: Specialized GoldSim Modules (page 52).

In all of these instances, you will be provided with a new Activation ID by the GoldSim Technology Group. You will then need to reactivate your license with the new Activation ID by following these simple steps:

1. Select **Help|Licensing…** from the main GoldSim menu to open the GoldSim License Manager dialog.
2. Press the **Activate…** button in the GoldSim License Manager dialog to display this dialog:

3. Enter the new Activation ID and press **Activate**.

Using a Network License

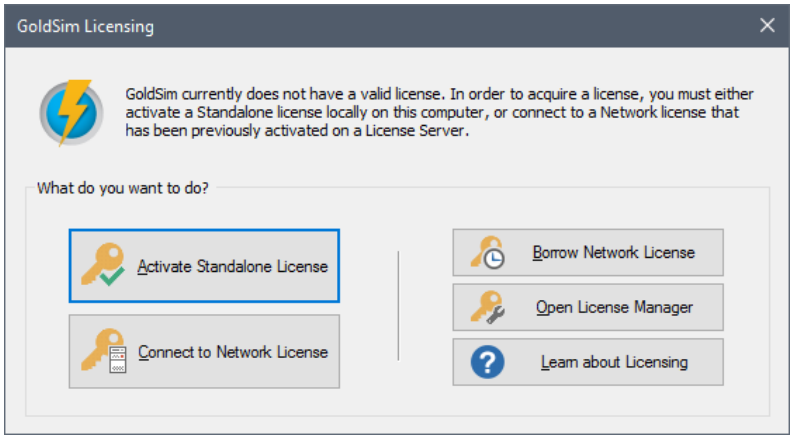
Network licenses allow you to easily share licenses across an organization. To use a Network license, you still must have GoldSim installed locally on your computer, but the license itself resides on a License Server.

In order to use the license, your computer must be persistently connected to the License Server (although as will be discussed below, licenses can be "borrowed" from the License Server so that they temporarily reside on your computer and a connection to the License Server is no longer necessary).

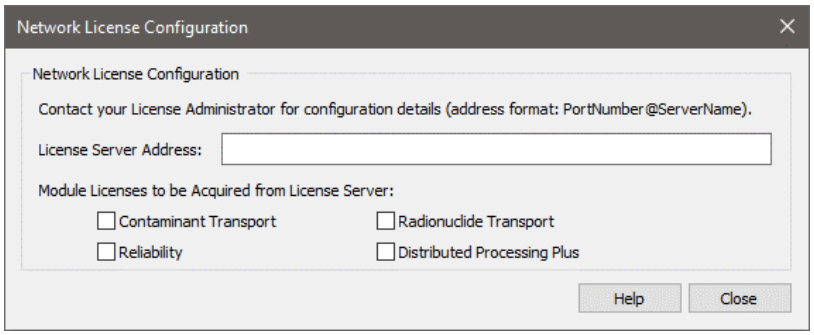
Connecting to a Network License

To use GoldSim by connecting to a Network license, your License Administrator must have already set up and activated the Network license and provided you with an address to the License Server.

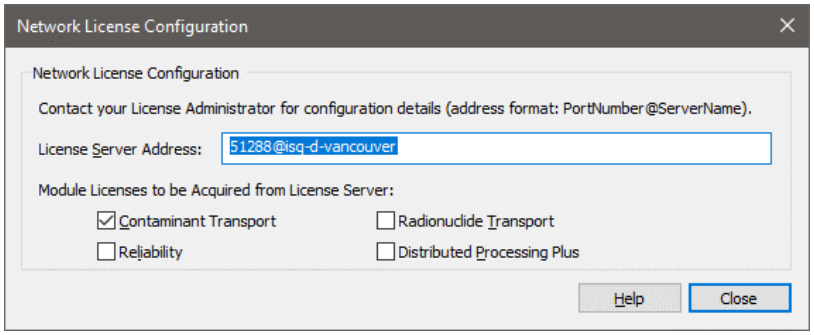
When you open an unlicensed copy of GoldSim, you will see the following dialog:



To use a Network license, press the **Connect to Network License** button. You will see the Network License Configuration dialog:



Enter the **License Server Address** provided to you by your License Administrator. This will take the form of a port number and a server name, such as 51288@isq-d-vancouver, where in this example 51288 is the port number and isq-d-vancouver is the server name). If there are modules available on the License Server that you would like to use, you can request a module by checking the box next to the module you would like to use:

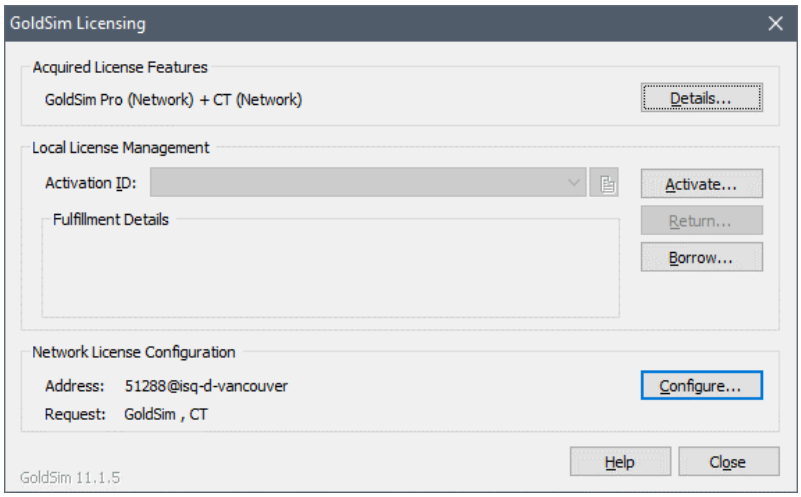


Note: When connecting to a Network license, you will only acquire those modules that you specifically request here. If you do not request a module, you will not acquire it (even if it is available on the License Server).

If there is an available license on the License Server, GoldSim will open after you press **Close**.

Note: If a GoldSim license was available, but a requested module was not, GoldSim will still open but a warning message will inform you that the requested module(s) were not acquired.

If you subsequently open the License Manager dialog (by selecting **Help|Licensing…** from the main GoldSim menu), the dialog will look something like this:



The top section, *Acquired License Features*, will indicate that your license is a Network license. If you were successful in acquiring any modules you requested from the License Server, this will also be indicated in this section.

The bottom section (*Network License Configuration*) shows the Network License Address and also the features you have requested from the License Server. Note that this section indicates what you have requested from the License Server. This does not indicate what you have actually acquired from the License Server. If all licenses are in use or the License Server does not have a module you are requesting, you will get one or more error messages indicating you were not able to acquire the requested feature(s). You can always see what features you have successfully acquired by looking at the *Acquired License Features* section.

Note that you only need to enter the Network License Address (and requested features) once. After you do so, the next time you open GoldSim, it will use that same information to attempt to acquire a license from the License Server.

Note: Once you have acquired a license, you can change the License Server and the modules you wish to request by pressing the **Configure…** button, which reopens the Network License Configuration dialog.

Borrowing a Network License for Offline Use

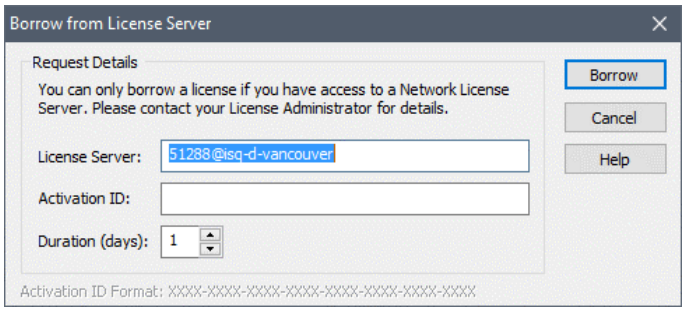
When using a Network license, you may occassionally need to use GoldSim while disconnected from the License Server (for example, when traveling). To facilitate this, GoldSim provides the option to ***borrow*** a license from a License Server for disconnected use. To initially borrow the license, you need to be connected to the License Server. But once the license is borrowed, you can disconnect from the License Server and use the license as though it were a local (i.e., Standalone) license.

At the time you borrow a license, you must specify a duration (in days) for the borrowing period. At the end of this period, the local license (on your computer) automatically expires and the license becomes available again on the License Server.

If you wish to borrow a license and are currently using a Network license, open the License Manager (by selecting **Help|Licensing…** from the main GoldSim menu). Within the License Manager dialog, press the **Borrow…** button.

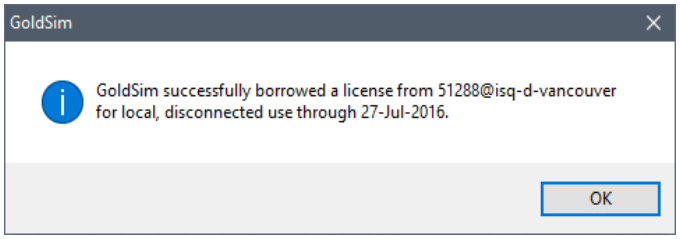
If your copy of GoldSim is currently unlicensed (but you do have access to the License server) and you wish to directly borrow a license, press the **Borrow Network License** button on the dialog that is displayed when you try to run GoldSim.

In both cases, the following dialog will appear:

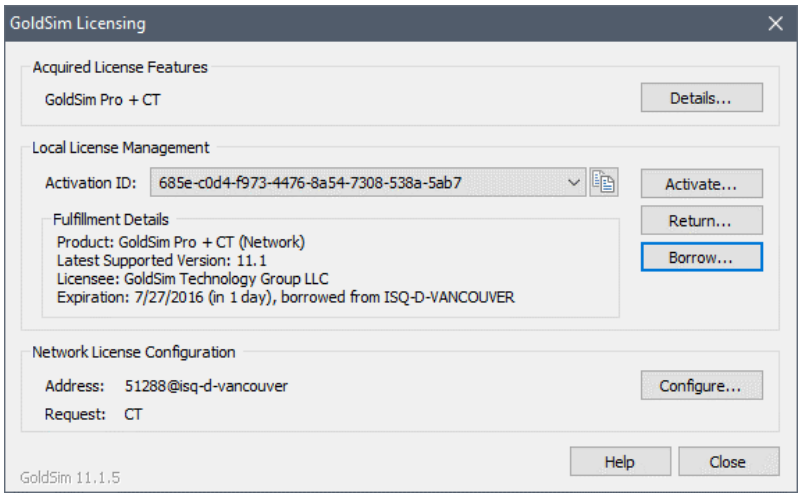


To borrow a license, you will need to enter a **License Server** address and the **Activation ID** for the license that you wish to borrow. You will need to get these from your License Administrator. You must also specify a **Duration** (in days) for which you wish to borrow the license. This can be no longer than 30 days (and may be further limited by your License Administrator).

After entering this information and pressing the **Borrow** button, you will see a progress dialog while GoldSim attempts to borrow the license from the License Server. This should typically only take a few seconds. If the borrow attempt is successful, you will see a message dialog that shows the License Server address and the date on which the borrowed license will expire:

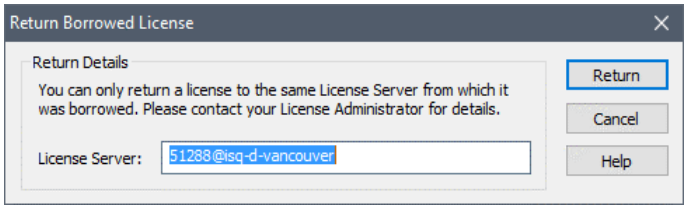


Once you have borrowed a license, in the *Local License Management* section of the License Manager, you can see details for the borrowed license. The details are similar to what would be shown for a local (Standalone) license, with the following exceptions: (1) the **Product** line indicates that the license is a Network license and (2) the **Expiration** line indicates that the license is borrowed (and displays the expiration date):



If you wish to return the license before the expiration date, you can return (deactivate) the license by pressing the **Return…** button. When you do this, you will see a message dialog asking you to confirm the return action. (Note that to return the borrowed license early, you must have access to the License Server.)

After you confirm that you want to return the borrowed license, you will be prompted for the License Server address:

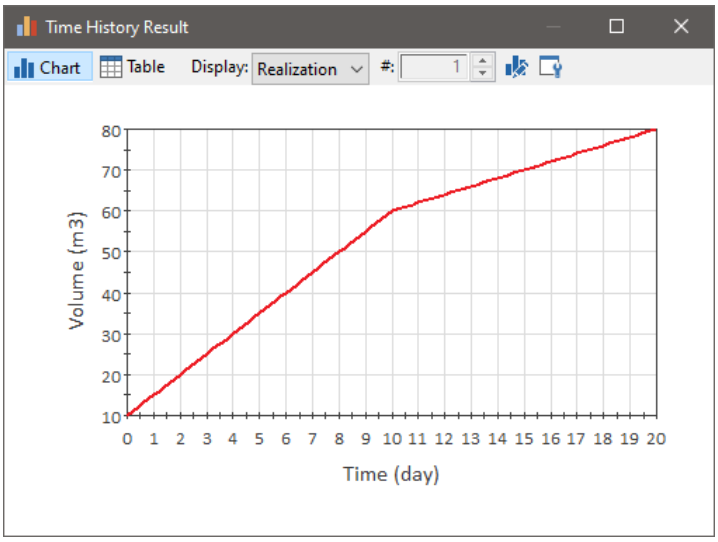


Once you have entered the License Server address, press Return. A progress dialog should appear while the return is carried out. If the return is successful, you will see a confirmation message.

Testing the GoldSim Installation

Once GoldSim is activated, you should ensure that the program was properly installed. To test the GoldSim installation, do the following:

1. Double-click on the GoldSim program icon (on the desktop or, using Windows Explorer, in the folder into which you installed GoldSim) to start the program.
2. Press **Esc** to close the Start dialog that is presented.
3. From the main menu, select **File | Open Example...**
4. Enter the folder named "General Examples".
5. Select a file named "FirstModel.gsm" and press **Open**.
6. Press **F5**.
7. A dialog stating that the simulation has completed will be displayed. Press **OK** to close the dialog.
8. You will see an object labeled "Volume" on the screen.
9. Right-click the object. A menu will be displayed. At the top of the menu, you will see a **Time History Result…** option.
10. Click on this option. The following chart will be displayed:



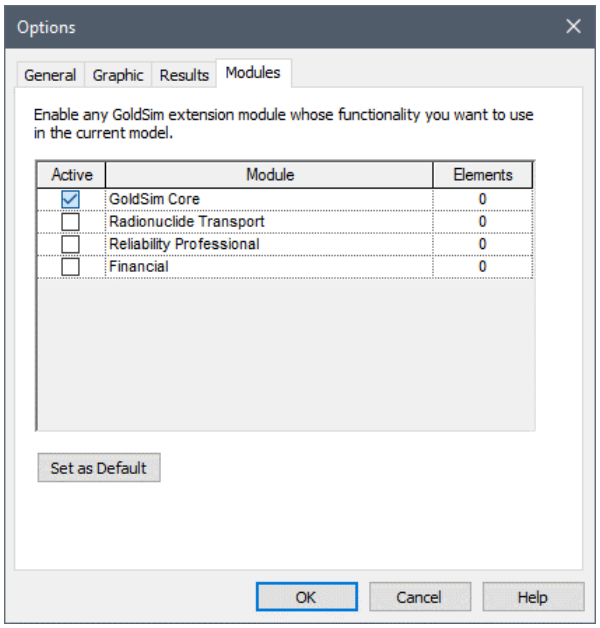
11. If you are able to complete these steps and you chart looks like this, GoldSim has been properly installed. (Close the chart, and you can close GoldSim.)

Activating and Deactivating Extension Modules

GoldSim was designed to facilitate the incorporation of add-on modules (program extensions) to enable the program to address specialized systems. These modules add additional features and capabilities to GoldSim. Your license determines which of these program extensions are available to you.

Read more: Specialized GoldSim Modules (page 52).

You can view which modules are available by selecting **Model| Options…** from the main menu, and selecting the **Modules** tab:



All extension modules that you are licensed to use appear in the dialog. If your license does not allow you to use a particular module, it will not be listed. You can activate and deactivate modules that you are licensed to use by clicking the **Active** checkbox. By default, whenever you activate GoldSim, none of the

available extension modules allowed by your license will be activated. To use them, you must activate them using this dialog.

If you deactivate a module, the specialized elements associated with that module will be deleted from your model (if any are present) and any menu options will be removed in the current file. If you make a module active, the various options associated with that module are made available again. If you press the **Set as Default** button, the selected modules will be activated for all new models that are created.

Note: If you try to open a file that contains elements associated with an extension module, and you are licensed to use that module but it is not currently active, GoldSim will automatically activate the module and open the file. If, however, you are not licensed to use the module, GoldSim will not open the file (and will display an error message).

Sharing a License Between GoldSim Versions on a Computer

GoldSim allows you to automatically share a single license between different GoldSim versions on a single computer. This is particularly useful when converting files from an old version of GoldSim to a new one. In such a case, you may want to have two versions of GoldSim on a single machine (e.g., Version 10.5 and Version 12), and be able to switch back and forth between versions or run both versions simultaneously.

GoldSim allows you to easily share a license in this way. After installing a second version on your machine and trying to run it, GoldSim will automatically detect and use your previously existing license (even if you are running the two versions simultaneously).

Learning to Use GoldSim

Although GoldSim's intuitive interface will tempt you to simply dive in and start playing with the software, you are strongly discouraged from doing so, even if you are an experienced modeler. Spending time up front (by following the steps outlined below) is the most efficient way to understand the software's features and capabilities and start building models in GoldSim.

1. **Take the GoldSim Tutorial**. The GoldSim Tutorial is by selecting **Help | Tutorial…** from the main GoldSim menu. The GoldSim Tutorial presents the basic concepts on which GoldSim is based and provides an overview of GoldSim's key features and capabilities. After taking the Tutorial (which takes perhaps one or two hours), you will have sufficient understanding to start using the software, and will get more out of the information presented in the Help topics. This is the minimum that you must do before using GoldSim.

2. **Take the Online "Introduction to GoldSim" Training Course**. Although the Tutorial is of value to quickly get an overview of GoldSim, it provides a very simple overview of only the most basic GoldSim concepts. The best and most effective way to learn GoldSim is to take a full training course. A free "hands-on" online Training Course is available that will provide you with a thorough understanding of the key concepts on which GoldSim is based and all of the fundamentals required to build complex models of nearly any kind of system. That is, it does not simply focus on the mechanics of using the GoldSim software; just as importantly, it explains the fundamental concepts underlying dynamic, probabilistic simulation in general.

Because the Course is quite thorough, it will likely take as long as 40 hours to complete. Of course, if you are already somewhat familiar with simulation (and/or have a strong quantitative background), you may in fact be able to cover the material in considerably less than 40 hours.

You can take the Course at your own pace (and the site will remember where you last left off). If you are new to simulation, the ideal pace is probably to spend perhaps just a couple hours per day with the Course. This then provides you with an opportunity to give some considered thought to the information that was presented, and prevent "information overload".

Although taking the Course is time-consuming, over the long-term it is by far the most efficient way to learn to use the software. Trying to learn a complex and powerful software tool such as GoldSim on your own by simply experimenting and consulting the reference material is likely to take far in excess of 40 hours, and by doing so, you will likely not discover many of GoldSim's most powerful features.

You can find the Course here:
https://www.goldsim.com/Courses/BasicGoldSim/.

3. **Request your free one hour web-based training session.** When you purchase GoldSim, you are entitled to a free one hour, live web-based training session in which one of our analysts provides an interactive training session via the Internet and telephone. You are strongly encouraged to take advantage of this free training.

4. **Open and explore the Example Files**. When you install GoldSim, a folder labeled "General Examples" is installed with the program. (You can quickly access these files by selecting **File|Open Example…** from the main GoldSim menu). The example model files show how to use each of the elements (the examples are referenced in the Help system and User's Guide where the element is introduced). These example model files are an excellent way to begin to experiment with GoldSim. While exploring the files, use GoldSim's context-sensitive Help (i.e., the **Help** button in each dialog) to access a detailed discussion of the element. (Note that these example files are installed in such a way that to edit and save them, you must "Save As", which prevents the original files from being overwritten).

5. **Download Example Files from the Model Libaray**. The GoldSim Help Center (https://goldsim.zendesk.com) contains a Model Library with a number of models illustrating how GoldSim can be used for particular applications. These models tend to be more complex than the simple example files found in the General Examples folder, but still relatively simple. Again, while exploring the files, use GoldSim's context-sensitive Help (i.e., the **Help** button in each dialog) to learn more about particular elements or features utilized in the model.

6. **Browse the User's Guide or Help System**. GoldSim has a large number of features, and you will not discover all of them by experimenting with simple example models. To fully utilize GoldSim's powerful features, browse through the User's Guide, using the index and table of contents as your guide. Each section of the User's Guide is heavily cross-referenced, so it is easy to just jump around. Note that the Help system contains all of the contents of the User's Guide, with the exception of the technical appendices.

7. **Contact us with questions**. When you purchase GoldSim, you are entitled to one year of free support. This does not include assistance in building and debugging your models, but it does include answering questions on how to use GoldSim's features, so feel free to contact us!

Using GoldSim's Help System

GoldSim has an extensive in-product help facility, which can be used to supplement this manual. The Help system can be accessed by selecting **Help | Help Topics** from the main GoldSim menu, pressing the **F1** key, or clicking on the Help button (the question mark) on the standard toolbar. Pressing the **Help** button (or **F1**) within any of the dialogs also provides access to Help (in a context-sensitive manner). All of the information in this document (with the exception of the appendices) is accessible via GoldSim Help.

Technical Support, User Resources and Software Upgrades

The GoldSim Technology Group is dedicated to providing complete solutions for our customers. We pride ourselves in providing prompt and extensive support and resources to our users, and are committed to ensuring that each installation of our software is successful and adds value to the customer.

GoldSim Maintenance Program

When you purchase GoldSim software, you receive one year of Software Maintenance, entitling you to the following:

- Free software upgrades so that you always have the latest version of the GoldSim software.
- Basic Technical Support via email and phone. Basic support covers installation and licensing questions, as well as questions about GoldSim's features and capabilities.

After the first year, if you wish to continue to have access to new versions and technical support, Software Maintenance can be extended each year with payment of an annual fee.

Details regarding the GoldSim Maintenance Program can be found at www.goldsim.com/Web/Products/BuyGoldSim/Pricing/MaintenanceProgram/.

Getting Technical Support

Users with active Software Maintenance can submit questions directly to the GoldSim support team. Evaluation users are also welcome to contact us with questions on GoldSim functionality. The **GoldSim Help Center** (https://goldsim.zendesk.com) is the primary portal for technical support. You can submit your questions directly from the Help Center. If your register and log in through the Help Center, you will be able check the status and view a history of all of your support requests.

The Help Center also includes:

- The **GoldSim Forum**, where you can you can post questions to the GoldSim community, or just browse existing messages;
- Articles on licensing questions and modeling tips; and
- An archive of past webinars (which demonstrate GoldSim features and capabilities).

Free Basic Technical Support does not include consulting, model trouble-shooting or detailed assistance with applying GoldSim to a particular problem.

Assistance of this nature is defined as Advanced Technical Support. Users may purchase Advanced Technical Support in pre-paid 10 hour blocks.

Details regarding Advanced Technical Support can be found at www.goldsim.com/Web/Resources/TechnicalSupport/.

Other GoldSim Resources

In addition to the GoldSim Help Center, additional resources are also available. These three resources can be accessed directly from the GoldSim website (www.goldsim.com):

- A free **Online Training Course** that will provide you with a thorough understanding of the key concepts on which GoldSim is based and all of the fundamentals required to build complex models of nearly any kind of system.
- The **GoldSim Model Library**, which contains a collection of example models to allow you to see how specific features of GoldSim can be used and/or how GoldSim can be used for specific applications.
- The **GoldSim Blog**, which provides an informal mechanism for GoldSim staff to share their knowledge, point out some of the more advanced (and perhaps overlooked) GoldSim features, share and discuss common mistakes we see in GoldSim applications, discuss interesting applications, and keep you abreast of our plans for further GoldSim developments.

You can stay up to date on the latest GoldSim news through these resources:

- The GoldSim LinkedIn Group, which is primarily used for announcements (e.g., new versions, interesting applications). You can join the Group here: www.linkedin.com/groups/1798413)
- Periodic email newsletters are sent two to three times per year. To be added to the newsletter list, contact us via the GoldSim Help Center (https://goldsim.zendesk.com).

Note: When you purchase GoldSim, you are entitled to a free one hour, live web-based training session in which one of our analysts provides an interactive training session via the Internet and telephone. You are strongly encouraged to take advantage of this free training.

Chapter 2: GoldSim in a Nutshell

> The purpose of computing is insight, not numbers.
>
> R.W. Hamming, *Numerical Methods for Scientists and Engineers*

Chapter Overview

This chapter provides an introduction to and "quick tour" of GoldSim. It presents the basic concepts of how simulation techniques can be applied to solve problems, and how a simulation model is created in GoldSim. It also provides an overview of the features and capabilities of the program.

If you read nothing else before starting to use the program, it is strongly recommended that you read this chapter, as it will tell you what the program is capable of doing, provide an overview of how to build a model, and direct you to those portions of the manual where you can obtain further information.

In this Chapter

This chapter discusses the following:

- Understanding Simulation
- What is GoldSim?
- Basic GoldSim Concepts
- Advanced Computational Features
- Documenting and Presenting Your Model
- Specialized GoldSim Modules
- The GoldSim Player

Understanding Simulation

Before describing what the GoldSim simulation framework is, and what it can be used to do, it is important to first discuss in general terms what we mean when we use the term ***simulation***.

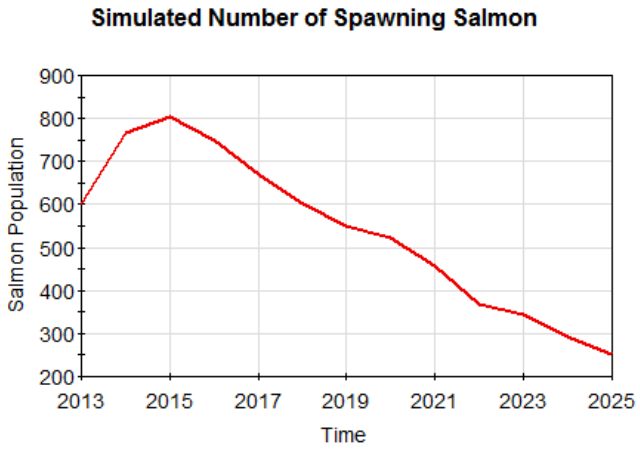
The term *simulation* is used in different ways by different people. As used here, simulation is defined as the process of creating a model (i.e., an abstract representation or facsimile) of an existing or proposed system (e.g., a business, a mine, a watershed, a forest, the organs in your body, the atmosphere) in order to identify and understand those factors which control the system and/or to predict (forecast) the future behavior of the system. Almost any system which can be quantitatively described using equations and/or rules can be simulated.

Dynamic Simulation

Simulations can be static or dynamic. In a static simulation, the system does not change with time. Static simulations can be useful for carrying out simple risk calculations and decision trees, in which there is no dynamic component to the model.

In a dynamic simulation, the system changes and evolves with time (in response to both external and internal influences), and your objective in modeling such a system is to understand the way in which it is likely to evolve, predict (forecast) the future behavior of the system, and determine what you can do to influence that future behavior.

In effect, a dynamic simulation is used to predict the way in which the system will evolve and respond to its surroundings, so that you can identify any necessary changes that will help make the system perform the way that you want it to. For example, a fisheries biologist could dynamically simulate the salmon population in a river in order to predict changes to the population, and quantitatively understand the impacts on the salmon of possible actions (e.g., fishing, loss of habitat) to ensure that they do not go extinct at some point in the future:



Probabilistic Simulation

In many systems, the controlling parameters, processes and events may be uncertain and/or poorly understood. In a ***deterministic simulation***, these parameters are represented using single values (which typically are described either as "the best guess" or "worst case" values). ***Probabilistic simulation*** is the process of explicitly representing this uncertainty by specifying inputs as ***probability distributions*** and specifying any random events that could affect the system.

If the inputs describing a system are uncertain, the prediction of future performance is necessarily uncertain. That is, the result of any analysis based on inputs represented by probability distributions is itself a probability distribution.

Hence, whereas the result of a deterministic simulation of an uncertain system is a *qualified statement* ("if we build the dam, the salmon population could go extinct"), the result of a probabilistic simulation of such a system is a *quantified probability* ("if we build the dam, there is a 20% chance that the salmon population will go extinct"). Such a result is typically much more useful to decision-makers who might utilize the simulation results.

A more detailed description of probabilistic simulation concepts, including a discussion of the advantages and disadvantages of probabilistic simulation, is provided in Appendix A, "Introduction to Probabilistic Simulation".

Steps in Carrying Out a Simulation

In order to illustrate what is involved in simulating a system, the steps necessary to carry out any kind of simulation are briefly summarized below:

1. **Define your objectives and measures of performance.** Before attempting to simulate a system, it is important to clearly identify what types of questions you are trying to answer with the model. The objectives of the model define the ***performance measures*** for the system. A performance measure is a model output by which you can judge the performance of the system (e.g., the salmon population in a river, or the net present value of a project).
2. **Develop the conceptual model**. The most important step in simulating any system is developing a ***conceptual model*** of the system. A conceptual model is a representation of the significant features, events and processes controlling the behavior of the system. It is essentially a body of ideas, based on available information, that summarizes the current understanding of the system.
3. **Create the mathematical model.** Once a conceptual model of the system is developed, it is necessary to represent it quantitatively within a ***mathematical model***. A mathematical model consists of a set of input assumptions, equations and algorithms describing the system.
4. **Quantify the input parameters.** The mathematical model identifies specific inputs (e.g., the flow rate for a river, the financial discount rate) which are required in order to simulate the system. These must be quantified by specifying their values or probability distributions.
5. **Implement and solve the mathematical model using a computational tool.** After developing the mathematical model and quantifying all of the input parameters, the model must be implemented within a computational tool capable of solving the equations representing the system. This implementation of the mathematical model within a computational tool is referred to as the ***simulation model.*** For simple systems, the computational tool might be your brain (if you can solve the equations in your head), a calculator, or perhaps a spreadsheet program. For more complex systems, a specialized computer program (such as GoldSim) is required.
6. **Evaluate, explain and present the results.** The final step in the simulation process is to produce results, evaluate and draw conclusions from these results, and present them to interested parties.

For very simple simulations, the steps described above could be carried out in order, proceeding from step 1 to step 6. For most real-world simulations, however, these steps should be carried out in an iterative manner. That is, as

new data and/or new insights into the behavior of the system are obtained, the model is refined and reanalyzed.

Models which are constructed and continuously updated in such a manner can provide a systematic framework for organizing and evaluating the available information related to a complex system, and can act as management tools to aid in ongoing decision-making.

As will be discussed below, GoldSim was specifically designed to make the construction of such models as easy and intuitive as possible.

The Power of Simulation

Simulation is a powerful and important tool because it provides a way in which alternative designs, plans and/or policies can be evaluated without having to experiment on a real system, which may be prohibitively costly, time-consuming, or simply impractical to do. That is, it allows you to ask “What if?” questions about a system without having to experiment on the actual system itself (and hence incur the costs of field tests, prototypes, etc.).

A few wide-ranging examples of how simulation can be used to ask such "What if?" questions in order to solve real-world problems in science, engineering and business are listed below:

Wildlife management: By simulating an animal population (such as salmon or elk), you can determine which combination of management practices is most likely to be successful at maintaining a stable population.

Strategic planning: By simulating the development, regulatory approval, and marketing of a new drug, you can determine a strategy that will maximize profits.

Reliability and Systems Engineering: By simulating the components, processes, failure modes and events controlling a complex engineering system (such as a space system, a machine, or a large industrial facility), you can predict the reliability of the system, and modify the design so as to increase reliability and decrease the probability and/or consequences of failures.

Water resources: By simulating the inflows and future demands on a water supply reservoir, you can optimize management practices to minimize the probability of needing to seek other sources and/or impose water use restrictions at some future date.

Environment: By simulating the performance of a proposed landfill, you can modify the design to minimize environmental impacts.

Manufacturing: By simulating the supply chain for a product, you can experiment with technological changes (e.g., improved communication) and changes in decision rules (e.g., ordering practices) to stabilize inventory levels throughout the chain.

Resource Planning and Management: By simulating a natural resource (such as a forest), you can determine which combination of management practices (e.g., selective harvesting, development of recreational facilities) maximizes the use of the resource and best satisfies the various stakeholders.

As will be shown in the following sections, GoldSim is flexible and powerful enough to be readily applied to any of these problems.

What is GoldSim?

GoldSim is a highly-graphical simulation program that runs on personal computers using the Windows operating system. Although it was specifically designed for carrying out dynamic, probabilistic simulations of complex systems, it can also be readily applied to simpler static and/or deterministic simulations.

Because simulation can be such a powerful tool for understanding and managing complex systems, a variety of graphical simulation tools currently exist. The following combination of features, however, makes the GoldSim approach unique:

GoldSim is user friendly, highly graphical, and very flexible. It can be applied to nearly any kind of system. You start to build a model in an intuitive manner by literally drawing a picture (an influence diagram) of your system.

GoldSim was specifically designed to quantitatively address the inherent uncertainty which is present in real-world systems. GoldSim provides powerful tools for representing uncertainty in processes, parameters and future events, and for evaluating such systems in a computationally efficient manner.

GoldSim provides powerful capabilities for superimposing the occurrence and consequences of discrete events onto continuously varying systems. This allows for the realistic simulation of discrete events such as financial transactions, accidents, system failures, storms, labor strikes, and lawsuits.

GoldSim was designed to facilitate the construction of large, complex models. You can build a model of your system in a hierarchical, modular manner, such that the model can readily evolve and add detail as more knowledge regarding the system is obtained. Other powerful features, such as the ability to manipulate arrays, the ability to "localize" parts of your model, and the ability to assign versions to a model which is constantly being modified and improved, further facilitate the construction and management of large models.

GoldSim is dimensionally-aware. GoldSim has an extensive internal database of units and conversion factors. You can enter data and display results in any units. You can even define your own customized units. GoldSim ensures dimensional consistency in your models and carries out all of the unit conversions internally. As a result, when you use GoldSim, it is never necessary for you to carry out (error-prone) unit conversions.

GoldSim is highly extensible. You can dynamically link external programs or spreadsheets directly into your GoldSim model. In addition, GoldSim was specifically designed to support the addition of customized modules (program extensions) to address specialized applications.

GoldSim allows you to create compelling presentations of your model. A model that cannot be easily explained is a model that will not be used or believed. GoldSim was specifically designed to allow you to effectively document, explain and present your model. You can add graphics, explanatory text, notes and hyperlinks to your model, and organize it in a hierarchical manner such that it can be presented at an appropriate level of detail to multiple target audiences.

These features allow GoldSim to be applied at multiple levels, depending on the nature of the application:

- as a powerful, flexible simulator;
- as a system integrator; and
- as a visual information management system.

A Powerful, Flexible Simulator

At the most fundamental level, GoldSim can be used as a powerful, flexible simulator. That is, you may only wish to apply it to a very specific problem in a technical discipline such as finance, industrial engineering, environmental science, or chemistry.

GoldSim's graphical interface and powerful computational features facilitate a wide range of simulations, ranging from a simple homework assignment put together in less than an hour, to a complex professional application built over a period of several months.

A System Integration Tool

Most real-world problems are multi-disciplinary in nature. That is, the system being simulated actually consists of many subsystems, and the sub-models for each subsystem must typically be built by people from a wide variety of disciplines. For example, a model intended to help manage an ecological system (e.g., a river) in order to support management decisions to protect an endangered species (e.g., salmon) likely would include sub-models that are developed by biologists, urban planners, hydrologists, civil engineers, economists, forestry professionals, and social and political scientists (among others).

Unfortunately, in many such cases, the model builders get caught up in the details of their sub-models, and lose sight of the "big picture". The end result is typically separate sub-models which are unnecessarily complex. More importantly, the complex interactions and interdependencies between subsystems are often ignored or poorly represented. Such an approach not only wastes resources, but is often too complex to be explained (and hence used) effectively, and too poorly integrated to represent the entire system in a cohesive and realistic way.

What is needed for such complex, multi-disciplinary systems is a tool that can be used to integrate all of the various sub-models into a single ***total system model***. A total system model focuses on creating a consistent framework in which all aspects of the system, as well as the complex interactions and interdependencies between subsystems, can be represented.

Because GoldSim is flexible and powerful enough to represent practically any aspect of your system, and because GoldSim provides unique capabilities for building your model in a hierarchical, modular manner, it is ideally suited to act as a system integrator. *In fact, this was the original and primary objective around which GoldSim was designed*.

A Visual Information Management System

Complex models often require a great detail of input data. These inputs may reside in databases, spreadsheets, or in written documentation. The user of a model (e.g., the author of the model, a reviewer of the model, or a decision-maker evaluating the results) can be most effective if this input information can be visually integrated with (and readily accessed and viewed alongside) the simulation model. In addition, for a complex model which requires a great deal of input, it may be desirable (or even mandated) that the simulation model can directly access various data sources (e.g., databases or spreadsheets) to ensure the quality of the data transfer. GoldSim was designed to facilitate both of these tasks.

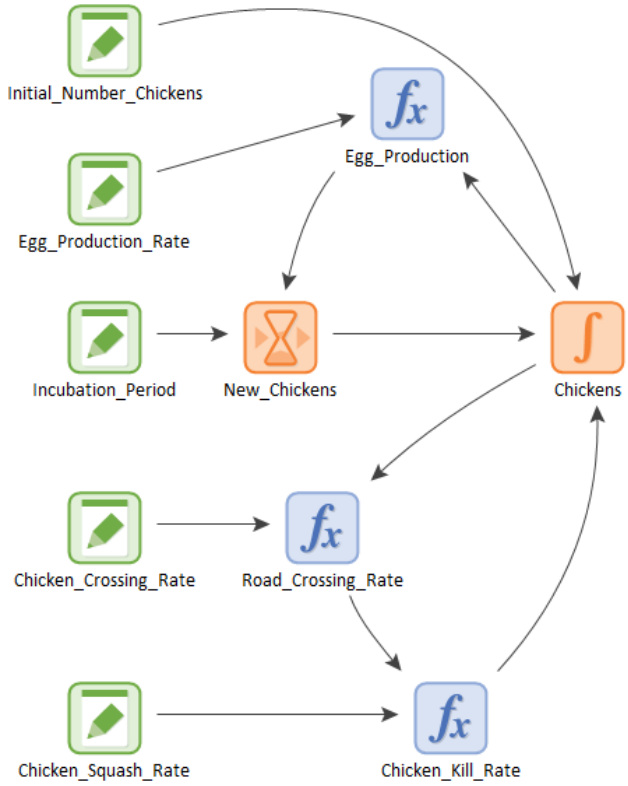
Even if you can directly and visually access the input data for your model, in order for your simulation model to be useful, you must also be able to explain its assumptions (and the implications of the simulation results) in a compelling and effective manner. GoldSim provides the tools to enable you to do so.

Hence, at the highest and most powerful level, GoldSim can used as a *visual information management system*, providing you with the ability to directly link to data sources, as well as describe, document and explain your model in a compelling and effective manner to any audience.

Basic GoldSim Concepts

The GoldSim Simulation Environment

The GoldSim simulation environment is highly-graphical and completely object-oriented. That is, you create, document, and present models by creating and manipulating graphical objects representing the components of your system, data and relationships between the data:



In a sense, GoldSim is like a "visual spreadsheet" allowing you to visually create and manipulate data and equations. As can be seen in the simple example shown above, based on how the various objects in your model are related, GoldSim automatically indicates their influences and interdependencies by visually connecting them in an appropriate manner. GoldSim also sets up and solves the equations represented by the objects and their interdependencies.

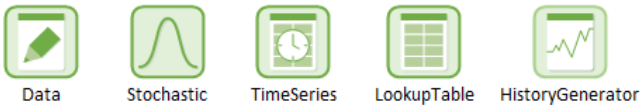
Elements: The Basic Building Blocks in GoldSim

The various objects with which a GoldSim model is constructed are referred to as ***elements***. Each element represents a building block of the model, and has a particular symbol or graphical image (which you can subsequently customize) by which it is represented on the screen. Typically, you give each element a unique name by which it is referenced (e.g., X, Revenue, Rainfall, Discount_Rate). Most elements accepts inputs, and in turn produce outputs.

GoldSim provides a wide variety of elements. Some of these elements provide a mechanism for the user to *enter input data* into the model. Other elements represent *functions* which operate on one or more inputs and produce one or more outputs. A special class of elements (stocks and delays) is critical for generating the dynamics in your models.

Input Elements

Input elements define the inputs to your model. There are five types of input elements: Data, Time Series, Stochastics, Lookup Tables and History Generators:



The most basic of the input elements are Data, Stochastics and Time Series. Data elements allow you to specify a single scalar value (e.g., the discount rate) or an array of related values (e.g., the salaries of each individual in a group). Time Series elements allow you to specify a time series of a value (e.g., monthly rainfall rates, quarterly cashflows). Stochastic elements allow you to specify that a particular value is uncertain by defining it as a probability distribution.

Lookup Tables and History Generators are somewhat more complex input elements. Lookup Tables can be used to define a response surface specifying how an output varies as a function of up to three inputs. History Generator elements generate random (stochastic) time series based on specified statistics (e.g., to represent the price of a security such as a stock or bond).

Function Elements

Function elements instantaneously compute outputs based on defined inputs. That is, they require one or more inputs, carry out a specified calculation on those inputs, and produce one or more outputs. GoldSim provides fifteen function elements.

The simplest and most general function element is an ***Expression element***. Expressions produce a single output by calculating user-specified formulas, such as 2 + 3, A*B, or sqrt(55). Similar to a cell in a spreadsheet, when defining an expression, you can use a wide variety of mathematical operators and functions. You can even use conditional operators (e.g., >,<, =) and *if, then* logic to define Expressions.

Other function elements have predefined functionality. For example, a Selector element provides an easy and transparent way to specify if..then logic in a model.

Stock and Delay Elements

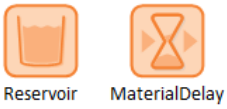
Stock and Delay Elements are specialized function elements with the unique property that their outputs are influenced by what has happened in the past. That is, unlike standard function elements, whose outputs at any given time are computed based solely on the current (instantaneous) values of their inputs, the outputs of these elements are determined by the *previous* values of their inputs. Such elements accumulate past events and provide systems with inertia and memory, and hence are responsible for internally generating the dynamic behavior of a system.

An example of a Stock element is the ***Reservoir***. A Reservoir accumulates materials, and is useful for representing things like bank accounts and quantities of materials or items (e.g., water, soil, salmon). In its simplest form, a Reservoir

requires as inputs an Initial Value, a Rate of Addition and a Rate of Withdrawal, and outputs a Current Value using the following equation:

$$\text{Current Value} = \text{Initial Value} + \int (\text{Rate of Addition} - \text{Rate of Withdrawal})dt$$

An example of a Delay element is the ***Material Delay***. Delays allow you to represent processes in which the output lags the input. The Material Delay accepts as input a flow of material (e.g., gal/day, $/yr, widgets/hr), moves it through a "conveyor" or "pipeline" (while optionally dispersing it), and then outputs the flow. Such an element can be used to represent such processes as the movement of water through soils or the movement of parts in a conveyor.



Linking Elements

GoldSim models are built by connecting the outputs of one (or more) elements to the inputs of other elements. These connections are referred to as links:

A complex GoldSim model can have hundreds (or thousands) of elements and links.

A Simple Example

The easiest way to understand GoldSim is to walk through a very simple example. In what follows, we illustrate how GoldSim could be used to carry out a simple dynamic simulation which computes the volume of water in a pond as a function of time.

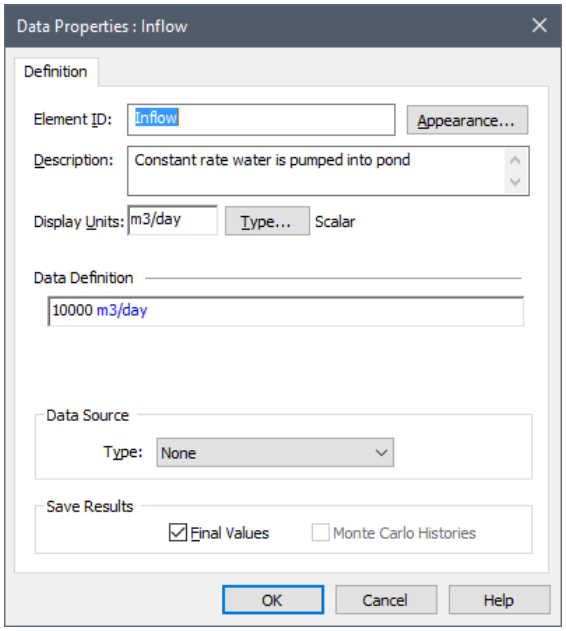
Note: The objective here is not for you to follow along and try to build this model (as you have not yet learned the basics of how to do so). Rather, the objective is simply to provide a very general indication of how GoldSim models are constructed and the kinds of results they produce.

Assume that the pond that we wish to simulate is initially empty. We continuously pump water out of a nearby river and into the pond at a rate of 10,000 m3/day. The pond leaks right back into the river, however, at a rate that is proportional to the current volume of water in the pond (i.e., the more water in the pond, the faster it leaks). In particular, 15% of the pond volume is assumed to leak out every day. We wish to predict the water level in the pond as a function of time.

We will build this model using three elements: a Data element, a Reservoir and an Expression. The Data element represents the rate of inflow to the pond, the Expression calculates the leakage from the pond, and the Reservoir represents the volume of water in the pond.

Therefore, we begin by inserting a Data element named "Inflow", an Expression named "Leakage" and a Reservoir named "Volume_in_Pond":

Next, we define the properties of the Data element "Inflow" by double-clicking on the element, which causes its editing dialog to be displayed:



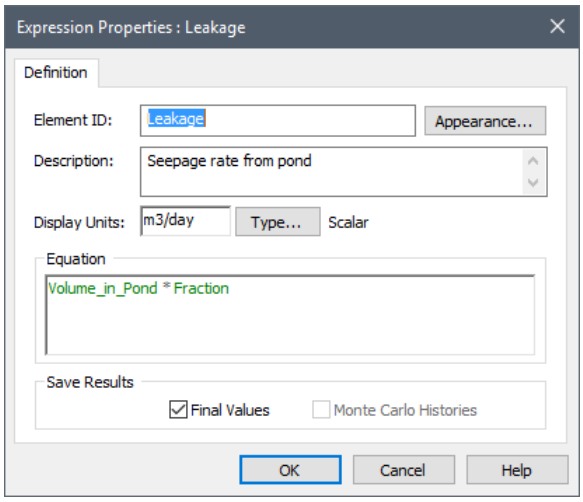
*The name of the element is specified in the **Element ID** field. You add a brief description to the element in the **Description** field. The data defining the element is specified in **Data Definition** field. When writing the Data Definition, the units of the input are specified following the value.*

To define the element, we enter the inflow rate of 10,000 m3/day. Note that we specifically define not only the value, but also the dimensions (the units) of the input. Note also that we do not add punctuation (the comma).

Next, we define the Expression element representing the leakage (outflow) from the pond. The leakage is equal to 15% of the pond volume per day. Mathematically, this can be written as:

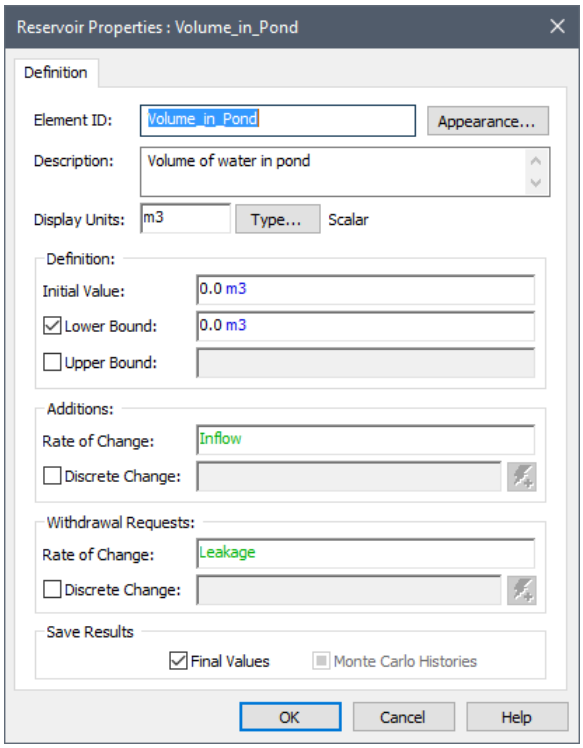
$$\text{Leakage} = \text{Volume\_in\_Pond} * 15\,\%/\text{day}$$

We type the right-hand side of this equation into the input field for the Expression representing the leakage:



*The expression representing the leakage is entered in the **Equation** field.*

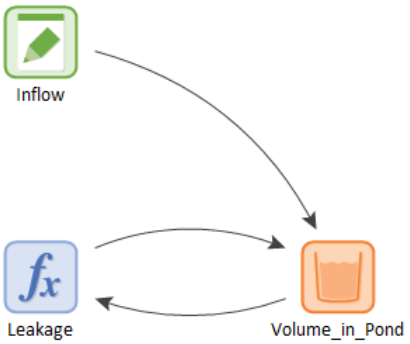
Finally, we must link the Inflow and Leakage to the Reservoir element. The properties dialog for a Reservoir (which is somewhat complex) is shown below.



*It is assumed that the pond is initially empty. The Inflow and Leakage are specified as **Additions** and **Withdrawa Requests** from the Reservoir. The remaining input fields for the Reservoir are not utilized in this simple example.*

For this example, the only required inputs for the Reservoir are the **Initial Value** (in this case, zero), the **Rate of Change *Addition*** (set equal to the Inflow), and the **Rate of Change *Withdrawal Request*** (set equal to the Leakage).

After defining the elements in this way, the screen looks like this:



The lines (referred to as an "influence") between the elements will initially be drawn as straight lines (rather than as curve lines). GoldSim allows you to subsequently change the appearance of these influences (e.g., make them curved).

The arrows indicate how the three elements are related. In this case, the system has a ***feedback loop***: Volume_in_Pond is a function of Leakage and Inflow, and the Leakage is a function of Volume_in_Pond. In fact, this is a classc example of a negative feedback loop: as Volume_in_Pond increases, the Leakage increases; as the Leakage increases, the Volume_in_Pond decreases. Negative feedback loops are self-correcting: rather than the pond volume continuing to increase, the feedback loop will eventually force it toward a steady state value.

Understanding Dynamic Simulation

GoldSim is a dynamic simulator, which means that your model can evolve and change with time. In this example, we are interested in predicting how the volume of water in the pond changes with time.

In order to do so, GoldSim must solve the equations represented by the elements and their linkages. In this particular example, the system can be represented by the following differential equation:

$$\frac{\delta V}{\delta t} = \text{Inflow} - \text{Leakage} = \text{Inflow} - 0.15 * V$$

where V is the volume in the pond, and $\delta V/\delta t$ is the time derivative of the volume (the rate of change of volume with respect to time).

This particular equation can actually be solved analytically:

$$V = V(0)\ e^{-0.15t} + \frac{\text{Inflow}}{0.15}\left[1 - e^{-0.15t}\right]$$

In general, however, a particular system will not have an analytical solution (i.e., it cannot be solved exactly), and must be solved *numerically* (i.e., using an algorithm that provides a numerical approximation to the actual solution).

GoldSim solves differential equations such as this through ***numerical integration***. That is, GoldSim solves for V as a function of time by integrating the right-hand side of the equation:

$$V(\tau) = V(0) + \int_0^{\tau} (\text{Inflow} - 0.15\ V)\ dt$$

To solve this (or any) integral numerically, it is necessary to discretize time into discrete intervals referred to as ***timesteps***. GoldSim then "steps through time" by carrying out calculations every timestep, with the values at the current timestep

computed as a function of the values at the previous timestep. In the case of the integral represented above, after discretizing time, GoldSim solves the equation by numerically approximating it as a sum:

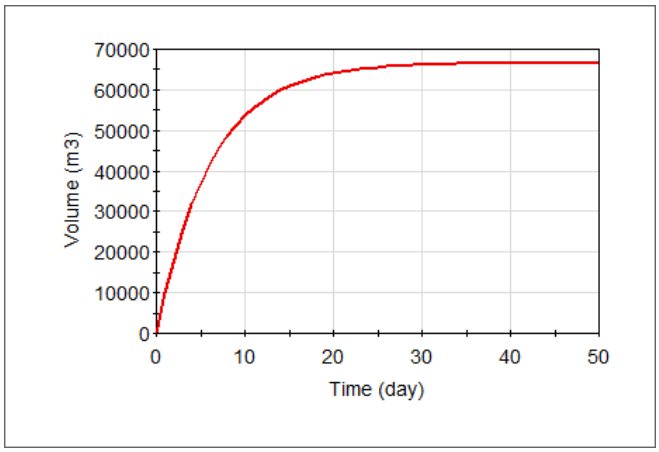
$$V(\tau) = V(0) + \sum_{0}^{\tau} [\text{Inflow} - 0.15 * V(\tau - \Delta t)] \Delta t$$

where Δt is the length of the timestep.

Hence, the value of V at time τ is computed based on the value of the Leakage (which is in turn a function of V) at the previous timestep. This particular numerical integration method (referred to as ***Euler integration***) is discussed further in Appendix G.

In order to dynamically simulate a system in GoldSim, you must specify the duration of the simulation (e.g., 365 days) and the length of the timestep (e.g., 1 day). The appropriate timestep length is a function of how rapidly the system represented by your model is changing: the more rapidly it is changing, the shorter the timestep required to accurately model the system.

For this simple example, we choose to run the model for a duration of 50 days with a timestep length of 1 day. The result, in the form of the volume of water in the pond as a function of time, is shown below:



As can be seen, the pond reaches a constant (steady-state) value after about 40 days. At this point, the flow rate into the pond matches the leakage rate out of the pond.

GoldSim is Dimensionally-Aware

As you no doubt noticed in the example, when data were entered, the dimensions were specified. One of the more unique and powerful computational features of GoldSim is that the program is *dimensionally aware*.

GoldSim has an extensive internal database of units and conversion factors. You can enter data and display results in any units. You can even define your own customized units.

When elements are created, you must specify their output dimensions. For example, when the Inflow element was created in the previous example, it was defined to have dimensions of volume per time (m^3/day). When elements are linked, GoldSim ensures dimensional consistency and carries out all of the unit conversions internally. For example, you could add meters and feet in an equation, and GoldSim would internally carry out the conversion. Note, however, that if you tried to add meters and hours, GoldSim would issue a warning message and prevent you from doing so.

As a result, when you use GoldSim, it is never necessary for you to carry out (error-prone) unit conversions.

Read more: Using Dimensions and Units (page 89).

Representing Uncertainty

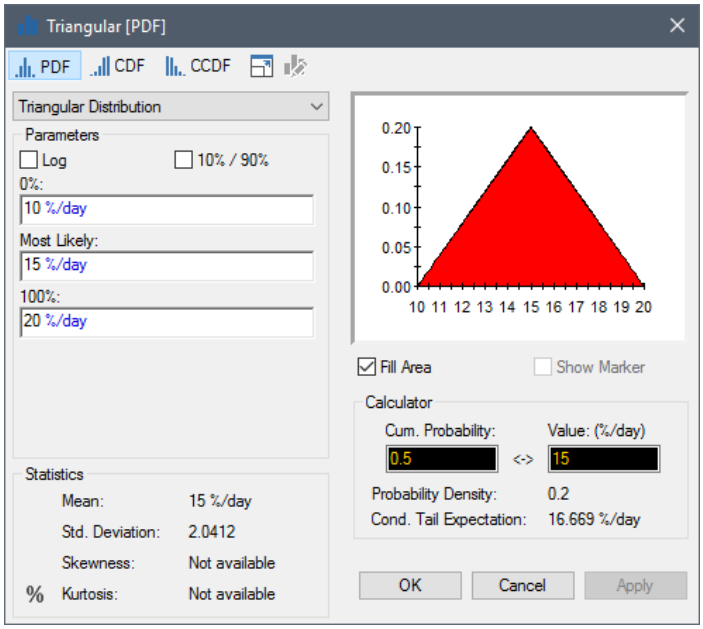
In many systems, you may be uncertain about some of the input parameters. In such a case, GoldSim allows you to define these parameters as probability distributions.

In the example presented above, suppose that we were uncertain of the leakage fraction. In particular, we will assume that rather than being 15%, the leakage fraction could be anywhere between 10% and 20% of the pond volume per day.

To represent this, we create a new ***Stochastic*** element (named Fraction), and modify the equation for Leakage as follows:

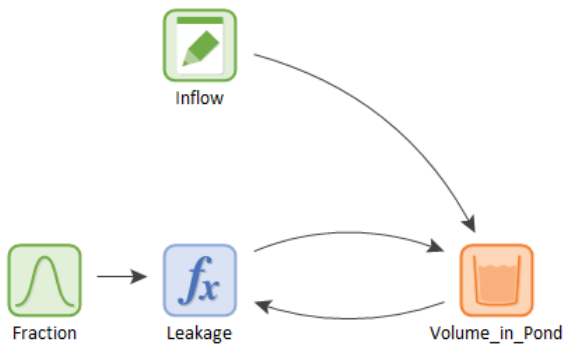
Leakage = Volume_in_Pond * Fraction

A Stochastic element is used to define a probability distribution. In this example, we will define Fraction (the leakage fraction) as a triangular distribution, with a minimum value of 10%/day, a most likely value of 15%/day, and a maximum value of 20%/day:



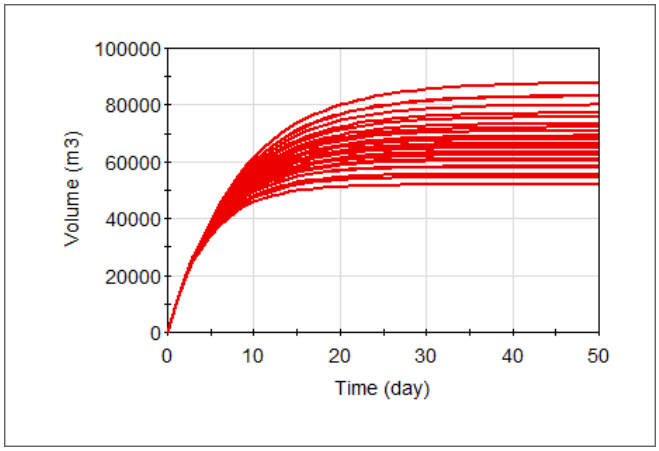
The type of probability distribution is selected from the list at the top of the dialog box. The parameters describing the shape of the distribution are defined under "Parameters".

The model would then look like this:

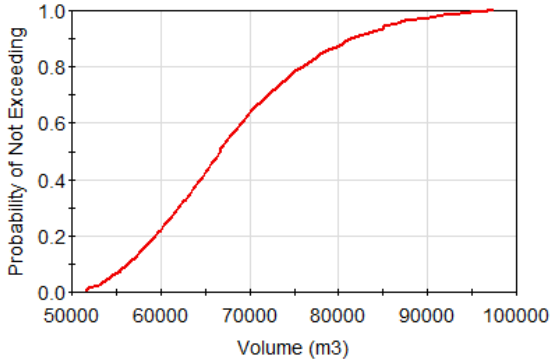


If the inputs to a model are uncertain, the outputs are necessarily uncertain. GoldSim *propagates* (translates) the input uncertainties into uncertainties in the results using ***Monte Carlo simulation***. In Monte Carlo simulation, the entire system is simulated a large number (e.g., 1000) of times. Each simulation is assumed to be equally likely, and is referred to as a ***realization*** of the system. For each realization, all of the uncertain parameters are sampled (i.e., a single random value is selected from the specified distribution describing each parameter). The system is then simulated through time (given the particular set of input parameters) such that the performance of the system can be computed.

This results in a large number of separate and independent results, each representing a possible "future" for the system (i.e., one possible path the system may follow through time). For example, 25 realizations of the pond example using an uncertain Leakage fraction produces 25 separate time history results:



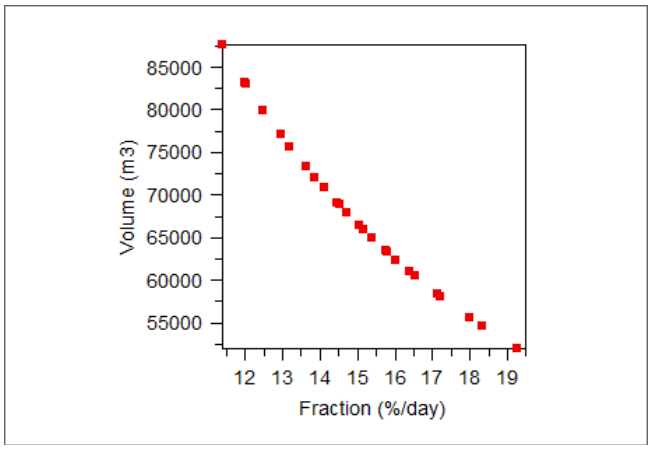
Another way to view these results is by plotting a probability of the final volume of water in the pond (after 50 days):



This plot (presented as a cumulative distribution function) indicates that the median final volume is about 65,000 m^3, and there is a probability that the final volume could be as high as about 95,000 m^3.

Probabilistic simulations are particularly useful because you can often use them to obtain a better understanding of the factors controlling the system.

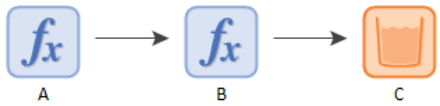
For example, by plotting the final volume in the pond as a function of the leakage fraction, we can better understand and quantify the sensitivity of the system to this key factor:



A primer on probabilistic simulation is presented in Appendix A.

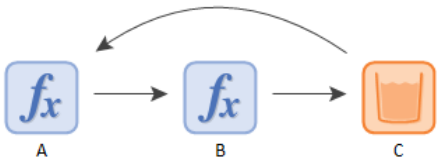
Representing Feedback Loops

Simple models have a direct chain of causality: input data affect some elements, which affect other elements, and so on, until eventually the elements which calculate the desired results of the model are reached:



GoldSim automatically analyzes your entire model to identify "who affects who", and ensures that the "upstream" elements are calculated prior to the "downstream" elements. At each time-step the elements are updated in this causality-based sequence.

Many systems, however, contain elements whose output can, directly or indirectly, affect one of their own inputs. This creates a looping or circular system (i.e., a "***feedback loop***").



Feedback loops are present in one form or another in most real-world systems, and can be readily modeled in GoldSim. The simple pond model presented previously is a good example of a system with a feedback loop. In the example above, A affects B which affects C, and then C “feeds back” to affect A and so on. That is, feedback loops represent a closed chain of cause and effect. Note that the terms “feedback” and “cause and effect” intentionally imply that the relationship between the variables is dynamic and the system changes over time (although systems with feedback loops can also reach a dynamic equilibrium).

In some cases, however, you may need to define circular logic in your model that is not dynamic at all. A simple simultaneous system of equations is an example of such a system. Such logic does not represent a feedback loop, in that there is no chain of “cause and effect” and no dynamics – in fact, the variables may not change with time at all. In GoldSim, these are referred to as ***recursive loops***, and they are treated differently from feedback loops. GoldSim can still solve such systems, but in order to do so, it is necessary for you to take some additional steps to define the sequence in which the calculations are carried out.

Read more: Evaluating Feedback Loops (page 361); Creating Recursive Loops Using Previous Value Elements (page 1033).

Simulating Delays

In many systems, a signal (e.g., a flow of material, a piece of information) is not transmitted instantaneously within a system or process, but instead is delayed. Examples include the movement of water though soils, the movement of material along a conveyor, and the transfer of information from one person to another.

Material or information can be conceptualized as moving through (transiting) a delay process. In some cases, the material or signal may be dispersed while in transit. For example, if you post 100 letters all at once, they will not be delivered all at once. Rather, there will be some variability in the time at which they are delivered (i.e., the delay time). In other cases, the material or signal is not dispersed. If a conveyor belt moves at a fixed speed, there will be no variability in the transit times for items that are placed on the conveyor.

Delays can have a major impact on the dynamics of a system, and it is therefore important to be able to represent them in a straightforward and realistic manner. GoldSim provides several types of powerful ***Delay elements*** to represent these delays.

Read more: Using Delay Elements (page 334).

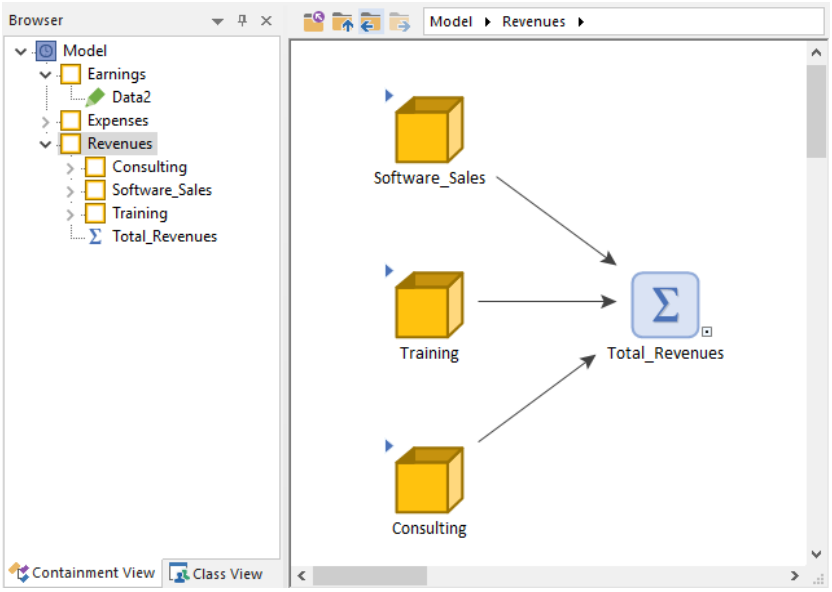
Building Hierarchical Top-Down Models

Complex models can have hundreds (or thousands) of elements. In order to manage, organize and view such a model it is useful (in fact, essential) to group the elements into ***subsystems***. A subsystem is simply a collection of elements.

Subsystems are created in GoldSim by placing elements into ***Containers***. A Container is simply a "box" into which other elements have been placed. In a sense, it is like a directory folder on your computer.

Containers can be placed inside other Containers, and any number of levels of containment can be created. This ability to organize model elements into a hierarchy provides a powerful tool for creating "top-down" models, in which the level of detail increases as you "push down" into the containment hierarchy.

The example below shows a system that has been divided into a number of distinct subsystems:



GoldSim provides an optional browser view of the system in a pane on the left of the window. The tree in the browser shows the containment hierarchy in a manner similar to how a computer's directory hierarchy is shown.

You can "drill down" into the next level of detail in the model by "opening" the Container. (One way to do this is by clicking on small triangle in the upper left-hand side of the Container.)

The ability to create hierarchical, top-down models, coupled with GoldSim's powerful documentation and presentation abilities, allows you to effectively describe and explain your model at different (and appropriate) levels of detail to different audiences.

Read more: Understanding Containers (page 96).

Additional Function Elements

Although you can create complex models using only the elements introduced in the previous sections, GoldSim provides a variety of additional elements that provide further modeling capabilities, including:

- **Logical elements**, which allow you to add easy-to-read logic diagrams to your models;
- A **Selector**, which provides a powerful and user-friendly way to create complex equations involving nested if…then logic; and
- An **Extrema**, which dynamically computes the highest or lowest values achieved by a specified parameter throughout a simulation (e.g., peak concentration in a river, minimum water level in a reservoir, minimum balance in a checking account).

Read more: Chapter 4: Using the GoldSim Elements (page 125).

Advanced Features

In addition to the basic features and capabilities discussed above, GoldSim provides a large number of advanced computational features which increase the power, flexibility and ease-of-use of the software. Several of these features are discussed below.

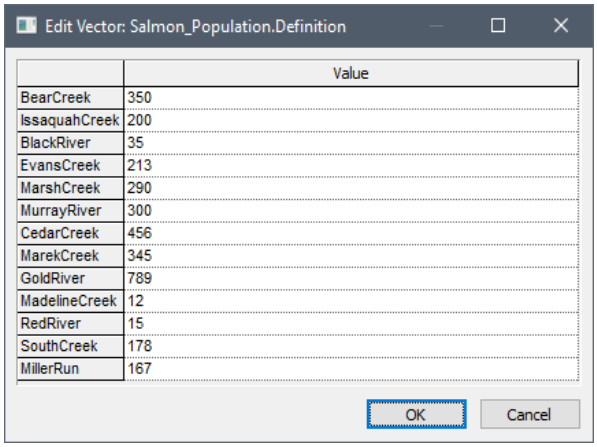
Manipulating Arrays (Vectors and Matrices)

In many systems, you will want to create and manipulate elements that represent collections of data, rather than individual items. For example, you may want to create an element that represents your company's revenue for each of five separate divisions, or an element that represents the salmon population in each of a number streams.

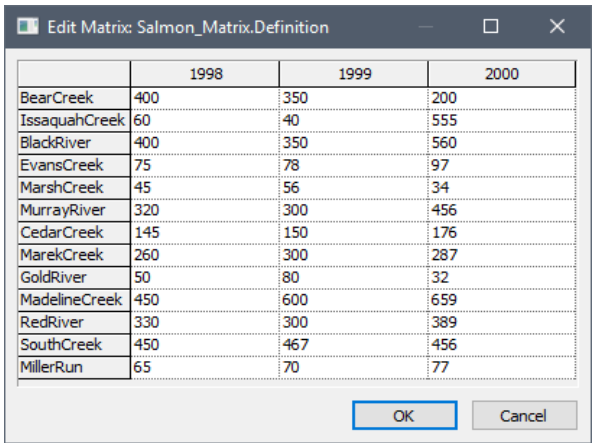
One way to do this, of course, would be to create separate elements for each object you wanted to model (e.g., five elements representing revenue, 13 elements representing salmon populations in different streams). Such an approach, however, is not desirable for two reasons:

- It could require you to create a very large number of elements (e.g., if you wanted revenues for 100 subgroups or wanted to evaluate salmon populations in 200 streams). This could result in very large, cluttered models.
- Usually, you will want to carry out the same types of calculations and operations on all related objects in such a collection (e.g., multiply all revenues by 2, compute the number of salmon eggs this year for all the streams based on the current salmon population). Having to do this individually for every object in a large collection would be very cumbersome and time-consuming.

To address these kinds of problems, GoldSim allows you to create and manipulate ***vectors*** and ***matrices*** (collectively referred to as ***arrays***). For example, you could create a vector Data element that represented the salmon populations in each of the streams, as shown below:



You could also create a matrix Data element that represented the salmon population in each of a number of streams for a period of 3 years, as shown below:



	1998	1999	2000
BearCreek	400	350	200
IssaquahCreek	60	40	555
BlackRiver	400	350	560
EvansCreek	75	78	97
MarshCreek	45	56	34
MurrayRiver	320	300	456
CedarCreek	145	150	176
MarekCreek	260	300	287
GoldRiver	50	80	32
MadelineCreek	450	600	659
RedRiver	330	300	389
SouthCreek	450	467	456
MillerRun	65	70	77

In addition to adding data in the form of vectors and matrices, you can manipulate these arrays in equations. For example, you could create an Expression element, and define it as:

2 * Salmon_Population

The output of the Expression would be an array, identical to the Salmon_Population array, except each item of the array would be two times greater. Note that if you did not use arrays to carry out this calculation, rather than creating 2 elements, you would need to create 26 elements (2 for each stream: 13 Data elements and 13 Expression elements) to accomplish the same thing!

If required, you can access a particular item of the array in an equation. For example,

Salmon_Matrix[BearCreek, 1999]

references a single (scalar) value representing the salmon population in Bear Creek in 1999.

GoldSim provides a wide variety of special operators which allow you to manipulate arrays. For example, if the name of the vector was Salmon_Population, the expression

Sumv(Salmon_Population)

would result in a single (scalar) value representing the sum of all items in the vector.

Read more: Using Vectors and Matrices (page 848).

Modeling Discrete Events

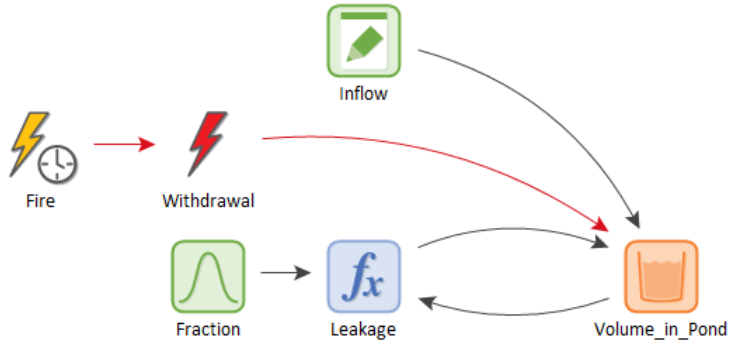
GoldSim provides powerful capabilities for superimposing the occurrence and effects of discrete events onto continuously varying systems. This allows for the realistic simulation of discrete events such as financial transactions, accidents, system failures, storms, labor strikes, and lawsuits. Events such as these can have important effects on the performance of many systems, and it is therefore important to represent them in a realistic manner.

GoldSim provides a variety of specialized elements for simulating the occurrence and consequences of discrete events. Events can be generated regularly ("occur exactly once a year on January 1"), randomly ("occur, on average, once a year"), or based on certain set of conditions (“when A is greater than B and the value of C has changed”). An event can trigger one or more consequences, such as changing the status of something in the model (“this task

is now complete"), achieving a specified milestone, or making a discrete change to some quantity in your model ("add $1000 to the account").

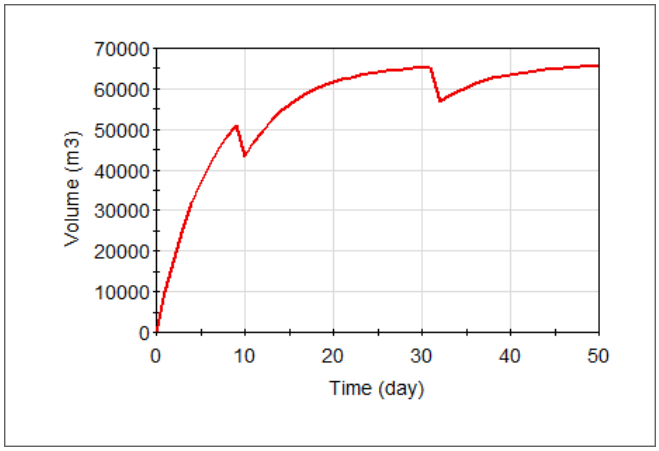
To provide an indication of how you can use this feature, let's add a simple event to the example involving the pond presented above in "A Simple Example". Suppose that water in the pond is used for fire suppression, and if a brush fire occurs nearby, firefighters withdraw 10,000 m^3 from the pond. Let's assume that it is summer, and there is a small fire nearby about once every 25 days.

We could simulate this using GoldSim's ***Timed Event*** and ***Discrete Change*** elements:



The Event "Fire" triggers the Discrete Change "Withdrawal" which modifies the Reservoir element representing the volume in the pond.

The result of such a simulation would look like this:



In this particular realization of the system, fires occurred around the 10th and 32nd days of the simulation. Because the event was specified as being random, it did not occur exactly every 25 days.

Read more: Chapter 5: Simulating Discrete Events (page 365).

Activating and Deactivating Portions of a Model

GoldSim provides the ability to make subsystems of your model (i.e., Containers) conditional. Conditionality allows you to make a Container and all of its contents inactive unless specific events occur and/or conditions are met. Elements in an inactive container are "dormant". That is, they are not updated or recalculated each timestep, and while they are inactive their output values never change. When other specific events occur and/or conditions are met, the Container (and its contents) can become active (and hence carry out their normal calculations). A conditional Container can activate and deactivate multiple times during a simulation.

Conditionality is a very powerful feature, and can be used to 1) temporarily "turn off" certain parts of your model (e.g., during a testing phase); or 2) simulate processes or features which themselves only exist or are active during certain parts of your simulation. This feature is particularly useful when using GoldSim to simulate projects.

Read more: Using Conditional Containers (page 968).

Controlling the Timestep in a Model

GoldSim provides a powerful timestepping algorithm that allows you represent the dynamics of your system very accurately. This includes the following:

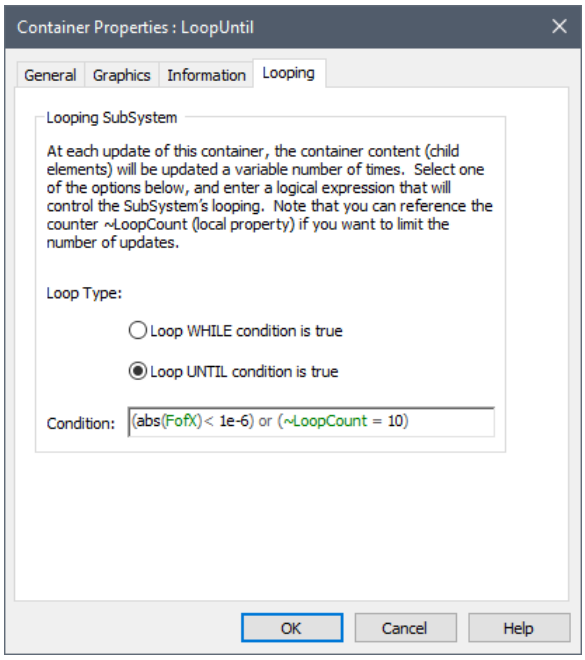
- You can define *Reporting Periods*, which compute and report *accumulated*, *average*, the *change* or the *rate of change* of values over specified periods (e.g., monthly, annually). Reporting Periods can be used in conjunction with a shorter "Basic Step" (e.g., you may model the movement of water or money through a system using a daily timestep, but need to report the cumulative amount of money or water that moved from one point to another each month)..
- You can increase or decrease the timestep length according to a specified schedule during a simulation (e.g., start with a small timestep, and then telescope out to a larger timestep). This can be useful, for example, if you know that early in a simulation, parameters are changing rapidly, and hence you need a smaller timestep.
- You can dynamically adjust (adapt) the timestep during a simulation based on the values of specified parameters in your model. For example, you could instruct GoldSim to use a timestep of 1 day if X was greater than Y, and 10 days if X was less than or equal to Y. Similarly, you could instruct GoldSim to use a short timestep for a period of 10 days after a particular event occurs, and then return to the default timestep.
- You can apply dynamic adaptive timestepping to specific Containers. This allows you, for example, to specify different timesteps for different parts (i.e., Containers) in your model. For example, if one part of your model represented dynamics that changed very rapidly (requiring a 1 day timestep), while the rest of the model represented dynamics that changed much more slowly (requiring a 10 day timestep), you could assign a 10 day timestep to the model globally, and a 1 day timestep to the Container representing the subsystem that changed rapidly.
- For some special types of systems, GoldSim provides additional dynamic timestepping algorithms (different from the timestep algorithms described above) to more accurately solve these equations. In particular, the Contaminant Transport Module utilizes dynamic timestep adjustment to accurately solve the coupled differential equations associated with mass transport.

Read more: Defining Reporting Periods (page 479); Advanced Timestep Options (page 484).

Carrying Out Iterative (Looping) Calculations

In some models, you may want to carry out an iterative calculation at each timestep. This might be useful, for example, if you have a coupled system of nonlinear equations that must be solved every timestep by iterating.

GoldSim allows you to create a Looping Container in which the elements inside are iteratively updated every timestep until a specified condition is met:



Such a looping calculation is facilitated by the fact that GoldSim also provides a specialized element that allows you to reference the previous value (of any variable in your model).

Read more: Using Looping Containers (page 1036); Referencing an Output's Previous Value (page 1030).

Dynamically Linking to Spreadsheets

GoldSim allows you to dynamically link a spreadsheet directly into your model.

In the simplest use of such a spreadsheet link, you can use the spreadsheet as a data source. In particular, a ***Spreadsheet element*** can import data from specified cells in a spreadsheet, assign specified units to these data, and make them available in your GoldSim model (as outputs of the element).

Note: When you import a row or column of spreadsheet cells into GoldSim (e.g., A1:A10), the data become items in a vector within GoldSim. When you import a range of cells involving multiple columns and rows (e.g., A1:E10), the data become items in a matrix within GoldSim.

In addition to importing data from a spreadsheet, you can use a spreadsheet as a custom element (with specific functionality). That is, you can dynamically send data from GoldSim to a spreadsheet, force the spreadsheet to recalculate, and then retrieve (updated) data from the spreadsheet back into GoldSim during a simulation (e.g., every timestep).

GoldSim also provides powerful capabilities to easily import lookup tables and time series data from spreadsheets to GoldSim. You can also readily export GoldSim results to a spreadsheet.

Read more: Spreadsheet Elements (page 982); Linking a Lookup Table to a Spreadsheet (page 319); Importing Data into a Time Series from a Spreadsheet (page 199); Exporting from a Time History Result Element to a Spreadsheet (page 786).

Importing Inputs from a Database

In simulations which require a great deal of input, it may be desirable (or even mandated) that the simulation model can access the various data sources directly to facilitate and ensure the quality of the data transfer.

As discussed above, one way to accomplish this in GoldSim is to import data from spreadsheets. GoldSim also provides a more powerful method. In particular, GoldSim input elements can be linked directly to an ODBC-compliant database. After defining the linkage, you can then instruct GoldSim to download the data at any time. When it does this, *GoldSim internally records the time and date at which the download occurred*, and this information is stored with the model results. This mechanism provides very strong and defensible quality control over your model input data.

Read more: Linking Elements to a Database (page 1107).

Building Custom Elements Using Scripts

In some situations, you may wish to define a complex function which cannot be readily implemented using the expression editing features supplied by GoldSim. For example, calculation of an output may require very complex logic which would be cumbersome to represent using a Selector element, or it may require a numerical solution technique (e.g., iteration); or perhaps you need to construct an array using complex logic.

To deal with such situations, you can specify a sequence of statements directly within the GoldSim interface using a Script element; in effect, building a custom element.

Scripts are created by inserting and editing statements or statement blocks, which may be variable definition statements, variable assignment statements, statements controlling the sequence of execution in the script (e.g., loops and if statements), or statements used for writing messages to the Run Log. The Script element sequentially evaluates the specified sequence of locally defined statements to determine its output(s).

Note: The Script element does not expect the user to learn or be familiar with a particular language. As a result, scripts are *not* created using a text editor. Rather, statements are inserted and edited within a "controlled environment" within the element's property dialog in which the user selects from a number of available statement types. The syntax is already defined for each type of statement – the user simply specifies the attributes and properties for each statement via a dialog box when the statement is inserted. Statements can subsequently be moved, deleted, and edited.

Read more: Script Elements (page 929).

Dynamically Linking to External Models

If GoldSim's built-in elements, the Script element or a dynamically-linked spreadsheet are not sufficient for representing a particular aspect of your model, you can dynamically link an external computer program directly to GoldSim. You must specify the parameters (outputs of existing GoldSim elements) which you wish to send to the external program, and the parameters that the external program will return to, and make available within, GoldSim.

In most cases, you need to only make minor modifications to the external program code to which you want to link in order for it to communicate with (i.e., be dynamically called by) GoldSim.

Note that this ability greatly increases the power and flexibility of GoldSim, allowing nearly any program to be dynamically linked into the dynamic, probabilistic and highly graphical GoldSim framework.

Read more: External (DLL) Elements (page 1004).

Building Large, Complex Models

In addition to the ability to build hierarchical models using Containers, GoldSim also provides a number of other features that were specifically designed to facilitate the construction, maintenance, and presentation of very large, realistic (and hence, often complex) models.

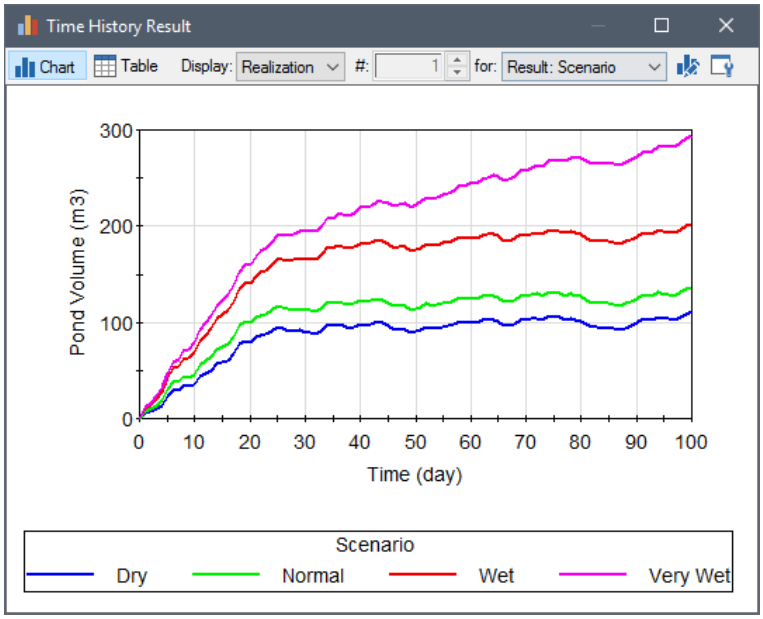
This includes:

- The ability to "localize" subsystems in your model so that variable names can be repeated without causing conflicts. This is particularly useful when your model contains numerous parallel systems (e.g., different divisions of a company), in which many of the equations and variable names would be identical. It also allows multiple people to work on different subsystems in a model without worrying about conflicting variable names.
- The ability to record versions (revisions) of a particular model file, so that you can identify the differences between the various versions of the file as the model is iteratively modified. (Which elements have changed? Which elements were deleted? Which elements have been added?)

Read more: Localizing Containers (page 1018); Tracking Model Changes (page 1099).

Modeling Scenarios

GoldSim provides a powerful capability that allows you to create, run and compare different scenarios for your model. Scenarios are differentiated by having different sets of input data. GoldSim's scenario modeling capability allows you to directly compare results generated by different sets of input parameters. In effect, when you use this capability, your model can store (and subsequently compare) multiple sets of outputs:



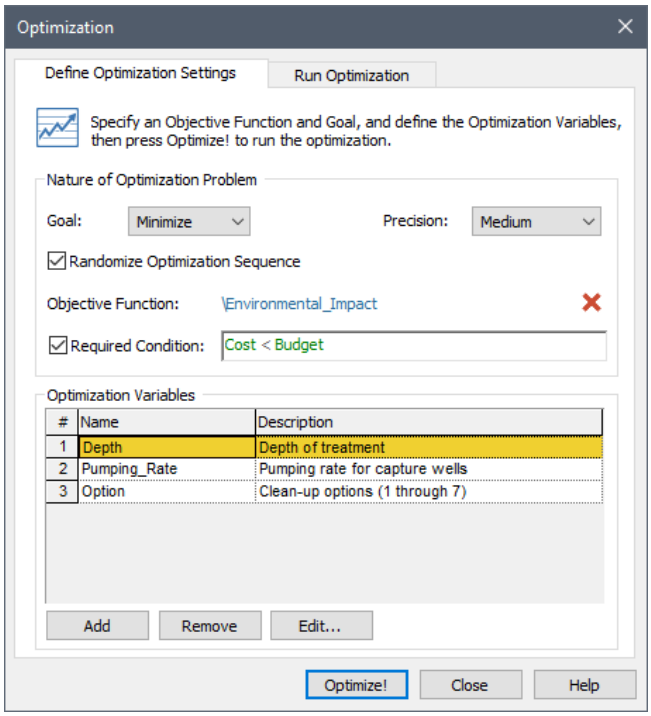
This can be very useful for carrying out sensitivity analyses, testing and comparing alternative designs, and asking "what if" questions.

Read more: Creating, Running and Comparing Scenarios (page 525).

Optimizing a Model

GoldSim provides the ability to carry out a special type of run to facilitate optimization of your model. For this type of run, you specify an objective function (a specific result that you would like to minimize or maximize), an optional constraint (a condition that must be met), and one or more optimization variables (variables in your model that you have control over).

GoldSim then runs the model multiple times, systematically selecting combinations of values for each of the optimization variables. By doing so, GoldSim can determine the values of the optimization variables that optimize (minimize or maximize) the objective function while meeting the specified constraint.



Typical uses of optimization include:

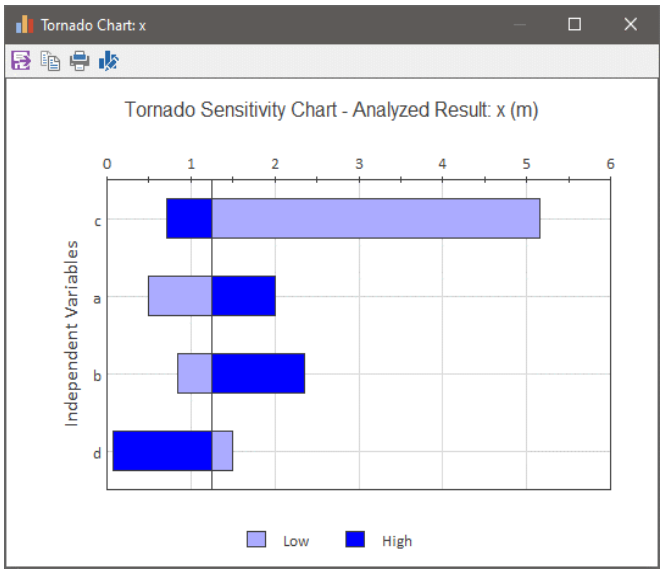
- Finding the best input data values for a model, in order to match observed historical data (i.e., calibration).
- Selecting the "best" option from among alternatives. "Best" could mean safest, cheapest, most reliable, or another appropriate measure.
- Optimizing the timing of actions or policy changes during the course of a simulation.

Read more: Running an Optimization (page 548).

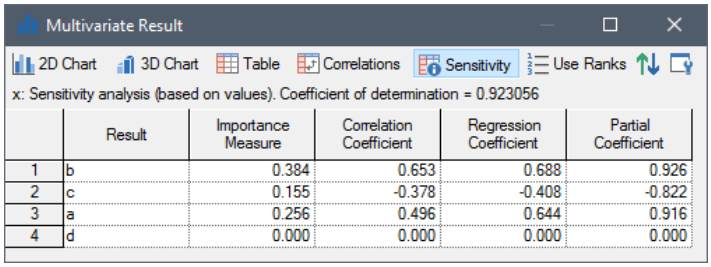
Carrying Out Sensitivity Analyses on a Model

GoldSim provides the ability to carry out a special type of run to facilitate sensitivity analyses. For this type of run, you specify the result you are interested in, and one or more variables that you want to analyze (which must be Stochastics or Data elements).

GoldSim then runs the model multiple times, systematically sampling each variable over a specified range, while holding all of the other variables constant. This then allows GoldSim to produce sensitivity plots (i.e., a tornado chart and X-Y function charts) to assist you in graphically identifying the variables in your model to which the result is most sensitive.



GoldSim also provides a second type of sensitivity analysis in which statistical sensitivity measures are computed by analyzing the results of multiple realizations of the model where all of the Stochastic variables are simultaneously sampled each realization:



	Result	Importance Measure	Correlation Coefficient	Regression Coefficient	Partial Coefficient
1	b	0.384	0.653	0.688	0.926
2	c	0.155	-0.378	-0.408	-0.822
3	a	0.256	0.496	0.644	0.916
4	d	0.000	0.000	0.000	0.000

Read more: Running Sensitivity Analyses (page 560); Viewing a Sensitivity Analysis Table (page 746).

Features for Documenting and Presenting Your Model

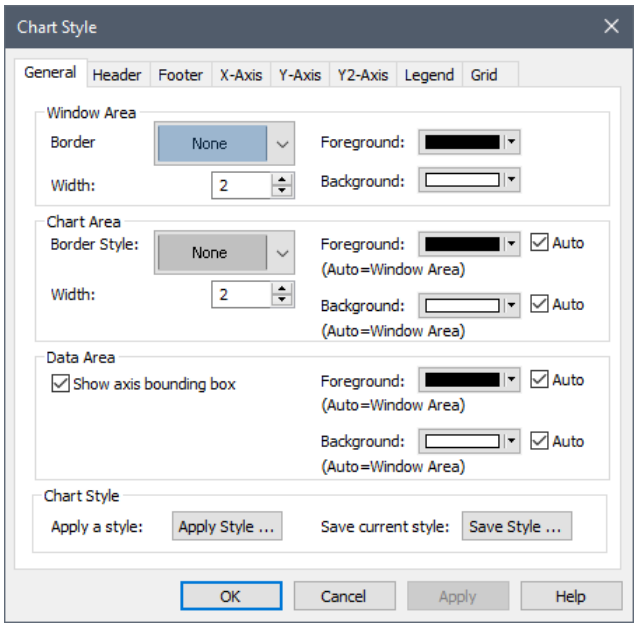
A model which cannot be easily explained is a model that will not be used or believed. As a result, GoldSim was specifically designed to allow you to effectively document, explain and present your model.

You can add graphics, explanatory text, notes and hyperlinks to your model, and organize it in a hierarchical manner such that it can be presented at an appropriate level of detail to multiple target audiences.

Creating Report Quality Result Graphics

GoldSim has powerful charting and display functions that allow you to plot and view your data in a variety of ways. You can plot time histories of your data, view probability distributions, create scatter plots and bar charts, and view tables of results. You can also combine multiple results on a single plot, and view multiple plots simultaneously. Using ***Result elements***, result charts and tables can be easily collected into one place for easy access within a model.

In addition, you can modify and save ***chart styles***, which allow you to customize (and reuse) the style (i.e., appearance) for each type of chart you may wish to produce:



Using these tabs, you have complete control over the appearance of your chart. You can customize the header, footer and legend, modify the chart axes, and change the data style (e.g., color, size and type of line). You can create also ***chart styles*****,** *which can subsequently be applied to similar charts.*

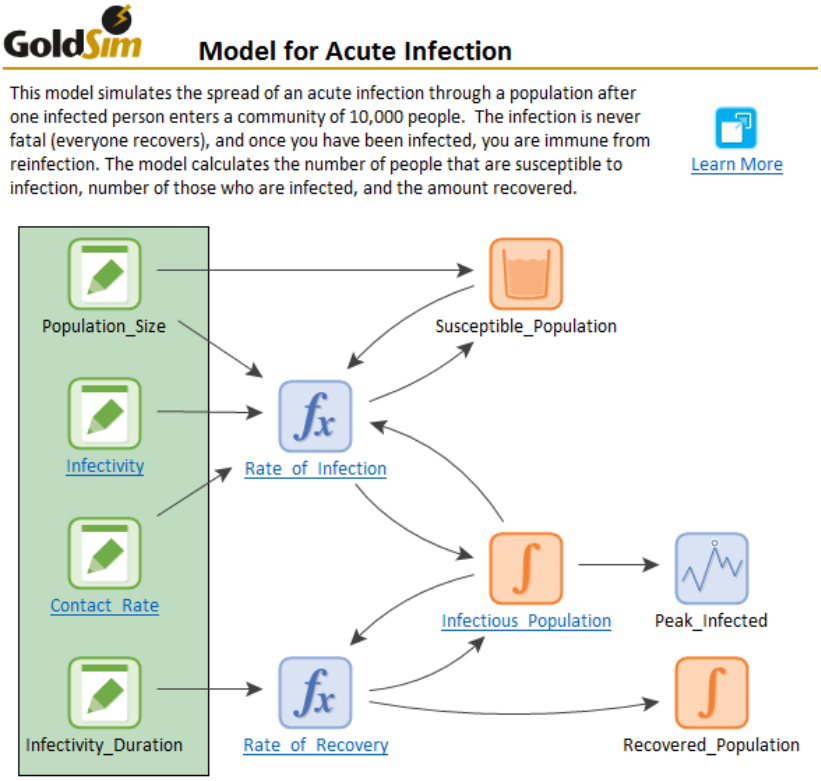
The charts and tables produced by GoldSim can be pasted into other applications (e.g., a word processor or a spreadsheet), or saved as separate graphics files.

Read more: Chapter 8: Displaying Results in GoldSim (page 577).

Internally Documenting Your Model

In order for a complex model to be understood and easily explained to others, it is critical that it be properly documented. GoldSim provides tools that allow you to internally document your model such that the documentation becomes part of the model itself, and hence is immediately available to anyone viewing the model.

GoldSim allows you to add text, images and other graphic objects directly to your model. In addition, you can add hyperlinks to other documents (e.g., a web site or a report). Clicking on the hyperlink then opens that document.



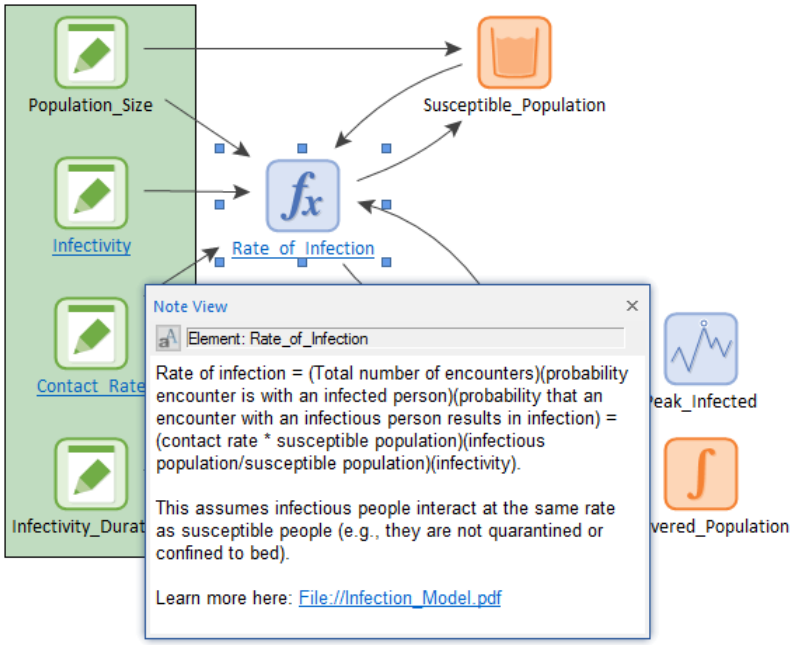
You can add text in any font or color, such as the title and description shown here. GoldSim provides drawing tools you can use to add text, lines, boxes (such as the one surrounding the four elements on the left) and other graphical objects. Hyperlink objects, such as the one labled "Learn More", can link directly to a separate document or a web site. You can also import graphics, such as logos (as seen here) or maps.

Note: To further facilitate documentation and presentation of your model, the default graphic images for a GoldSim element can be replaced by a custom image of your choice. For example, if a Reservoir element was being used to represent the population of a city, you could replace the default Reservoir image with an image of people or buildings.

Adding Descriptions and Notes

In addition to adding graphics, text and hyperlinks, you can provide a Description for each element. The Description is displayed in a tool-tip whenever you place your cursor over the element in GoldSim.

To provide more information, you can also attach a Note to any element in your model. Notes are text files of arbitrary length that are stored with the model:



Notes can include hyperlinks to documents or websites. In this example, the Notes links to a document stored in the same directory as the model file.

Using GoldSim as a Presentation Tool

As discussed previously, GoldSim was specifically designed to allow you to organize model elements into a hierarchy (using *containers*). This facilitates the creation of "top-down" models, in which the level of detail increases as you "push down" into the containment hierarchy.

Such a capability is essential if you wish to effectively describe and explain your model at different levels of detail to different audiences. For example, your manager may only want to see the "big picture", while a technical colleague may want to see the low-level details of a particular model.

The ability to create hierarchical, top-down models, in which at any level, details can be "hidden" (inside containers), coupled with GoldSim's powerful documentation features, allows you to design models which can be effectively explained to any audience at the appropriate level of detail.

Read more: Chapter 9: Documenting and Presenting Your Model (page 803).

Specialized GoldSim Modules

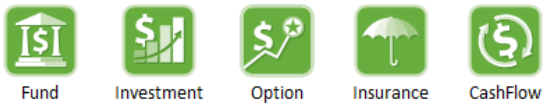
Although the standard elements incorporated within GoldSim can be used to build powerful and complex models, it was realized from the outset of the development of GoldSim that in some situations specialized elements and features may be required in order to efficiently model some kinds of systems. As a result, GoldSim was designed to readily facilitate the incorporation of additional modules (program extensions) to enable the program to address specialized problems.

Because extension modules can be highly specialized, they are described in separate documents.

The existing GoldSim extensions are briefly described below.

Financial Module

The Financial Module allows you to probabilistically simulate financial systems that include components such as accounts and funds, investments, options, projects or undertakings with specified cash flows, and insurance policies:



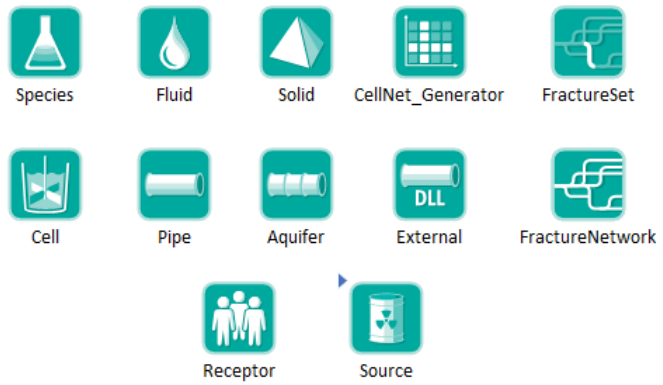
The Financial Module adds these five specialized elements to GoldSim.

By combining the specialized financial elements in the Financial Module with GoldSim's underlying probabilistic, dynamic simulation framework, you can quickly simulate and analyze complex financial systems, as well as complex engineering and business systems that have a financial component.

The Financial Module is described in detail in the **GoldSim Financial Module User's Guide**.

Contaminant Transport Module

The Contaminant Transport Module consists of specialized elements for representing contaminant species, transport media, transport pathways, contaminant sources, and receptors, and the coupled sets of differential equations underlying these systems:



The Contaminant Transport Module (RT version) adds these twelve specialized elements to GoldSim.

Note: Two versions of the Contaminant Transport Module are available (called CT and RT). RT is a premium version of the Contaminant Transport Module, and contains some specialized features and elements not included in the CT version.

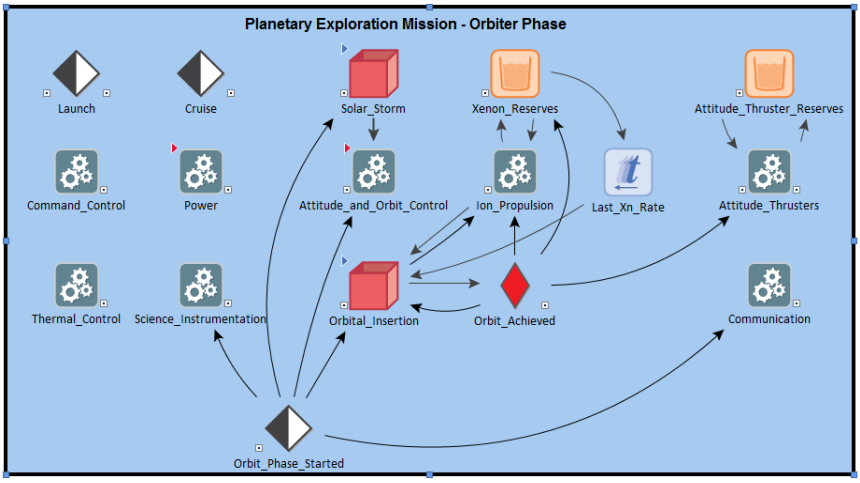
By linking these environmental elements together (and integrating them with GoldSim's basic elements), you can build complex contaminant transport simulations.

The Contaminant Transport Module is described in detail in the **GoldSim Contaminant Transport Module User's Guide**.

Reliability Module

The GoldSim Reliability Module allows you to probabilistically simulate the reliability of complex engineered systems over time. GoldSim provides the ability to model the interdependence of components through requirements and fault trees, as well as the capability to define multiple independent failure modes for each component.

The fundamental outputs produced by the Reliability Module consist of predicted reliability metrics (e.g., reliability, maintainability and availability) for the overall system, and for individual components within that system. In addition, GoldSim catalogs failure scenarios, which allows for key sources of unreliability to be identified.



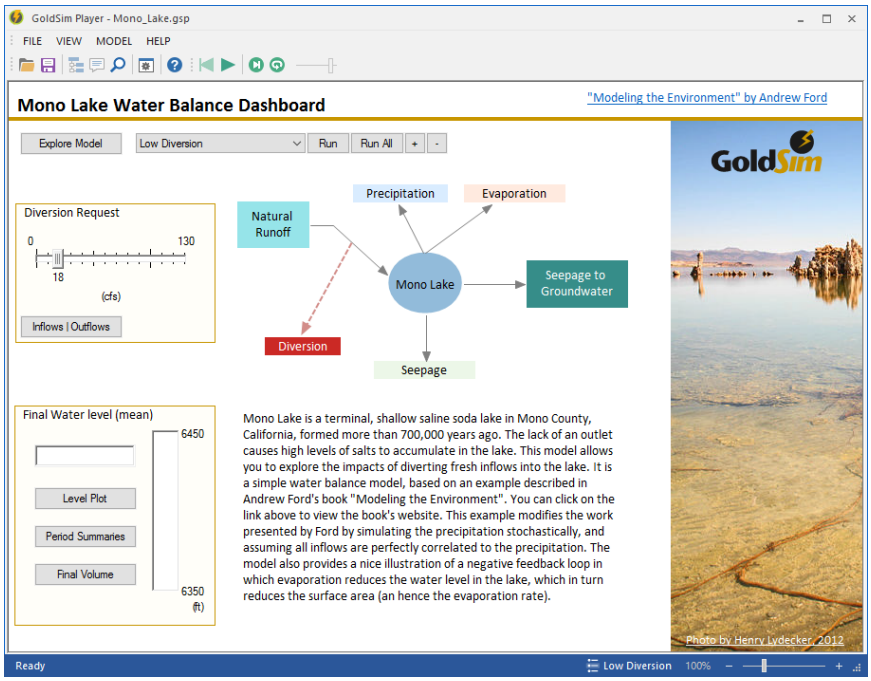
The Reliability Module can be used to:

- evaluate the reliability performance of systems and ascertain their compliance with customer or regulatory requirements;
- investigate the impact of the operational environment on system reliability; and
- simulate the effects of reliability on system throughput, or on other user-defined metrics.

The Reliability Module is described in detail in the **GoldSim Reliability Module User's Guide**.

Dashboard Authoring Module

GoldSim provides a set of tools that allow a GoldSim modeler to design and construct "dashboard" interfaces for models. The interfaces can be designed to look like "dashboards" or "control panels", with buttons, gauges, sliders and display panels, and the author can imbed instructions, tool-tips and graphics to provide instructions on the use of the model. Such an interface allows a model to be easily used by someone without requiring them to be familiar with either the GoldSim modeling environment or the details of the specific model:



In effect, the Dashboard Authoring tools enable you to use GoldSim as a high-level programming language to create custom simulation applications for distribution to end users who may not necessarily be modelers. Users do not need to have a licensed version of GoldSim to view and run a "dashboarded" model. They simply need to download the free GoldSim Player.

Read more: The GoldSim Player (page 55).

The Dashboard Authoring tools are incorporated into all versions of GoldSim. They are described in detail in a separate document, the **GoldSim Dashboard Authoring Module Users Guide**.

Distributed Processing Module

Monte Carlo simulation, in which multiple realizations of a system are simulated, naturally lends itself to distributed processing, since each realization is totally independent of the others. GoldSim has the capability to utilize multiple computers (linked over a network such as a LAN or even the Internet) to carry out probabilistic simulations of a system. Such a feature greatly facilitates probabilistic simulation of highly complex systems (in which a single realization may take many minutes or even hours).

The Distributed Processing Module is described in detail in the **GoldSim Distributed Processing Module Users Guide**.

The GoldSim Player

The GoldSim Player is a special version of GoldSim that allows you to "play" or “read” an existing GoldSim model without having to license the GoldSim software.

In general, the user interface for the GoldSim Player is identical to that of the full GoldSim version, with menu options and controls for editing the model removed or disabled. You can view and navigate any GoldSim model using the GoldSim Player. This allows a modeler to distribute a model to others without requiring them to license GoldSim.

If a Dashboard was created for the model using the Dashboard Authoring Module, you can even modify selected inputs and run the model using the GoldSim Player.

The GoldSim Player can be downloaded (for free) from the GoldSim Web site (www.goldsim.com/player).

Read more: Dashboard Authoring Module (page 54); Creating a GoldSim Player File (page 844).

Chapter 3: Building a Model in GoldSim

> The great successful men of the world have used their imaginations, they think ahead and create their mental picture, and then go to work materializing that picture in all its details, filling in here, adding a little there, altering this a bit and that a bit, but steadily building, steadily building.
>
> Robert Collier

Chapter Overview

This chapter describes the GoldSim user interface and presents the basic techniques required to build a model. The objective of the chapter is to acquaint you with the user interface components and provide you with the procedural knowledge required to navigate and carry out basic functions in the user interface. Conceptual issues (e.g., which element should I use to accomplish a particular task?) are discussed in the following chapter (Chapter 4).

Since the only way to learn a new tool is to use it (rather than just read about it), it is highly recommended that as you read this chapter, you simultaneously begin to use and explore the program. That is, as a feature or action is described in the text, experiment with it yourself within GoldSim.

Warning: This chapter assumes that you have read the previous chapter, "GoldSim in a Nutshell", which provides some basic background information on the features and capabilities of GoldSim.

In this Chapter

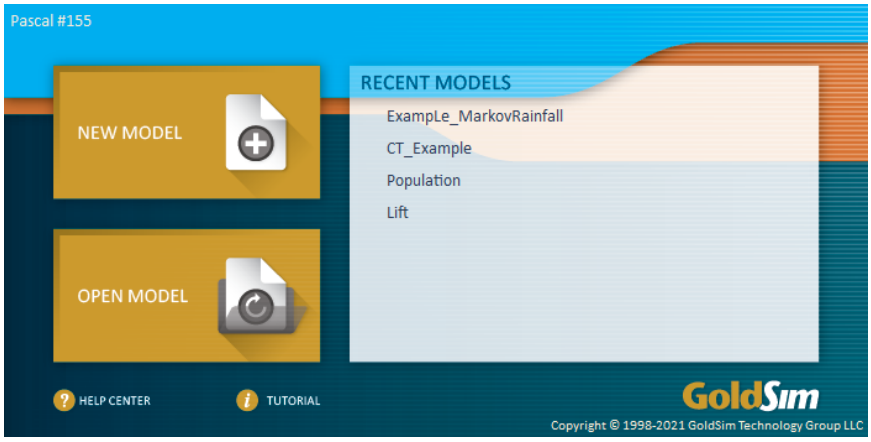
The following topics are discussed in this chapter:

- The GoldSim User Interface
- Creating Elements and Links
- Navigating and Viewing a Model
- Running a Model and Viewing Results

The GoldSim User Interface

The GoldSim Start Dialog

Whenever you start GoldSim, the following dialog is displayed:



The choices on the Start dialog are as follows:

New Model: This opens a new (blank) model.

Open Model: This displays a dialog for opening an existing model.

Recent Models: The eight most recently opened models are displayed here. Holding your cursor over a filename displays information (path, date modified, and size) regarding the file. Clicking on the filename opens the model.

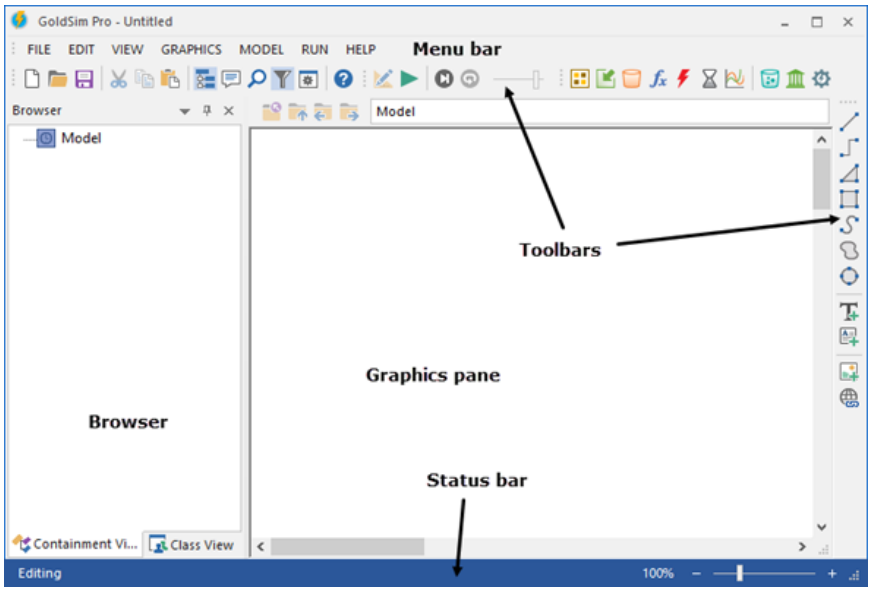
You can also close the Start dialog and open a new model by clicking anywhere outside of the dialog or pressing the **Esc** key.

Pressing **Help Center** will take you to the GoldSim Help Center, the primary web portal for accessing technical support. Pressing **Tutorial** will open a Tutorial. The GoldSim Tutorial presents the basic concepts on which GoldSim is based and provides an overview of GoldSim's key features and capabilities.

Read more: Getting Technical Support (page 21).

User Interface Components

When you open a new model in GoldSim, you see the following screen:



The largest part of the screen is occupied by the ***graphics pane***. This is where the graphical depiction of the model is shown. It is the "canvas" on which the model is drawn. For most users, this is where most model building and manipulation tasks will be carried out.

Note: If you have activated a GoldSim extension module, there may be some default items present in your models. For example, the Contaminant Transport Module adds a Container named Materials.

When you open GoldSim for the first time, the browser will be shown. The browser represents an alternative way to view a GoldSim model. In particular, it organizes the model in one of two ways:

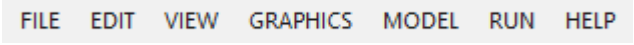
- In a hierarchical manner (by containment), similar to the way that files and directories on a computer are organized;
- By element type.

Browser toolbar button

The browser is initially docked on the left side of the screen. You can move it, undock it (so that it floats as a separate window) or deactivate (hide) it. You can turn the browser off and on by pressing the browser toolbar button or by pressing **F6**.

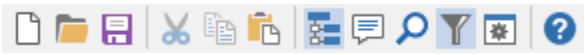
Read more: Using the Browser (page 106).

The ***menu bar*** provides access to menus from which nearly any GoldSim operation can be carried out. Although there are sometimes more convenient ways to carry out a particular action in GoldSim (e.g., toolbar buttons, context-sensitive menus), if you are stuck, you will find that most GoldSim functions and operations can be carried out via the main menu.



The user interface also includes a number of toolbars. All toolbars are present the first time you open GoldSim. All toolbars (as well as the menu bar) can be customized, hidden, and moved if desired. (In the screenshot above, several of the toolbars have been hidden.) The two most commonly used toolbars are the ***Standard toolbar*** and the ***Run Control toolbar*** .

- The Standard toolbar provides buttons for common GoldSim actions (e.g., Save a file, Run the model):



- The Run Control toolbar provides buttons for running (and pausing) a model:

The ***status bar*** at the bottom of the screen provides information regarding the mode that the model is in, as well as access to tools (e.g., zooming). It also indicates the status of a simulation while it is in progress.

The appearance of the user interface components can be configured and customized to match the way that you like to use GoldSim. For example, you can customize toolbars, change the appearance of the graphics pane, and modify the appearance of objects in the interface.

Read more: Chapter 6: Customizing the Interface (page 435).

Types of GoldSim Objects

The GoldSim simulation environment is highly-graphical and completely object-oriented. That is, you build, document, and present models by creating and manipulating objects representing variables and relationships between the variables. For the purposes of discussing how to manipulate objects in GoldSim, it is important to differentiate between two types of objects: model objects and graphical objects.

A model object is used to quantitatively represent the variables and relationships in your model. Elements, the basic building blocks of a GoldSim model, are the primary model objects. Input and Output objects associated with each element, as well as Influences, are also model objects.

Read more: Element Inputs and Outputs (page 75); Understanding Influences (page 99).

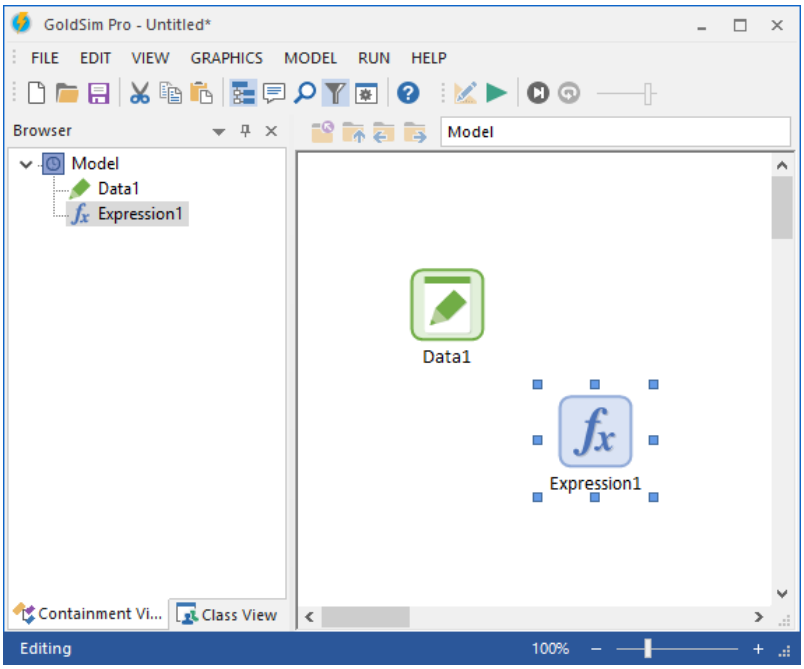
A graphical object is used to embellish or document the model. Graphical objects consist of images, text, lines, and other graphics that you can add to your model in order to document it. They have no impact on the simulation model itself, and only serve to improve the way in which the model is presented and documented. This chapter focuses on the use of model objects.

There are some differences in the manner in which these two types of objects are manipulated in GoldSim, and this is specifically noted throughout the documentation. In particular, whenever the word "object" is used to describe an action or behavior, it applies to both model objects and graphical objects. If a particular action or behavior only applies to a certain type of object, the object type (e.g., model object, element, or graphical object) is explicitly used.

Common Mouse Actions in GoldSim

The most common and important GoldSim mouse actions are summarized below:

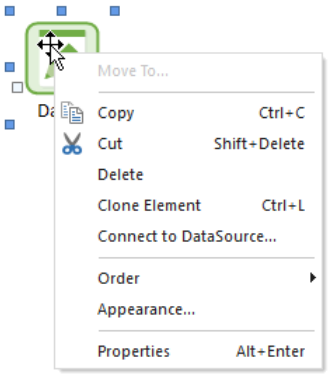
A click selects an object in the graphics pane or the browser. The selected object is highlighted.



Note how the selected element (Expression1) is highlighted in both the graphics pane and the browser.

A double-click on an element displays a dialog for editing its properties. (Pressing Esc, or the OK or Cancel button in the dialog, subsequently closes the dialog.)

A right-click anywhere in the interface displays a context-sensitive menu (also referred to as a *context menu*). The contents of a context menu depend on the position of the cursor when you click.



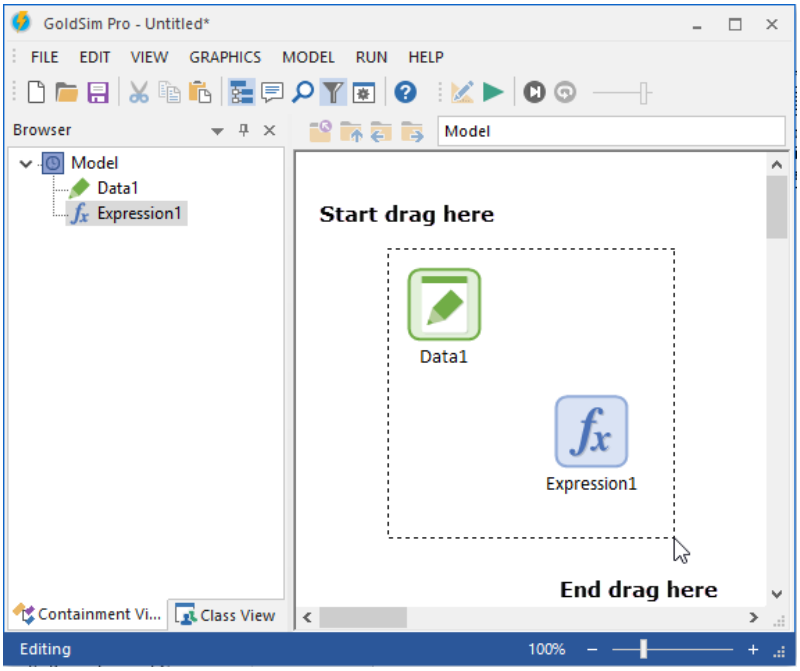
If you right-click on an element, a menu is displayed containing actions you can take for that element:

Note: GoldSim utilizes right-click context menus extensively. In fact, you may come to rely almost solely on this technique to carry out most GoldSim actions. If you want to do something with an object, and are in doubt about how to accomplish the action, right-click!

Moving an object: You can move an object in the graphics pane by *dragging* it from one location to another. Note, however, that you cannot move an element from or to the browser.

Displaying a tool-tip: You can display a tool-tip for a model object in the graphics pane and browser by holding the cursor over the object (without clicking).

Selecting multiple objects: You can select multiple objects in the graphics pane by Ctrl-clicking on multiple objects in succession or by creating a "selection box" by *dragging* your cursor from one point in the graphics pane (not on an object) to another point.

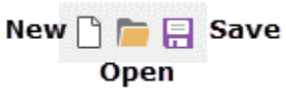


To select elements Data1 and Expression1, use the cursor to drag a box around the two elements.

Saving, Opening, and Closing GoldSim Files

GoldSim models are saved in files with the extension gsm (e.g., mymodel.gsm). GoldSim does not produce separate input and output files. The model definition and the results generated by the model are all stored in one file – the gsm (GoldSim Model) file.

The Standard toolbar provides buttons for saving and opening files:



To save a file, press **Ctrl+S**, press the **Save** button on the Standard toolbar, or select **File|Save** from the menu bar

The first time that you save a new file, you will be prompted for the file name.

GoldSim can have only one model file open at a time (although you can have multiple instances of GoldSim running simultaneously, each with a different model file).

If you select **File|Save As** from the menu bar, GoldSim saves the current model with a new (user-specified) name, keeping the newly named file open. Selecting

File|Save Copy As from the menu bar also saves the file to a new (user-specified) name, but keeps the original file open.

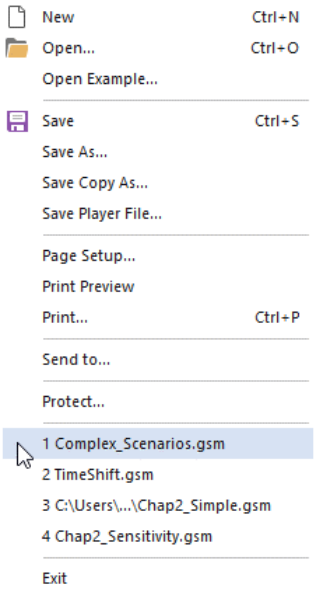
If you have made changes to a file but have not yet saved it, this will be indicated by an asterisk (*) next to the file name in the title bar for the GoldSim window.

To close a file (without exiting GoldSim), you can either open a new file or open an existing file. When you do so, if the current file has been changed, you will be prompted to save it before the new file is loaded.

To open a new GoldSim file, press the **New** button on the Standard toolbar, press **Ctrl+N**, or select **File | New** from the menu bar.

To open an existing file, press the **Open** button on the Standard toolbar, press **Ctrl+O**, or select **File | Open** from the menu bar. You will be prompted for a file name. To open an existing file, press the **Open File** button on the Standard toolbar, press **Ctrl+O**, or select **File | Open** from the menu bar. You will be prompted for a file name.

You can also open previous files you have saved by selecting one from the **File** menu.



The most recently saved files are listed at the bottom of the File menu.

Restoring Files After an Unexpected Failure Using Auto-Save

GoldSim allows you to recover a copy of your model file should GoldSim unexpectedly terminate for some reason while your file is open. This would allow you to restore changes you made to the file since you last manually saved it.

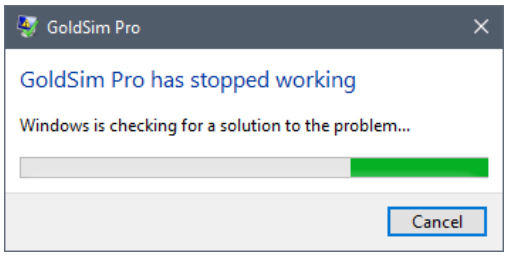
Note: Obviously, GoldSim should not terminate unexpectedly. If it ever does, please contact the GoldSim Technology Group at through the GoldSim Help Center (https://goldsim.zendesk.com).

The feature works by saving a copy of your model at a user-specified frequency (by default, every 10 minutes) to a separate location. In particular, the recovery file is saved temporarily in the local AppData directory of your computer (i.e., it

does not overwrite the original file). If GoldSim encounters a problem and closes abruptly (i.e., the software crashes), Windows will automatically restart GoldSim, and you will be given an opportunity to view the auto-saved recovery file. If you had made a number of changes and had not saved your original file for some time prior to the crash, the recovery file may represent a "newer" version of the file than the original file. When GoldSim restarts, you will be given the opportunity to replace your original file with the recovery file. If you choose not to use the recovery file, it will be automatically deleted (until it is regenerated with the next auto-save).

To understand how the auto-save feature works, it is useful to walk through the dialogs generated by GoldSim during this process.

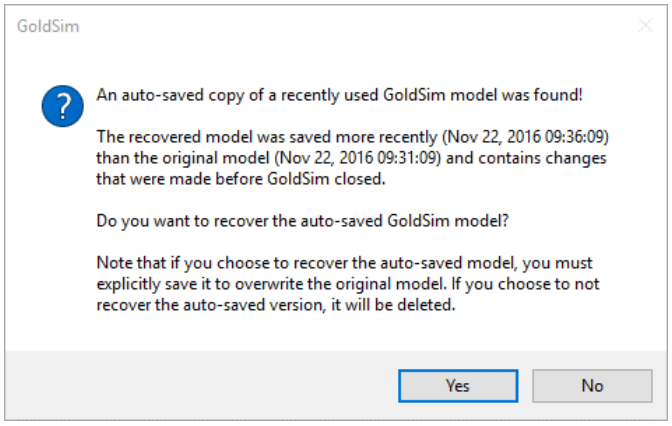
If GoldSim unexpectantly terminates, Windows will automatically restart the software, and you will be presented with the following screen:



It is critical that you do not press **Cancel** when you see this (or the next) dialog. If you do, your auto-saved recovery file will be deleted!

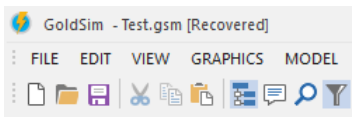
A second dialog will then appear, indicating that GoldSim is looking for a recovery file.

Finally, once the file is located, the following dialog will be displayed:



Note that the dialog will tell you if the recovered model file is more recent than the original file. If you choose "No", the recovered file will be deleted and a new file will be opened.

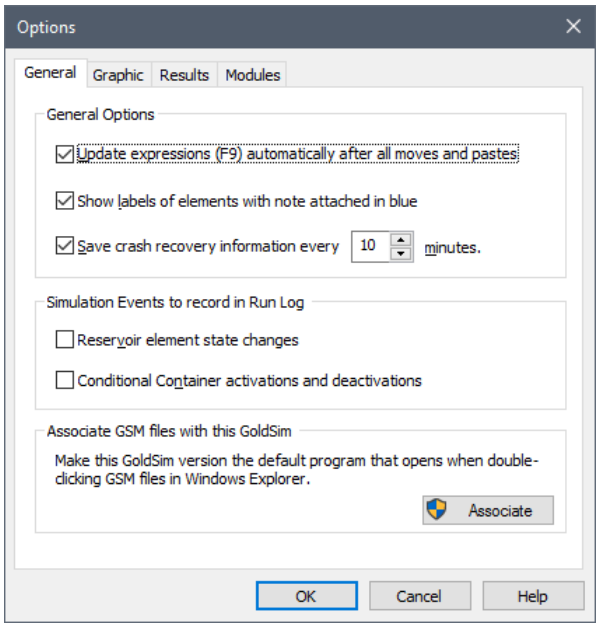
If you select "Yes", the recovered file will be opened. In the Title Bar, you will notice that "[recovered]" will be appended to the end of the filename:



If you choose to Save, you will be prompted for a filename. You can save this model with the same name as the original (to overwrite it) or save it with a new

name. Once that is done, the auto-saved model will be deleted from Apps Data directory on your computer.

The frequency at which the model is auto-saved can be controlled from the **General** tab of the Options dialog (accessed via **Model | Options…** from the main menu):



By default, the **Save crash recovery information every *X* minutes** is checked on and set to 10 minutes.

Several points should be noted regarding the auto-save feature:

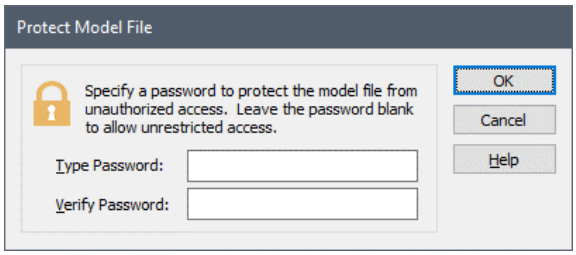
- Auto-save files are deleted whenever a file is saved or closed.
- This feature is only available on systems using Windows Vista and higher.
- This feature is not available for the GoldSim Player.
- The file will only be auto-saved if the file is in Edit mode and the application is in an idle state (e.g., a dialog is not open). Otherwise the save will be queued.

Note: The auto-saved file is saved in the GoldSim sub-directory of the AppData directory for the local user of the system in which GoldSim is Running (e.g., C:\Users*username*\AppData\Local\GTG\GoldSim). You can quickly find this location by opening Windows File Explorer and typing the keyword %LocalAppData% into the address bar.

Password-Protecting a Model File

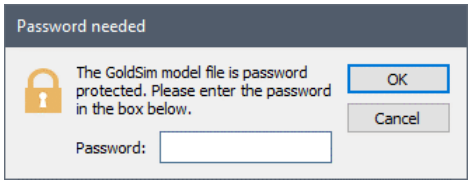
In some instances, you may wish to protect a model file with a password, such that in order for someone to open it, they must provide a password.

You can do this by selecting **File|Protect…** from the main menu. When you do this, the following dialog will appear:

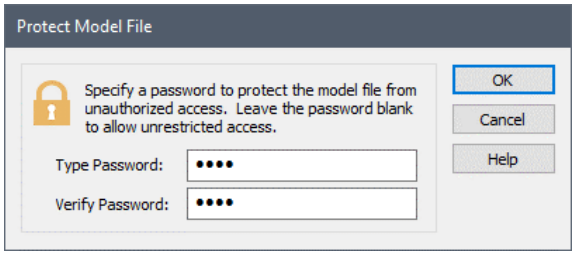


The password must have a length of 4 to 20 characters.

After you do this, anyone who tries to subsequently open the model will be presented with the following dialog:



Once a file is opened, you can remove the password by selecting **File|Protect…** from the main menu. If the file is protected, it will prompt you for the password again. Once you enter it, the Protect Model File dialog will be displayed (this time with the password):



To remove the password-protection, simply clear both fields and press **OK**.

Note that once a file is password-protected, users will be prompted for a password under the following circumstances:

- When the user tries to open the file;
- When the user tries to change the password (by accessing **File|Protect…**;
- When the model is used to create a Player file, and the Player file is opened;
- When the model is imported as a SubModel; and
- When the model is opened using command line arguments.

Warning: If you forget the password, there is no way to recover the file (as providing any kind of "backdoor" would weaken the security). So if you choose to use this feature, make sure you record the password!

Read more: Creating a GoldSim Player File (page 844); Importing SubModels (page 1083); Running GoldSim from the Command Line (page 571).

Sending Your Model to Someone Via Email

If you wish to send a model to someone else via email, you can quickly do so by selecting **File|Send to…**. GoldSim will open your default email program, and attach the model file to a new message.

Simulation Modes

At any given time, a GoldSim model is in one of four states (referred to as ***modes***):

Edit Mode: The model is currently being edited and does not contain any simulation results.

Run Mode: The model is currently running. In this mode, you can pause the simulation and view the model, but model objects can not be edited (although graphical objects can be changed).

Result Mode: The model has been run and contains simulation results. In this mode, you can navigate the model and view results, but model objects cannot be edited (although graphical objects can be changed).

Scenario Mode: This is a special mode (similar in some respects to Result Mode) that only exists if you are using GoldSim's scenario feature. To be in this mode, the model must contain at least one scenario that has been defined by the user, and at least one scenario must have scenario results. In this mode, you can navigate the model and compare scenario results, but no elements (other than Result elements and Scenario Data elements) can be added, deleted or edited.

Read more: Understanding Simulation Modes (page 517); Carrying Out a Simulation (Run Mode) (page 519); Viewing Results (Result Mode) (page 524); Creating, Running and Comparing Scenarios (page 525).

The mode that the model is in is clearly identified in the status bar (in the lower left-hand corner of the GoldSim window). In addition, the status bar takes on a different color in each mode:

This model is in Edit Mode. The status bar is blue.

This model is in Run Mode. The status bar is pink.

This model is in Run Mode, but is paused. The status bar is rust brown.

This model is in Result Mode. The status bar is green.

This model is in Scenario Mode. The status bar is orange.

You can only edit a model when it is in Edit Mode (and to a very limited extent, in Scenario Mode). When you create a new model file, it is in Edit Mode until you run it for the first time.

If you are viewing a model that is in Result or Run mode, editing will be locked (e.g., most of the property dialogs and menu items will be grayed out), although you can edit graphical objects such as text and images.

Creating Elements and Links

Elements are the basic building blocks of a GoldSim model. GoldSim models are built by connecting the outputs of one (or more) elements to the inputs of other elements. These connections are referred to as links. A complex model can have thousands of elements and links.

GoldSim Element Types

GoldSim provides a wide variety of built-in elements for entering data and manipulating variables. Each element represents a building block of the model, and has a default symbol by which it is represented in the graphics pane and an icon by which it is represented in browsers and menus.

The GoldSim elements can be divided into the following categories:

- Input elements
- Stock elements
- Function elements
- Event elements
- Delay elements
- Result elements

An additional type of element, the Container, is used to hierarchically organize other elements.

The basic element types, their functions, and their default graphic symbols and icons are summarized in the following sections.

Note: The symbols used for elements in the graphics pane can be customized by the user. However, the icons (which appear in the browsers) cannot be changed.

Overview of Input Elements

Input elements are used to create inputs (exogenous data) that subsequently define the properties of other elements.

Element	Default Symbol	Browser Icon	Function
Data			Defines scalar, vector or matrix data.
Stochastic			Defines uncertain data as probability distributions.
Time Series			Accepts time histories of data and converts them to an appropriate form for use in the model.

Element	Default Symbol	Browser Icon	Function
Lookup Table			Defines a one, two or three dimensional lookup table (response surface).
History Generator			Generates stochastic time histories based on specified statistics.

Read more: Using Basic Input Elements (page 156); Using Time Series Elements (page 192); Using Lookup Table Elements (page 307); Generating Stochastic Time Histories (page 893).

Overview of Stock Elements

Stocks elements are elements which impart inertia and memory to a system. These kinds of elements are responsible for internally generating the dynamic behavior of a system. At any point in time in a simulation, the outputs of stock elements are computed based on the historical values of their inputs. Mathematically, stocks represent time integrals.

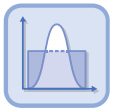
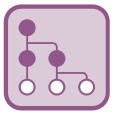
Element	Default Symbol	Browser Icon	Function
Integrator			Integrates values. Also can compute moving average of a specified input.
Reservoir			Integrates (and conserves) flows of materials, allowing for upper and lower bounds to be specified.
Pool			More complex version of Reservoir, making it easier to model multiple inflows and outflows.

Read more: Using Stock Elements (page 233).

Overview of Function Elements

Function elements are elements that manipulate and transform information or material. At any point in time in a simulation, the outputs of these elements are computed based on the current values of their inputs.

Element	Default Symbol	Browser Icon	Function
Expression			Defines mathematical or logical expressions.

Element	Default Symbol	Browser Icon	Function
Script			Allows you to create your own custom element using a simple procedural language.
Previous Value			Returns the value of its input from the previous model update.
Extrema			Computes the highest (peak) or lowest (valley) value achieved by its input.
Selector			Defines expressions with nested if…then logic.
Splitter			Splits an incoming signal into multiple outputs based on specified fractions.
Allocator			Allocates an incoming signal into multiple outputs given specified demands and priorities.
Sum			Facilities the addition of multiple values.
Convolution			Solves a convolution integral.
Logic Tree			Allows complex logic to be defined in terms of a logic tree consisting of various gate nodes (e.g., AND, OR) and conditions.
And			Combines multiple conditions using logical AND.
Or			Combines multiple conditions using logical OR.

Element	Default Symbol	Browser Icon	Function
Not			Logical NOT.

Read more: Using Basic Function Elements (page 281); Script Elements (page 929); Solving Convolution Integrals (page 884).

A special subcategory of function elements can be used to link GoldSim to external applications:

Element	Default Symbol	Browser Icon	Function
External (DLL)			Dynamically links to a user-specified external function (compiled as a DLL).
Spreadsheet			Dynamically links to an Excel spreadsheet.
File			Dynamically copies a file to a specified directory (for use by External elements).

Read more: Using External Application Elements (page 982).

Overview of Event Elements

Another category of elements allows you to superimpose the occurrence and effects of discrete events onto continuously varying systems:

Element	Default Symbol	Browser Icon	Function
Timed Event			Generates discrete event signals based on a specified rate of occurrence, regularly or according to a specified distribution (i.e., randomly).
Triggered Event			Generates discrete event signals based on one or more specified conditions.
Decision			Generates one of up to three defined discrete event signals based on specified conditions.
Random Choice			Generates a user defined discrete event signal based on specified probabilities.

Element	Default Symbol	Browser Icon	Function
Milestone			Records the time at which a particular event or specified condition(s) occurs.
Status			Generates a condition (True/False) in response to particular events or specified conditions.
Discrete Change			Generates a discrete change signal (a value) that can subsequently discretely modify the values of other elements (e.g., Integrators and Reservoirs).
Interrupt			Interrupts a simulation when a specified event or condition occurs and displays a user-defined message and/or writes a message to the run log.

Read more: Chapter 5: Simulating Discrete Events (page 365).

Overview of Delay Elements

Delay elements represent a type of element which imparts inertia and memory to a system by delaying (and optionally dispersing) continuous and discrete signals or flows. Like Stocks, at any point in time in a simulation, the outputs of Delays are computed based on the historical values of their inputs.

Element	Default Symbol	Browser Icon	Function
Material Delay			Delays (and optionally disperses) material flows.
Information Delay			Delays (and optionally disperses) a signal.
Event Delay			Delays a discrete event signal. Can also be used to simulate queues.
Discrete Change Delay			Delays a discrete change signal. Can also be used to simulate queues.

Read more: Using Delay Elements (page 334).

Overview of Result Elements

Result elements provide a convenient and powerful mechanism to collect, analyze and display simulation results.

Element	Default Symbol	Browser Icon	Function
Time History Result			Displays time history results.
Distribution Result			Displays probability distributions.
Final Value Result			Displays bar, column and pie charts (and tables) of final values.
Multi-Variate Result			Displays multi-variate results (scatter plots, correlation tables, raw data).
Array Result			Displays result vectors and matrices.

Read more: Creating and Using Result Elements (page 593).

Creating Elements

There are four ways to create (insert new) elements in GoldSim:

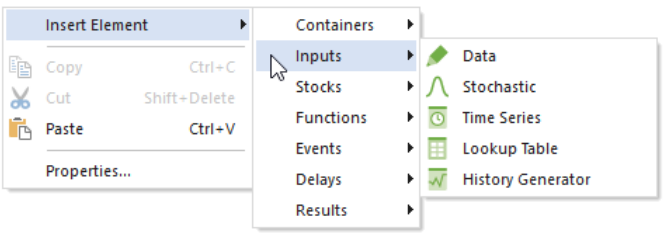
- using the context menu of the graphics pane;
- using the element toolbar;
- using the context menu for a Container element; and
- using the main menu.

The first two methods ar the most common and straightforward method, and they also have the advantage that they allow you to specify exactly where the element is inserted in the graphics pane.

Inserting an Element Using the Context Menu of the Graphics Pane

The steps involved to insert a new element using the context menu of the graphics pane are as follows:

1. Right-click anywhere in the graphics pane away from an object (i.e., in an empty part of the screen). A context-sensitive menu is displayed.
2. Place your cursor over the **Insert Basic Element** item to expand the menu. All of the GoldSim elements are listed by category.

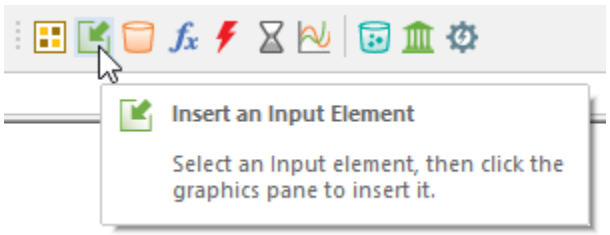


3. Click on the element type that you wish to insert.

4. The editing dialog for the element is displayed.
5. Enter the properties for the element and press **OK**.
6. The element will be inserted in the graphics pane with its upper-left corner *at the location of the cursor when you right-clicked*.

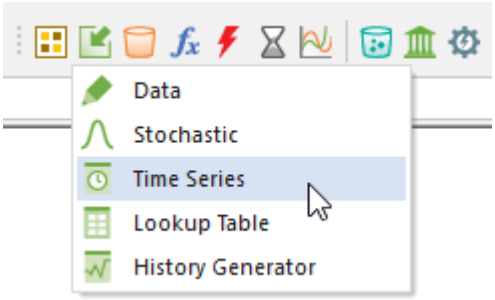
Inserting an Element Using the Element Toolbar

One of the toolbars provided by GoldSim at the top of the screen is the Element toolbar. Each button in the toolbar represents a different element category:



The steps involved to insert a new element using the context menu of the graphics pane are as follows:

1. Left-click on the button corresponding to the element category of interest. A menu will be displayed showing all of the elements in that category:



2. Left-click on the element type that you wish to insert. When you do so, the cursor will change and will look like this:

3. Move the cursor to where you wish to place the element and left-click.
4. The editing dialog for the element is displayed.
5. Enter the properties for the element and press **OK**.
6. The element will be inserted in the graphics pane with its upper-left corner *at the location of the cursor when you left-clicked*.

Inserting an Element Using a Container or the Main Menu

Although the most common way to insert a new element is to use the context menu in the graphics pane, you can also insert an element by using the context menu of a Container element or by selecting **Model | Insert Element** from the main menu. In both cases, you will be presented with a menu from which you can select an element to insert.

When using these two methods, you cannot control where on the graphics pane the element is inserted. It will always be inserted in the upper left-hand corner of the graphics pane.

If the context menu of a Container is used, the element will be inserted in the selected Container. If the main menu is used, the element will be inserted in the current Container.

Read more: Understanding Containers (page 96).

Element Inputs and Outputs

GoldSim models are built by linking the outputs of one (or more) elements to the inputs of other elements. Most GoldSim elements have at least one input and one output.

The easiest way to see the inputs and outputs is to use the input and output ***ports***. By default, ports are hidden until you hold your cursor over the element.

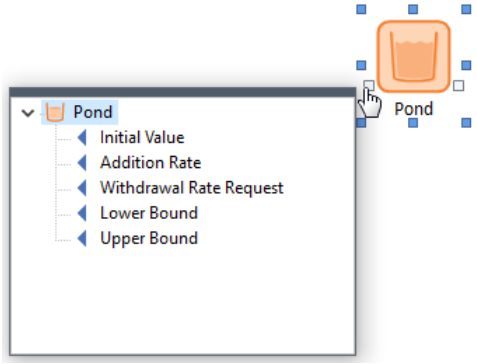
Note: Ports are also automatically shown under some other circumstances even without holding your cursor over the element (e.g., if the element has results). You can also optionally control when ports are displayed. Ports are discussed in more detail in the next section.

Read more: Understanding Input and Output Ports (page 76).

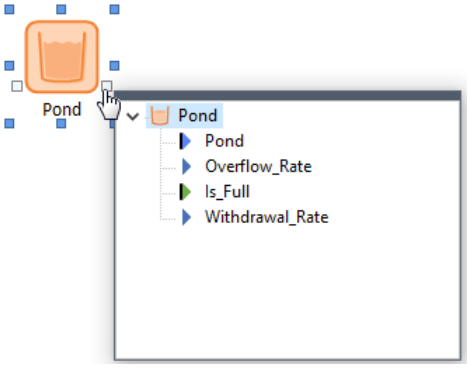
In all cases, however, holding your cursor over an element will cause the ports to be displayed. The ports appear as small squares at the bottom corners of the element:

Placing your cursor over a port changes the appearance of the cursor to a pointing hand, If you left-click on the port with this cursor, a browser view window (referred to as an input or output ***interface***) is displayed.

The input interface displays the element's inputs:



The output interface displays the element's outputs:



Note: You can also view the inputs and outputs in the browser.

Read more: Using the Browser (page 106).

As can be seen above, inputs and outputs have distinct names. Input names are "hard-wired" for each element type and cannot be changed by the user (e.g., the input names for all Reservoir elements are the same: Initial Value, Addition Rate, Withdrawal Rate Request, etc.). These input names correspond to the labels for the input fields in the property dialog for the element.

Some elements, such as an Expression, have a single output. Other elements, such as a Reservoir, have multiple outputs. If an element has multiple outputs, one of the outputs is usually defined as the ***primary output*** for the element. Any other output for the element is referred to as a ***secondary output***.

The name of the primary output of an element is always the same as the name of the element itself. Hence, the name for the primary output of the Reservoir element shown above is “Pond”, the same as the name of the element. The output names for secondary outputs are "hard-wired" for each element type and cannot be changed by the user. In the example above, “Overflow_Rate”, “Is_Full” and “Withdrawal_Rate” are secondary outputs.

Output names are important, because links between elements are created by referencing the name of the output of one element in an input field of another element.

Read more: Referencing Outputs of Other Elements (Creating Links) (page 80).

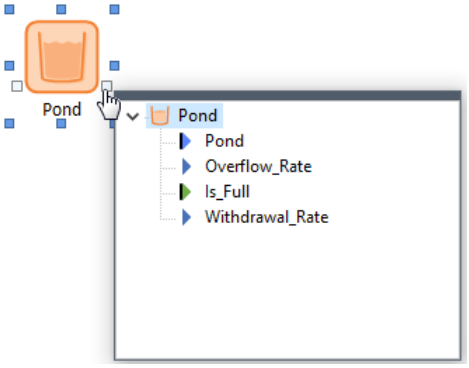
Understanding Input and Output Ports

Most GoldSim elements have both input and output ***ports***. (A small number of elements have only one or neither.)

Holding your cursor over an element will cause the ports to be displayed. The ports appear as small squares at the bottom corners of the element:

Ports serve two important purposes:

1. By left-clicking on them, you can view a list of the inputs and outputs for the element:

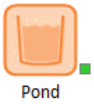


There are several reasons to do this, with the most common one being viewing the list of outputs in order to display results for a particular output.

Read more: Viewing Results (page 119).

2. By changing their appearance, ports are used to convey status information regarding the element and provide important visual cues when navigating a model. In particular,

   - When in Result Mode, if an element has results, the output port becomes green:

     Read more: Viewing Results (page 119).

   - If an input or output of the element is linked to an element in another Container, a dot appears in the middle of the input and/or output port:

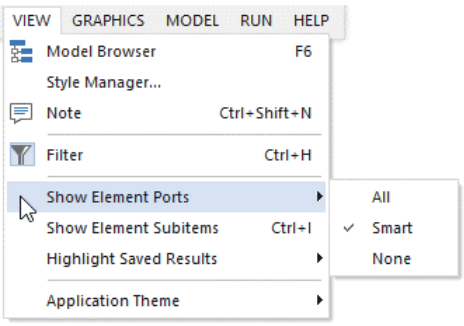
     Pond1 has an input that comes from another Container. Pond2 has an input that comes from another Container and has an output that is used in another Container.

     Read more: Influences Between Containers (page 101).

Note: There is a third instance in which the ports change their appearance. In particular, if an element has a manually "forced" precedence to address an ambiguous causality sequence, the input port becomes gold. This, however, is a highly advanced feature and would rarely be encountered.

Read more: Addressing Ambiguous Causality Sequences (page 1045).

The ports for an element are always displayed when you hold your cursor over it. However, you can control how ports are displayed when the cursor is not being held over an element. This is controlled via the main menu by selecting **View | Show Element Ports**:



As can be seen, there are three options:

- **Smart**. This is the default. If this is selected, ports are only shown if they have some status information to display (e.g., results, links to other Containers). In the examples shown above, this is why only one of the two ports are shown in some cases.
- **All**. The ports are always shown.
- **None**. None of the ports are shown.

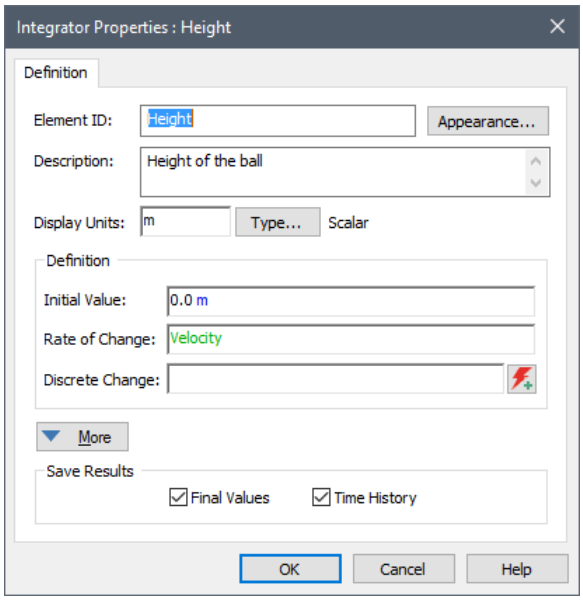
In the overwhelming majority of cases, the default (**Smart**) is the appropriate option. Occasionally, you may want the hide all ports (**None**) so as to make the graphics pane look less complicated. It is rare that you would want to show **All**.

Note: Changes to the appearance of the ports are not saved with the file. Every time you reopen the file, the appearance returns to the default (Smart).

Editing an Element's Properties and Creating Links

The properties of an element can be edited either when it is first created, or by double-clicking on it at any time (or by selecting the element and pressing **Alt-Enter**).

The properties dialog for a typical element (in this case, an Integrator) is shown below:



With a few special exceptions (e.g., Containers, Result elements), all elements have the following fields or buttons:

Element ID. The name of the element

Description. A brief (255 characters) description of the element.

Appearance button. Provides access to a dialog for changing the graphical appearance of the element.

Display Units. The units (which determine the dimensions) of the element's primary output.

Type button. Provides access to a dialog for editing the type (value or condition) and order (scalar, vector, matrix) of the element's primary output.

Save Results checkboxes. Used to specify whether or not results are saved for the element.

Definition fields. One or more input fields that define the properties of the element.

Editing an Element's Name, Description and Appearance

The default **ID** (name) for a new element is the element type followed by a number (e.g., Expression1, Integrator3). You can, of course, change the name.

Note: Element names can only include letters, numbers, and the underscore ("_") character. They cannot include spaces and must begin with a letter. In addition, some names (e.g., sin, cos, min) are reserved for use as functions and cannot be used as an element name.

Note: Two types of elements (Result elements and Dashboards) have slightly more flexibility in terms of their names. In particular, their names can include spaces.

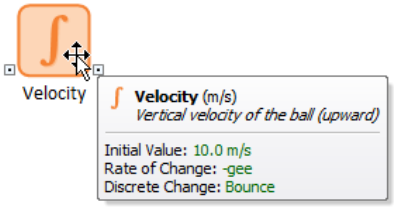
In addition to changing the element's name in the dialog, you can also edit it by Ctrl+double-clicking on the name of the element in the graphics pane. If you Ctrl+double-click on the element name in the graphics pane, it will become selected and available for editing (indicated by the dark background).

Note: By default, element names are forced to be unique (i.e., the elements are global). For most applications, however, you will want to build models which have elements with non-unique names. In order to do so, the each identically-named elements must have a different ***scope***. You can use a feature called localized Containers to create local scopes.

Read more: Localizing Containers (page 1018).

You should enter a **Description** for the element below the **ID** in the properties page. Descriptions can be up to 255 characters long. The Description field shows two lines. If you enter more than two lines of text, scroll bars appear. While entering a Description, you can use **Ctrl+Return** to insert a line break.

Note that the Description appears in the tool-tip displayed for the element in the graphics pane and the browser.



A tool-tip is displayed when you hold the cursor over the element in the graphics pane. The description is always displayed in the tool-tip below the element name.

Adding descriptions for every element makes your model much more transparent and easy to understand. It is strongly recommended that you add a description at the time you create the element. In larger models, it is highly unlikely that you will go back and add descriptions to the elements after you have completed the model.

Note: Descriptions are intended to be relatively short (255 characters). You can add very detailed documentation to an element by attaching a Note to it.

Read more: Creating, Editing and Viewing Notes (page 821).

You can access a menu for changing the graphical appearance of an element by pressing the **Appearance…** button.

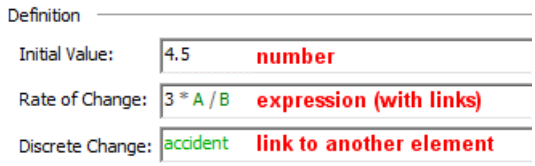
Read more: Editing the Appearance of Elements (page 452).

Specifying the Contents of an Input Field

You specify the contents of an input field in a properties dialog in one of three ways:

- You type in a number;
- You create a link to another element by entering the name of an output of that element; or
- You enter a mathematical expression, such as 3*log(250). Note that the expression itself can incorporate links (the names of element outputs), such as A*log(B), where A and B are output names.

Examples of all three of these types of inputs are shown below:



Referencing Outputs of Other Elements (Creating Links)

Some elements, such as an Integrator, have a single output, while other elements, such as a Stochastic or a Reservoir, have multiple outputs. If an element has multiple outputs, one of the outputs is usually defined as the ***primary output*** for the element. Any other outputs for the element are referred to as ***secondary outputs***.

Read more: Element Inputs and Outputs (page 75).

The name of the primary output of an element is always the same as the name of the element itself. Output names are important because links between elements are created by referencing the name of the output of one element in one of the

input fields for another element. In the example above, A, B, and Accident are the names of the primary outputs of the elements A, B and Accident, respectively.

The names for secondary outputs are "hard-wired" for each element type. For example, a Stochastic always has two secondary outputs named "Probability_Density" and "Cumulative_Probability". As a result, when referencing the secondary output of an element, it is not sufficient to simply enter the output name, as GoldSim would not be able to distinguish between the outputs if there were multiple occurrences of that type of element in the model (e.g., if there were two Stochastics in the model, GoldSim would not know which element was being referred to).

To avoid this problem, an output which is not the primary output is referenced by using both the element name and the output name: elementID.outputID. For example, the two secondary outputs of the Stochastic element named B would be referenced as:

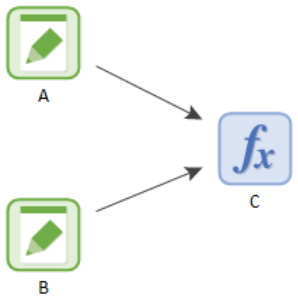
B.Probability_Density

and

B.Cumulative_Probability.

Links and Influences

When a link is made between the output of one element and the input of another element in the same Container, GoldSim automatically draws an arrow connecting the two elements in the graphics pane:



These arrows are referred to as influences.

Read more: Understanding Influences (page 99).

Entering and Editing Expressions in Input Fields

When you place your cursor into an input field and begin to type, you will notice that GoldSim color-codes the text as you type. Red underlined text indicates that GoldSim cannot interpret that portion of the expression (e.g., due to incorrect syntax). Once the item becomes valid, it will no longer be shown in red and underlined. If you leave an input field that is invalid (e.g., change the focus to another field), the entire field will be highlighted in pink.

Read more: Error Checking in Input Fields (page 94).

Note: In addition to displaying errors and color-coding text as you type, as you enter characters into an input field, GoldSim automatically suggests the names of existing outputs (that are consistent with those characters) that you may want to link to at the bottom of the input field.

Read more: Displaying Link Suggestions in Input Fields (page 84).

When you first place the focus in (i.e., click into) an input field (or if you stop typing within an input field), a tool-tip is displayed. If the expression is invalid, the tool-tip will explain why; if the expression is valid, it will display its current value. If you start typing (or move the focus to another field), the tool-tip will disappear. If you stop typing, the tool-tip will reappear. You can also view the tool-tip for an input field by simply holding the cursor over the field (while the focus is elsewhere). The tool-tip disappears when you move the cursor away.

The table below summarizes the mathematical and relational operators that are supported by GoldSim for use within expressions in input fields, along with their ***precedence***:

Precedence	Type	Operators
Highest	parentheses	()
	exponentiation	**,^
	unary minus	-
	multiplication, division	*, /
	addition, subtraction	+, -
	relational test	>, <, >=, <=
Lowest	equality test	=, ==, <>,!=

The precedence of the operators determines the manner in which expressions are interpreted and evaluated. For example, in the expression:

4 + 3 * 6

3 times 6 would be evaluated first, then 4 would be added to that quantity (resulting in a value of 22) because the "*" operator has a higher precedence than "+" operator. However, (4 + 3) * 6 would result in a different value (42) because the parentheses have higher precedence than the "*" operator.

Warning: The precedence of the unary minus as listed in the table above (lower precedence than exponentiation) only applies when it precedes a variable (as opposed to a number). That is, the expression -X**2, where X = 3 would be interpreted as -9. However, if a unary minus directly precedes a *number*, it is always considered to be part of the number itself, and hence the operator has a higher precedence that exponentiation. That is, the expression -3**2 would be interpreted as 9.

Note: The equality (= = and =) and inequality (<> and !=) operators assume that two values are identical if they are the same to 12 significant figures. Because double-precision arithmetic (used in the GoldSim code) has a precision of about 15 significant figures, random roundoff errors should generally not become significant. However, there is a caveat to this rule: if GoldSim compares a non-zero value to a zero value, they are never treated as identical, even if the non-zero value is extremely small. For example, if A was exactly 1 and B was different from 1 at the 14th significant figure, then A=B would be true, but A-B=0 would be false.

In addition to the operators listed above, GoldSim also provides a number of built-in functions (e.g., sin, cos, log) and constants (e.g., π, e, the gravitational constant, Avogadro's number) which can be used to build expressions. GoldSim also provides three logical operators (And, Or, Not) which only operate on conditions.

Read more: Understanding Output Attributes (page 88)***;*** Creating Conditional Expressions (page 134)***;*** Entering Mathematical Expressions into Element Input Fields (page 126).

When creating expressions, spaces are ignored. For example, the expressions "4*5" and "4 * 5" would both be interpreted as 20. You should feel free to add spaces to your expressions in order to improve their readability. The two exceptions to this rule are 1) when you are adding ***unit strings*** to expressions (e.g., m/sec, $/day) spaces within the unit string are not allowed; and 2) when you are using a unary minus with a number (e.g., -3C), spaces between the minus sign and the number are not allowed.

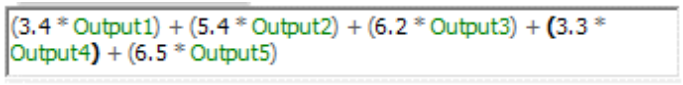
Read more: Using Units in Element Input Fields (page 91).

GoldSim color-codes expressions to make them easier to read. The colors used are:

Black:	Numbers and functions
Green:	Output names (links) and functions
Gray:	Operators
Blue:	Units
Underlined and Red:	Invalid
Light Gray	Not yet evaluated

In addition, if you use nested sets of parentheses in an expression, when you click inside the expression, GoldSim will highlight the nearest matching pair.

If the expression that you type into an input field is longer than the field in the dialog, the field will automatically expand when it has the focus such that the entire expression can be viewed.



Note: The input field for an Expression element is larger than for other elements (i.e., it is always expanded and hence accommodates several rows without requiring the focus).

Divide By Zero Errors in Input Fields

In some cases, you may enter an expression into an input field such as X/Y where at some point during the simulation, both X and Y are zero. In most instances, when GoldSim encounters zero in the denominator of an expression, it will display a fatal error and stop the simulation. However, if *both* the numerator and the denominator are zero, GoldSim will not display a fatal error; instead, the resulting expression will be set to zero and the simulation will continue. This can be very convenient, as it allows you to avoid adding complex logic to check for such cases.

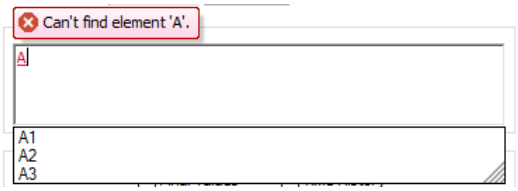
Note, however, that GoldSim only sets the expression to zero if both the numerator and denominator are zero. To understand this, consider an example where A and C are equal to zero, and B is non-zero. In this case, the following two expressions would be treated differently by GoldSim:

- A*B/C: would return zero, as A*B would be evaluated first (and considered to be the numerator for C.
- A*(B/C) would result in a fatal error, as B/C would be evaluated first, and B is non-zero.

Displaying Link Suggestions in Input Fields

When editing an input field, by default GoldSim automatically suggests the names of existing outputs at the bottom of the input field. That is, when you place your cursor into an input field and begin to type, GoldSim provides a list of suggestions for output names that are consistent with what you have entered so far.

For example, assume that the outputs A1, A2 and A3 all exist in your model (at a scope that is accessible from the current input field), and within an input field you type the letter A. The following will be displayed at the bottom of the input field:



If you simply want to select the first item in the list, you can press the **Tab** key. The suggestion box will close, the selection will be inserted, and in the input field, the cursor is placed to the immediate right of the selected output.

You can select one of the other suggestions either by selecting it with your mouse or using the **Up** and **Down** arrow keys to select an option.

If you use the mouse to make the selection, the suggestion box will close, the selection will be inserted, and in the input field, the cursor is placed to the immediate right of the selected output.

If you use the **Up** and **Down** arrows to make the selection, then the following rules apply:

- You can continue to move through the list using the **Home**, **End**, **PgUp** and **PgDn** keys.
- If you press the **Tab** key or right arrow, the suggestion box will close, the selection will be inserted, and in the input field, the cursor is placed to the immediate right of the selected output.
- If you press a non-character key (such as an operator like +), the suggestion box will close, the selection will be inserted, and in the input field, the operator is inserted and the cursor is placed to the immediate right of the inserted operator.

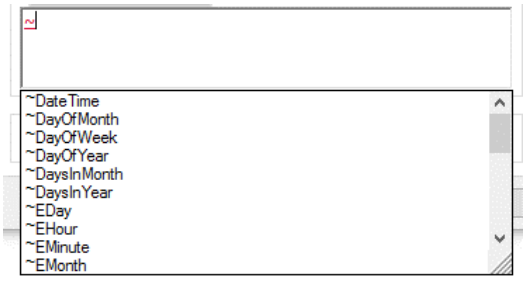
The suggestion list will also be closed if you left or right click elsewhere in the input field, or press **Esc**.

The following should be noted regarding how GoldSim constructs the suggestion list:

- The list only contains items that are within the scope of the input field.

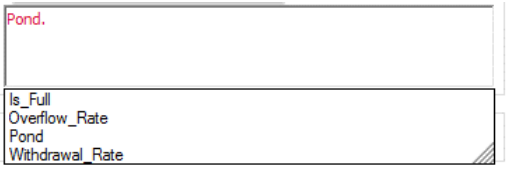
  Read more: Localizing Containers (page 1018).

- All locally available variables are included in the list (you can see these by typing ~):



Read more: Understanding Locally Available Properties (page 874).

- If you wish to link to a secondary output, you can do so by typing a period after the element name in the input field. The suggestion box will then list any secondary outputs that exist for that element:

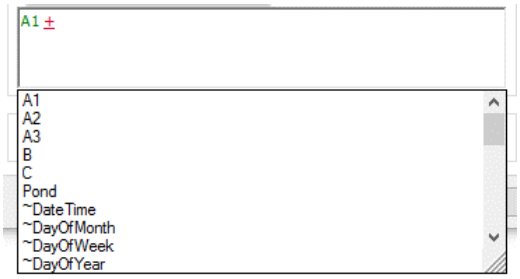


Read more: Referencing Outputs of Other Elements (Creating Links) (page 80).

- Similarly, if you wish to link to an exposed output of a localized Container, you can do so by typing a period after the name of the Container in the input field. The suggestion box will then list any exposed outputs that exist for that Container.

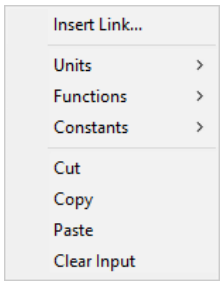
Read more: Localizing Containers (page 1018).

- Pressing **Ctrl+Space** causes the suggestion box to be displayed. If the cursor is to the immediate right of a character, then the list that is consistent with the preceding character string is shown. If the cursor is not to the immediate right of a character (e.g., if there is a space or operator before the cursor), then a list of ALL available outputs is provided.

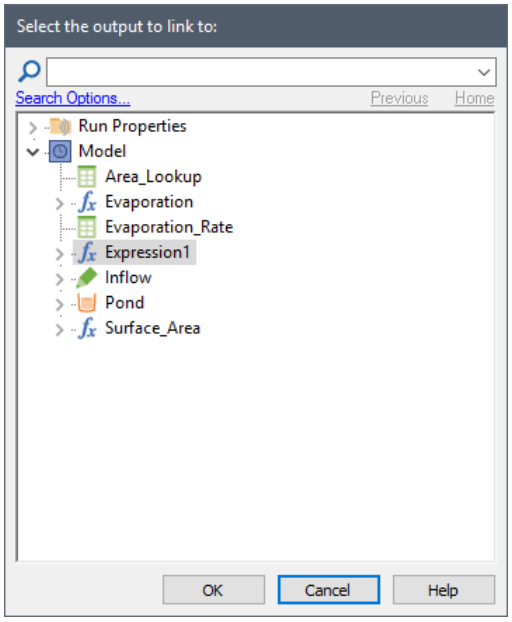


Input Field Context Menu

Right-clicking within an input field (or pressing **Ctrl+M**) displays a context menu to assist you in adding links and creating expressions:



Selecting **Insert Link…** from this menu (or pressing **Ctrl+I** directly from the input field) displays a browser tree showing all of the elements in the model:



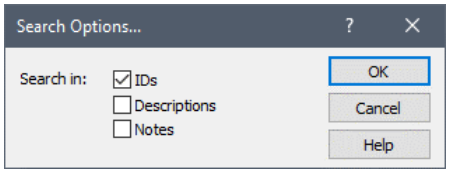
Note: For some elements, an input field may only accept a limited class of links, and will not allow the user to enter an expression. In these cases, the Insert Link dialog will only display a limited subset of the elements in the model (those that can actually be linked to this particular input).

This tree is organized by containment (and in alphabetical order) in the same manner as the browser. To insert a link from this dialog, you select a specific output object (or an element having a primary output), and then press **OK** (or simply double-click on the output). The output name will be inserted into the expression.

Note: The **Previous** and **Home** buttons at the top of the dialog are very useful for rapidly finding elements to link to. Whenever you use the Insert Link dialog, GoldSim opens the tree in the directory containing the element to which you are linking (i.e., it assumes that in most instances you will want to link to a nearby element). GoldSim also remembers the Container of the last place that you inserted a link from. Pressing the **Previous** button opens the tree at this location. Pressing **Home** returns to the directory of the element to which you are linking. Holding the **Ctrl** key down while opening the dialog (i.e., selecting Insert Link) is equivalent to opening the dialog and immediately pressing the **Previous** button.

At the top of this browser is a search field to assist you in finding elements. Enter a string and press the Search button to the left of the string (the magnifying glass) or press **F3** to find the next item in the browser that matches the search string. The search is not case-sensitive.

You can control where GoldSim searches by pressing **Search Options…**, which will display a dialog for selecting whether you want to search in IDs, Descriptions, and/or Notes.



Read more: Creating, Editing and Viewing Notes (page 821).

Note: These Search options are stored in the Windows Registry (so that once you change them, they will remain until you edit them again, even when editing other GoldSim files).

The context menu for an input field can also be used to insert the built-in functions and constants provided by GoldSim, and to insert units into an expression.

Read more: Understanding Containers (page 96)***;*** Finding Elements (page 113)***;*** Entering Mathematical Expressions into Element Input Fields (page 126)***;*** Using Dimensions and Units (page 89).

Deleting Links and Influences

You cannot delete a link between two elements by simply deleting the influence. In fact, GoldSim provides no direct way to delete the influence (e.g., you cannot select it and press Delete).

The only way to delete a link (and hence the influence representing it) is to remove the output being referenced from the input field of the other element. For example, if Data element A is entered into one of the input fields for element B, a link will be created (and an influence will be drawn) between element A and element B. To delete this link (and influence), you must delete the reference to A in the input field for B.

Note, however, that it is possible to *hide* an influence (so that it is not visible in the graphics pane).

Read more: Filtering Influences (page 448).

Understanding Output Attributes

All element outputs in GoldSim have three ***output attributes***: a type, an order, and ***dimensions***:

Type: The output type is either a value or a ***condition***. Values can take on any real number. Conditions have only two states: True or False.

Order: The order of an output can be scalar, vector or matrix. A scalar is a single item. A vector is a column (or row) of items. A matrix is a table (with rows and columns) of items.

Dimensions: Outputs can be assigned dimensions (e.g., length, volume, velocity) which can be displayed in any units that you choose (meters, gallons, feet/second). Dimensions can only be assigned to values (not to conditions).

Most GoldSim outputs default to being dimensionless, scalar values.

Output attributes are important because GoldSim uses them to ensure consistency between inputs and outputs when you link elements. That is, when you define the output attributes for an element, this also affects the required input attributes for that element.

For example, if you assign units of liters to a Reservoir element, GoldSim will only accept an input into the "Initial Value" field for the Reservoir which has dimensions of volume. (For those readers with programming experience, this is analogous to a programming language which is strongly-typed.)

Read more: Error Checking in Input Fields (page 94).

Note: The strong-typing built into GoldSim may at first appear bothersome: until you get used to ensuring that the inputs to an element are consistent with the specified output attributes, you may wish that GoldSim did not enforce this. It is our experience, however, that users quickly become accustomed to this requirement and greatly appreciate it as they become more proficient with the program. The idea is that a small amount of inconvenience when you first begin to learn the tool is more than made up for in the prevention of errors as you are building your models.

Note: The output attributes refer to the primary output of the element. For elements with multiple outputs, the attributes of the secondary outputs are automatically inferred by GoldSim based on the attributes of the primary output.

Read more: Element Inputs and Outputs (page 75).

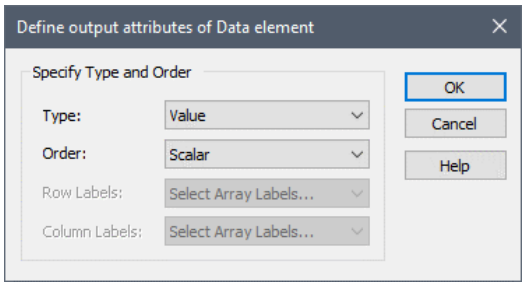
For some types of elements (e.g., an Expression), you can specify all three output attributes. For others, some output attributes are fixed and cannot be changed by the user. For example, the output of a Reservoir is always a value (only the order and dimension can be specified), and the output of a logical element (And, Or, Not) is always a scalar condition (in this case, the output attributes are completely fixed).

The output attributes that you will most commonly specify are the dimensions. Dimensions are specified by defining the ***Display Units*** for the element. For any element which can be assigned dimensions, the Display Units can be specified on the main dialog (directly below the Description field). Note that if the output

is defined as a condition (rather than a value), the **Display Units** field is grayed out.

Read more: Using Dimensions and Units (page 89).

If the other two attributes (order and type) can be modified for an element, a **Type…** button will be present in the dialog immediately to the right of the **Display Units**. Pressing this button displays the following dialog:



The type is specified in the Type box by selecting Value or Condition. The order (scalar, vector, or matrix) is specified by selecting from the Order list. If the order is vector or matrix, you define the Labels for the array in the Row Labels and Column Labels boxes.

Many models can be built using only scalar values. Vectors and matrices, however, are very powerful, and you will want to take advantage of them for more complex simulations.

Read more: Using Vectors and Matrices (page 848).

Although the use of condition outputs is not necessarily required in GoldSim (in many cases you can accomplish the same thing using values), their use can streamline and add clarity to a model. Conditions are particularly useful when modeling discrete events.

Read more: Chapter 5: Simulating Discrete Events (page 365).

Continuous and Discrete Outputs

In most situations, information is transferred between elements (via links) continuously in time. For example, if Expression element X is defined as being equal to A + B, the values of A and B are continuously sent to X (i.e., the information is "broadcast" through the link throughout the simulation). Conceptually, at any given time in the simulation, X is receiving a signal from A and B.

In order to propagate discrete events (and their consequences) between elements in a model, however, it is necessary to send information between elements intermittently as a "spike" or discrete "packet" of information. To facilitate this, GoldSim allows certain elements to emit and receive (i.e., produce as outputs and/or accept as inputs) *discrete signals*. Discrete signals are a special category of outputs which emit information discretely, rather than continuously.

Read more: Chapter 5: Simulating Discrete Events (page 365).

Using Dimensions and Units

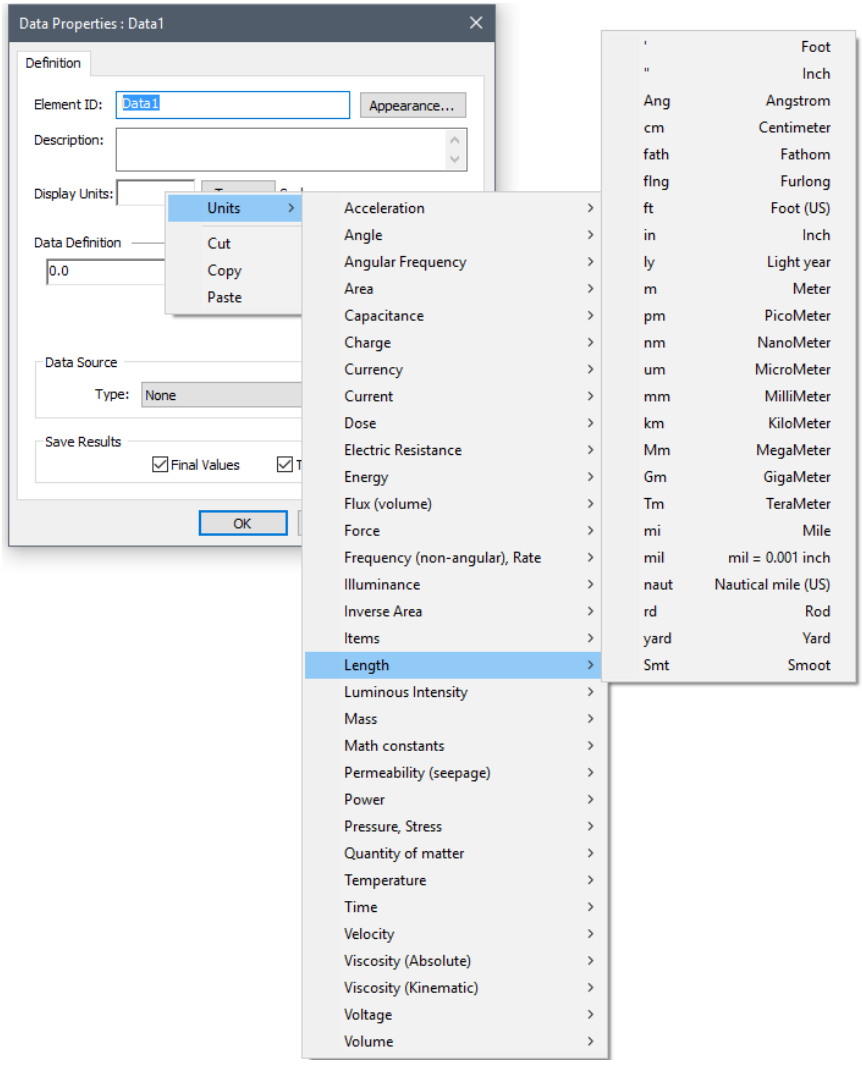
One of the more powerful features of GoldSim is that it is dimensionally-aware. You enable this capability by assigning display units (and hence dimensions) to the elements (and hence to the inputs and outputs) of your model. GoldSim has an extensive internal database of units and conversion factors. You can enter data and display results in any units. You can even create your own units.

When you create a link, GoldSim ensures dimensional consistency and carries out all unit conversions internally. For example, you could add feet and meters in an expression, and GoldSim would internally carry out the conversion. (If you

tried to add feet and seconds, however, GoldSim would issue a warning message and prevent you from doing so.)

You assign dimensions by entering the Display Units. The Display Units determine both the dimensions of the output(s) for the element, and the units in which the output will be displayed (in tool-tips and result tables and charts). You must enter a valid unit string (e.g., m, m3) made up of unit abbreviations. Appendix D lists all of the internal units (and their valid abbreviations) provided by GoldSim.

The context menu for the Display Units field includes a sub-menu containing valid units and their abbreviations. Clicking on one of these inserts it into the field.



When entering unit strings, the following rules should be followed:

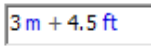
- Units can only be separated by a "-" or a "/". No other operators or blank spaces are allowed. For example, meters per second would be entered as "m/sec". Grams per meter per second would be entered as "g/m-sec" or as "g/m/sec". “g/m sec” would be invalid.
- For clarity, you can use parentheses in unit strings. For example, "kg/(m-sec)" is a valid string.

- Only the first "/" in the string (or the first "/" within a set of parentheses) is recognized, and the rest are ignored. Everything after the slash is assumed to be in the denominator. For example, "1/m/m" and "1/m-m" would both be interpreted as inverse square meters.
- Units are raised to a power by either following the unit with a number or with "^". For example, square meters could be entered as "m2" or "m^2". Inverse seconds could be entered as "sec-1", "sec^-1" or "1/sec". When units are raised to a power, the power must be an integer.
- Metric (SI) units are case-sensitive. For example, Mm and mm represent Megameters and millimeters, respectively.
- If you are referring to a temperature, use C (Celsius), F (Fahrenheit), K (Kelvin), or R (Rankine). If you are referring to a *difference* in temperature, use Cdeg (Celsius degrees), Fdeg (Fahrenheit degrees), K or R.
- If you are using US units pound or ounce for force or mass, you must distinguish between force and mass by appending an 'f' for force (e.g., lbf) and an 'm' for mass (e.g., lbm).
- When entering a unit abbreviation in an input field, GoldSim allows you to add an "s" to the end of the abbreviation, and in most cases will recognize it, even if the abbreviation has not been defined. For example, GoldSim will interpret yrs as yr. The rule GoldSim uses is as follows: if GoldSim does not recognize a unit that ends with an "s", it removes the "s" and again tries to recognize it. Note that not all such cases will necessarily work as intended. For example, ms would be interpreted as milliseconds (not meters).

A simple example file illustrating the use of dimensions and units (Units.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Using Units in Element Input Fields

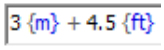
When you enter units within an input field for an element, you can do so by simply inserting them after the values in your expression:



You must, however, abide by several rules to ensure that the expression you enter can be unambiguously interpreted by GoldSim:

- Within a unit string, you cannot have any spaces. For example, meters per second must be entered as m/s rather than m / s.
- In general, you should enter a space *after* each unit string. In some cases, this space is required to ensure that the expression can be unambiguously interpreted (e.g., if the unit string is followed by a subtraction or division). In other cases, even if GoldSim is able to unambiguously interpret the expression, it is good practice to add a space after unit strings to make the expression more readable.

You can also explicitly identify the units by enclosing them in braces:



Braces are not required, but they can help make expressions more readable. Moreover, when you use them, it is not necessary to abide by the two rules mentioned above.

Note: Braces can only be used in an element's input fields. You can not use braces when defining the display units for an element.

In general, you only append unit strings to numbers. You should never append a unit string to an output name (a link) which itself has dimensions (this will result in a warning message). You can, however, append units to an output name or expression if the output or expression is dimensionless:

A m + 4 ft	OK if and only if A is dimensionless
(A*B) ft	OK if and only if (A*B) is dimensionless

Dealing with Currency Units

Unlike all other types of units, currency conversion rates cannot be assigned a single constant value (i.e., they change with time). To facilitate using various currency units, GoldSim provides a special dialog for specifying and editing currency units. It is accessed by pressing **Model | Currencies…** from the main menu.

Note: Specifying and editing currency units is described in detail in Chapter 3 of the **GoldSim Financial Module User's Guide**.

Dealing with Temperature Units

You must take special care when using temperature units in GoldSim, since unlike other unit categories, different temperature units are related not just through a conversion factor, but an offset. That is, the zero-values for Celsius (C) and Fahrenheit (F) temperatures are not absolute (i.e., whereas 0 m = 0 ft; it is not true the 0 F = 0 C).

To handle this properly, when you deal with temperatures in GoldSim, you have to be clear whether you are actually specifying a temperature (C, F, or K) or degrees of a particular temperature scale (Cdeg, Fdeg, or K). Temperature and degrees of temperature are treated the same in K, so there is no reason to differentiate when expressing temperature in K.

Use of these units is best explained through examples:

- If the temperature yesterday was 20C, and today is 5C warmer, you should calculate today's temperature as "20 C + 5 Cdeg". If you mistakenly entered "20 C + 5 C", it would be interpreted as "293.15 K + 278.15 K" which equals 571.3 K or 298.15C!
- Similarly, when defining a temperature as a Stochastic, you must be careful. For example, a normal distribution for a temperature defined in Celsius degrees as 20 +/- 5 should be specified as Mean: 20 C, SD: 5 Cdeg. Specifying it incorrectly as Mean: 20 C, SD: 5 C would result in a very large standard deviation!
- If you use a compound unit, you should always specify degree units. For example, when defining of a rate of temperature change of 2.5 Celsius degrees per day, you should enter "2.5 Cdeg/day", NOT "2.5 C/day".

Understanding Units for Month and Year

GoldSim provides a number of units to represent time (e.g., day, sec, hr). Like all units in GoldSim, time units must have a constant definition. For example, the definition of a day is 86400 seconds.

In this regard, there are two time units in GoldSim that warrant special attention: "mon" (month) and "yr" (year). (Note that "a" can also be used for year).

In particular, these units should be used sparingly (if at all), and if they are used, it should be done with great caution. To understand why, consider a case where you were specifying a rainfall rate in an input field. You could, for example, define a rainfall rate as 3 mm/mon. If you were to do so, during a simulation, you might assume then that this implies that 3 mm will fall in January, 3 mm will fall in February, and so on. If this was the case, this would actually mean that the rainfall rate was changing (since January has more days than February, it would imply that the rate of rainfall in February was higher). That is, it would mean that 3 mm/mon is not a constant value in time over the simulation!

However, like all other units in GoldSim, "mon" and "yr" must have a fixed definition. And as a result, 3 mm/mon is a constant value that does not in fact change with time (i.e., based on the simulated month). This is because the unit "mon" is defined as follows: 1 mon is equal to 30.4375 days. It is the average length of a month (365.25 days/12). So 3 mm/mon would be interpreted by GoldSim as 3 mm/30.4375 days = 0.09856 mm/day. Similarly, the unit "yr" (or "a") is defined as follows: 1 yr or 1 a is equal to 365.25 days.

The problem, of course, is that the actual length of a month and a year change with time, and hence referencing the units "mon" and "yr" in your model can be ambiguous. GoldSim enforces a constant definition for these units (the length of an average month and the length of an average year) so there is in fact no ambiguity, but this could easily be misunderstood by someone viewing your model. As a result, as a general rule, unless it is very clear that you are referring to average months or years (i.e., the actual calendar date is not critical for the simulation), you should avoid using the units "mon" and "yr" in your models.

Automatically Appending Units

When you enter a dimensioned number, link or expression into an input field which expects (based on the element's display units) a different set of dimensions, the text will be displayed in red, indicating that the input is invalid. For example, if you specify the display units for an Expression element as days, and you define it as "10 ft", GoldSim will indicate that there is an error.

Note, however, that if you enter a dimensionless number into an input field that expects a dimensioned input, rather than treating the input as invalid, GoldSim will automatically apply the correct dimensionality to the number when you close the dialog by appending the appropriate units (based on the specified display units for the element). For example, if you specify the display units for an Expression element as days, and you define it as "10", GoldSim will automatically append "days" to the entry when you close the dialog.

Note that GoldSim will only do this for dimensionless numbers. Hence, if you specify that the display units for an Expression element as days, and you define it as "A", GoldSim will indicate that there is an error (unless A has dimensions of time). Similarly, if you define the element as an expression (e.g., 3 + 4), GoldSim will not automatically append units and will indicate that there is an error.

Unit Casting

In some cases, you may need to turn a dimensioned value into a dimensionless value in order to use it in an expression. This is necessary, for example, if you need to use an empirical equation (which by definition may be dimensionally inconsistent), or if you need to raise a value to a power, where the power itself has dimensions, such as X**Time.

GoldSim allows you to do this by *casting* a dimensioned value or expression to a dimensionless value. For example, the expression

A |ft|

would evaluate A (which, in this case, must have dimensions of length), convert it to a value in feet, and cast it (output it) as a dimensionless value. That is, | | removes dimensions from a preceding dimensioned value and produces a dimensionless value.

The following are all valid expressions using unit casting:

A |m3| + 5	OK if and only if A has dimensions of volume
(A*B) |ft|	OK if and only if (A*B) has dimensions of length
Ctime |yr|	OK if and only if Ctime has dimensions of time

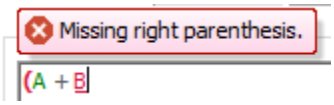
A simple example file illustrating casting units (Units.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Error Checking in Input Fields

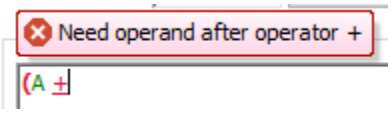
As you enter an expression into an input field, GoldSim attempts to interpret the expression, and if it is unable do so, it indicates this in two ways:

- The item in the expression that is causing the problem is highlighted ; and
- A tool-tip is displayed to explain the error.

For example, in the following expression, GoldSim indicates that a right parenthesis is missing by marking as red and underlining the last item in the expression (just prior to the error), and displaying a tool-tip:

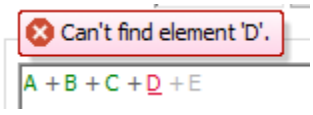


In this example, GoldSim indicates that a plus sign must be followed by another operand:



If you start typing (or move the focus to another field), the tool-tip will disappear. If you stop typing, the tool-tip will reappear.

Note that when evaluating an expression, GoldSim identifies and underlines the *first* error it encounters. Items shown to the left of the error are displayed in green (for links), black (for values), gray (for operators) or blue (for units), indicating that these have been successfully parsed and interpreted. Items shown to the right of the error are shown in light gray, indicating that they have not yet been parsed:



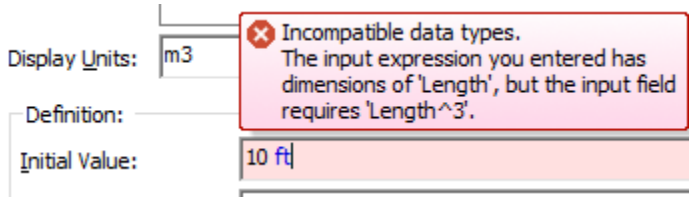
Once you change the focus away from an invalid input field, the entire field will be highlighted in pink to indicate that there is a problem:

You can view the tool-tip for an input field such as this by simply holding the cursor over the field (while the focus is elsewhere). The tool-tip disappears when you move the cursor away.

In some cases, GoldSim may be able to interpret the expression you enter, but the output attributes may be incorrect. That is, GoldSim uses the specified output attributes (dimensions, order and type) to ensure consistency when you enter information into input fields. If the attributes of the specified input number, link or expression are inconsistent with the required attributes for the field, the input is considered invalid and the entire field will be highlighted in pink.

Read more: Understanding Output Attributes (page 88).

For example, if you created a Reservoir element and assigned it display units of m^3, then the Initial Value input for the Reservoir must have dimensions of volume. If not, the input would be considered invalid:



It is important to understand that *a model with an invalid input cannot be run*. If you attempt to run such a model, GoldSim will display an error message.

Note: Whenever you change the output attributes for an existing element, GoldSim will keep the existing input numbers, links or expressions in the input fields (and mark them as invalid). There is, however, one exception to this rule. If you change the display units for an element, GoldSim will automatically reset any inputs which are currently specified as zero to be consistent with the new dimensions. For example, if you create a new Reservoir element, and assign it display units of m, and then later change this to gallons (but have not yet defined an Initial Value), GoldSim will automatically replace the default input for the Initial Value (0 m) with 0 gal.

Creating Links Using the Link Cursor

Link cursor

The ***link cursor*** provides an alternative method for creating links between elements using the browser and input/output interfaces rather than the element's editing dialog.

In particular, double-clicking on an input or an output object in the browser or interface invokes the link cursor. Moving to a compatible (in terms of type, order and dimensions) input or output (in the browser or input/output interface) and double-clicking on it creates a link. If the link is compatible, both "boxes" on the cursor will turn green when you place the link cursor over the input/output to which you wish to link (initially, the bottom box is green and the top box is red)

You can deactivate the link cursor (returning it to a normal cursor) by right-clicking anywhere in the screen or by pressing the **Esc** key.

Understanding Containers

A complex model may consist of many hundreds or thousands of individual elements. In order to manage, organize and view such a model it is useful (in fact, essential) to create separate sub-groups or collections of elements.

Such sub-groups are created in GoldSim by placing elements into *Containers*. A Container is simply a "box" into which other elements have been placed. In a sense, it is like a directory folder on your computer. Containers can be placed inside other Containers, and any number of levels of containment can be created.

The graphics pane in GoldSim shows the elements inside a single container. When you open a file in GoldSim, you will initially be viewing the inside of the Model Container (also referred to as the ***Model Root***). This is analogous to the top-most directory on your computer.

To create a new sub-group of elements within the Model Root (or any other Container) in your model, you need only insert a Container element.

Containers in a model are easily identified in the graphics pane: they all have a small triangle in their upper left-hand corner:

Click the triangle to "enter" a Container.

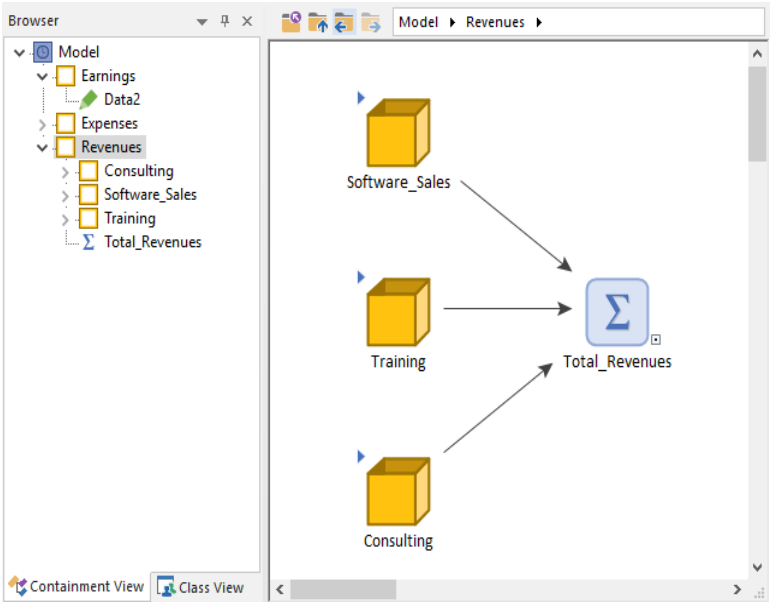
You can "enter" a particular Container (view its contents) by clicking on the triangle. You can also enter a Container via a Ctrl+double-click on the element (holding the **Ctrl** key down while double-clicking the left mouse button).

When you create a new Container element, it is initially empty (it contains no elements or objects of any kind). You place new elements in a Container by entering it and inserting elements, or using the context menu of the Container. You can also copy and/or move an element between Containers.

Read more: Moving Elements Between Containers (page 103).

Containers can be placed inside other Containers, and any number of levels of containment can be created. This ability to organize model elements into a hierarchy provides a powerful tool for creating "top-down" models, in which the level of detail increases as you "push down" into the containment hierarchy.

The example below shows a system which has been divided into a number of distinct sub-groups.



The browser shows the containment hierarchy in a manner similar to how a computer's directory hierarchy is shown. You can expand the Container in the browser to show its contents.

You can move through the containment hierarchy using the navigation bar at the top of the graphics pane:

You can also navigate Containers using the following hot-keys:

Keys	Action
Alt-Left	Moves back to previously viewed Container.
Alt-Right	Moves forward (only active if you have already moved back).
Alt-Home	Moves up to the Model Root.
Alt-Up or Alt-PgUp	Moves up one level.

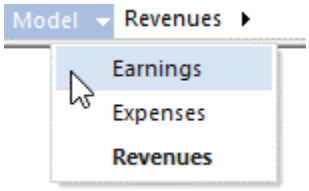
Note: Many modern mice come with additional buttons that are typically used to navigate the history of visited "places" (websites or folders). These buttons are also supported by GoldSim. The Backward and Forward buttons go backward or forward in the visited Container history. Pressing either of these buttons while holding the Ctrl key down goes up one level in the hierarchy. Pressing either of these buttons while holding the Ctrl and Shift keys down goes to the top level of the model.

Note: If you hold down the Move Back or Move Forward buttons when you click them, a drop list filled with recently visited Containers (in that direction) will be displayed.

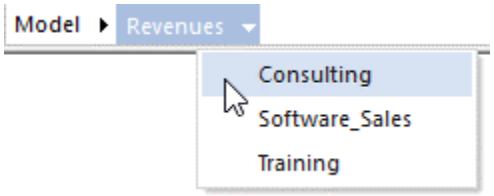
Just to the right of the Container navigation buttons is the Container navigation bar:

This shows the full path to the Container you are viewing (in the example above, the "Revenues" Container, which is one level down from the "Model" or highest-level Container is being viewed).

You can use the navigation bar to jump to another Container by clicking on the triangle to the right of any item:

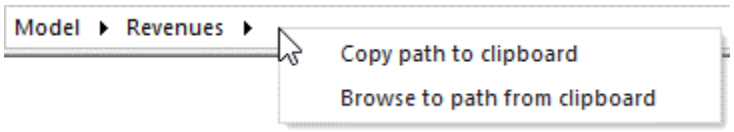


"Earnings" and "Expenses" are Containers at the same level as "Revenues" (the currently viewed Container). Clicking on either one of those would jump to that Container.



"Consulting", "Software_Sales" and "Training" are Containers inside "Revenues" (the currently viewed Container). Clicking on any one of these would jump to that Container.

Right-clicking in the Container navigation bar brings up the following context menu:



Selecting "Copy path to clipboard" copies the current Container path to the clipboard, allowing you to paste it into other documents (e.g., a report describing the model). Selecting "Browse to path from clipboard" immediately jumps to the path Container path currently stored in the clipboard.

While the various images in the graphics pane can be customized by the model author, the small icons in the browser cannot be changed. Hence, Containers in the browser are always indicated by a small box. Expanding the Container in the browser shows all of its contents (all of the elements it contains).

Read more: Editing the Appearance of Elements (page 452).

Note that the browser and the graphics pane are synchronized. Hence, if you click on an object in the browser, the Container in which the object resides will

be shown in the graphics pane. This provides a convenient way to navigate through the subsystems in the model.

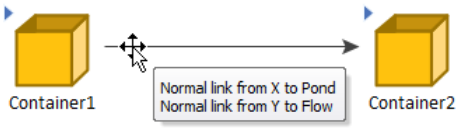
Read more: Using the Browser (page 106); Using Containers (page 137).

Note: When you save a GoldSim file, GoldSim remembers the last Container that was being viewed, and that Container is shown the next time the file is opened.

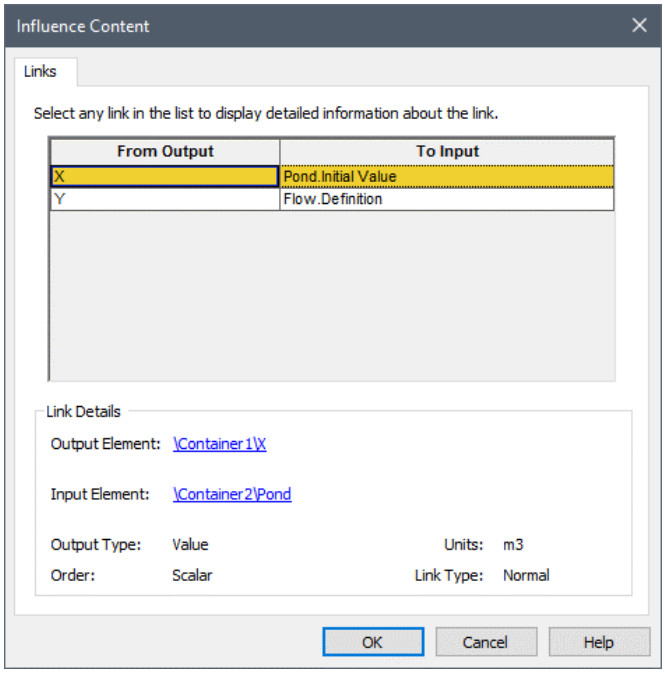
Understanding Influences

When you create a link between two elements, GoldSim draws an arrow between the two elements in order to graphically indicate that the two elements are linked.

This arrow is referred to as an ***influence***. If an element in one Container is linked to an element in another Container, an influence will be drawn between the Containers. If multiple elements in one Container are linked to one (or more) elements in another Container, then the influence represents multiple links. Placing your cursor over the link displays a tool-tip indicating the links the influence represents:



Influences have properties, which you can view by double-clicking on the influence arrow (or right-clicking on the influence and selecting **Show Links…**):



The property dialog for an influence lists all the links represented by the influence. Each link is represented by rows: an Output (where it originates), and an Input (where it ends).

When you select a specific link in the top part of the dialog, it is highlighted in yellow and its details are displayed in the bottom part of the dialog. The details include a listing of the full path of the input or output. The "path" refers to the containment path (e.g., A\B\C\X indicates that the element named "X" is located in Container C, which is inside Container B, which is inside Container A).

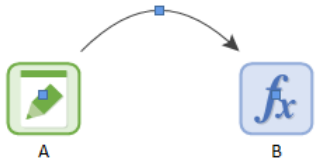
Note: Input names are hard-wired. A specific input is referenced in the Influence dialog as ElementId.InputID (e.g., "Volume.Initial Value" refers to the Initial Value input of the Reservoir element named Volume).

Read more: Element Inputs and Outputs (page 75).

You can jump to the element associated with a particular input or output by clicking on the path in the Link Details section.

The details also describe the Output Type (e.g., value, condition), Units, and Order (e.g., Scalar, Vector or Matrix). The Link Type is also indicated. Most links in a model will be “normal” links. Other types of links (e.g., coupled links and Previous-value links) can only be created by using one of the extension modules to GoldSim (e.g., the Contaminant Transport Module).

By default, all influences are curves (drawn with no curvature). You can add curvature to the influence by selecting it and dragging the control point (the small square) with your cursor:



You can modify the appearance of influences by changing their color and thickness, changing their shape (straight lines or orthogonal lines), adding nodes to segment straight lines, and adding text.

In some instances, in order to simplify the appearance of the graphics pane you may want to hide all the influences of a particular type (e.g., hide all influences consisting of condition outputs). This is referred to as filtering the influences.

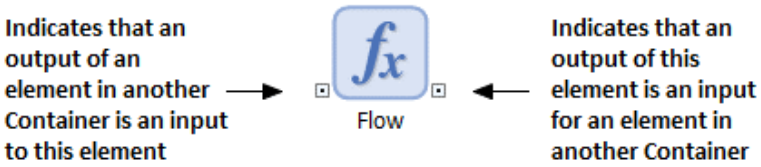
Read more: Editing the Appearance of Influences (page 445)***;*** Filtering Influences (page 448).

Note: Influences are not drawn between the element(s) being referenced by a Result element (a specialized element in GoldSim) and the Result element itself. This is because unlike other elements in GoldSim, when you reference an output of an element within a Result element, it is not treated as a “link”. GoldSim provides other tools for viewing these kinds of connections.

Read more: Browsing Between Result Elements and Referenced Outputs (page 597).

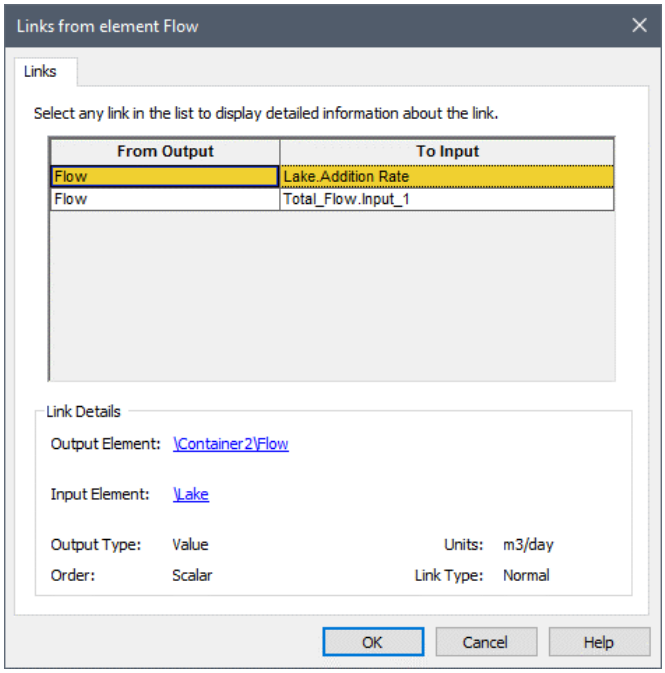
Influences Between Containers

When an element is linked to an element in another Container, it is useful to be able to visually signify this (i.e., since the linked element is in a different Container, when viewing the element there is no port to which the influence can be connected). GoldSim provides a solution to this problem. If an element is linked to an element in a different Container, GoldSim indicates this by placing a dot in the input and/or output port:



Read more: Understanding Input and Output Ports (page 76).

Right-clicking an outlined port accesses a context menu with the option to "Show Links from Element" (for output ports) or "Show Links to Element" (for input ports). Selecting this option will open a dialog showing all the links from or to the element, respectively:



Each link is represented by rows: an Output (where it originates), and an Input (where it ends).

When you select a specific link in the top part of the dialog, it is highlighted in yellow and its details are displayed in the bottom part of the dialog. The details include a listing of the full path of the input or output. The "path" refers to the containment path (e.g., \Container2\Flow indicates that the element named "Flow" is located in a Container named Container2.

Note: Input names are hard-wired. A specific input is referenced in the Influence dialog as ElementId.InputID (e.g., "Lake.Addition_Rate" refers to the Addition Rate input of the Reservoir element named Lake).

Read more: Element Inputs and Outputs (page 75).

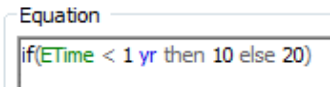
You can jump to the element associated with a particular input or output by clicking on the path in the Link Details section.

The details also describe the Output Type (e.g., value, condition), Units, and Order (e.g., Scalar, Vector or Matrix). The Link Type is also indicated. Most links in a model will be "normal" links. Other types of links (e.g., coupled links and Previous-value links) can only be created by using one of the extension modules to GoldSim (e.g., the Contaminant Transport Module).

Referencing Time in GoldSim

In a dynamic simulation, it is often necessary for you to explicitly reference time in a mathematical expression that you enter as an input to an element (i.e., you might want an input to take on different values at different times).

Within GoldSim, you can reference the ***elapsed time*** since the simulation began as **ETime**. For example, the input to the following Expression element takes on a value of 10 for times less than 1 year, and 20 afterward:



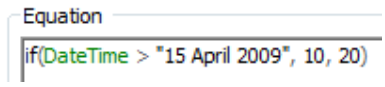
The if function is one of the built-in functions provided by GoldSim. This function has three arguments and can be written in two ways:

If(A then B else C) or If(A,B,C)

The above would be interpreted as "If A is a true condition, the expression is equal to B, otherwise it is equal to C".

Read more: Entering Mathematical Expressions into Element Input Fields (page 126).

GoldSim also allows you to begin your simulation at a specific date/time (e.g., January 1, 2005) and reference the calendar (as opposed to elapsed) simulation time (as **DateTime**):



Read more: Referencing Dates in Expressions (page 135).

Both ETime and DateTime are actually special model outputs referred to as ***Run Properties***.

Read more: Understanding and Referencing Run Properties (page 505).

Note: When you place the cursor over an element, an input or an output prior to running a simulation, GoldSim displays a tool-tip showing the object's current (expected) value. If the object is a function of ETime, by default this calculation assumes a value of 0s. You can modify the value used in such a calculation by editing **Time to use for Edit Mode updates** in the Advanced Time Settings dialog (accessed from the **Advanced…** button on the **Time** tab of the Simulation Settings dialog).

Read more: Using Tool-Tips (page 111); Referencing Time in Edit Mode (page 496).

Copying, Moving, and Deleting Elements

You can cut, copy and paste elements to and from the Windows clipboard using the **Ctrl+X**, **Ctrl+C** and **Ctrl+V** keys, respectively. Elements can be deleted by selecting the element and pressing the **Delete** key. These actions can also be carried out from the main menu (under **Edit**) or from the context menus for elements and the graphics pane.

Multiple elements can be selected, and then cut or copied to the clipboard and pasted. You can also cut or copy an entire Container, in which case the Container and all of its contents will be copied to the clipboard.

Warning: When you paste an element, GoldSim will append a number to the name if it conflicts with an element at the location where it is being pasted. When you paste an entire Container, GoldSim will automatically localize the Container if the names of elements inside the pasted Container conflict with those at the location where it is being pasted. Elements with the same name will conflict if they are located in the same scope. Localizing a Container changes the scope of its contents.

Read more: Localizing Containers (page 1018).

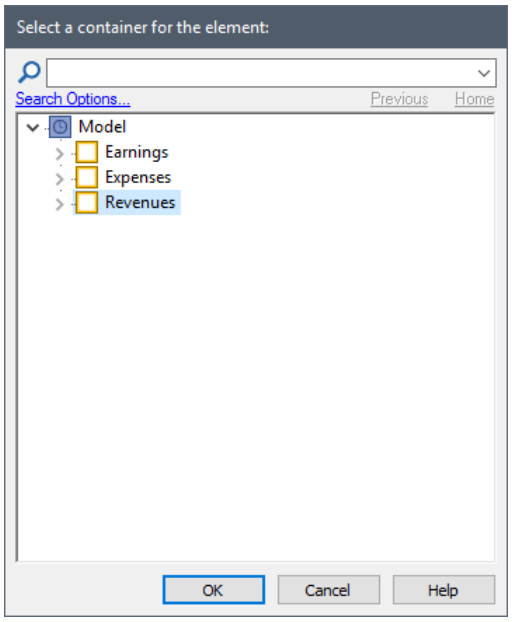
Moving Elements Between Containers

Often while building a model you will want to reorganize your model by adding Containers and moving elements into them, or moving elements between existing Containers. GoldSim provides two methods by which you can move one or more elements between Containers.

For both methods, you must first select the element (or elements) which you wish to move (multiple elements can be simultaneously selected).

Note: You can use these same methods to move graphical objects (such as images and text) that you have added to the graphics pane. You can also simultaneously select and move elements and graphical objects from one Container to another.

The first method for moving the elements(s) involves using the context menu for the object. After selecting the elements(s), access the context menu for a selected element (via a right-click) and choose **Move To…**. A browser window showing all of the Containers in the model will be displayed.



Select a Container and press **OK** to move the objects(s).

Alternatively, you can drag the selected element(s) within the graphics pane to a Container present in the graphics pane. When you do this, the Container will be outlined in a blue box. When you then release the left mouse button, the element(s) will be moved into the Container. (Note that you cannot drag elements out of the graphics pane onto the browser or onto a different model.)

Note: If you try to move an element into a localized Container such that a naming conflict occurs (i.e., because the Container already has an element with that name inside), GoldSim will warn you and provide you with an opportunity to change the name of the element being moved.

Read more: Localizing Containers (page 1018).

Warning: Whenever you paste or move an element, GoldSim automatically updates all input expressions in the model and rebuilds the ***causality sequence*** to ensure that the pasted/moved element is properly linked to other elements in the model. For large models (many hundreds of elements) this process could take a noticeable amount of time. You can disable this automatic updating by clearing the "Update expressions automatically after all moves and pastes" checkbox in the Options dialog (accessed via **Model | Options**…). If the option is cleared, you can still manually force an update by pressing F9 or selecting **Model | Update Expressions**. Regardless of whether this option is checked, however, GoldSim always carries out an update prior to running a model.

Read more: The Causality Sequence and Element Updating (page 358).

Copying Elements Between Model Files

In many cases, you may wish to create different portions of your model in different model files. For example, one individual may be working on one part

of a model (a particular subsystem), while another is working on a different subsystem. At some point, you would then want to combine the various subsystems into a single model file.

GoldSim allows you do so by simply opening two instances of GoldSim (each with a different file), copying the desired elements (including entire Containers) to the clipboard, and then pasting them into the other model. When doing so, however, you must be aware of three points:

- Multiple objects can be copied to the clipboard at one time (e.g., you can select multiple objects and copy them to the clipboard). You can also copy an entire Container (and all of its contents) to the clipboard.
- When copying Containers between models, GoldSim will *localize* the Container if the names of elements inside the pasted Container conflict with those in the model into which it is being pasted.
- If you are copying elements with vector or matrix inputs or outputs between models, you must ensure that the Array Labels defining those vectors and matrices are identical in both models. If they are different, it would cause a conflict when the item is pasted, and GoldSim will issue a warning message and prevent you from doing so.

Read more: Localizing Containers (page 1018)***;*** Using Vectors and Matrices (page 848).

Navigating and Viewing a Model

GoldSim's graphical user interface provides a number of powerful tools to make it easy for you to navigate and view both simple and complex models. While the graphics pane represents the "canvas" on which you graphically build a GoldSim model, the browser represents the "road map" allowing you to quickly navigate through your model. Tool-tips within both the graphics pane and the browser allow you to quickly obtain an overview of a model without constantly opening property dialogs. Powerful search capabilities allow you to find any element in your model. And perhaps most importantly, the ability to easily view model dependencies (who affects who?) allows you to better understand and interpret the behavior of complex models.

Each of these features is discussed in detail below.

Navigating Within the Graphics Pane

The graphics pane shows the contents of a single Container. You can move around within the graphics pane using the vertical and horizontal scroll bars and scroll arrows at the right and at the bottom of the pane.

Read more: Understanding Containers (page 96).

Note that if you scroll far enough horizontally or vertically you will eventually reach the "edge" of the graphics pane. That is, the graphics pane represents a document of fixed size.

Read more: Adjusting the Size of the Graphics Pane (page 444).

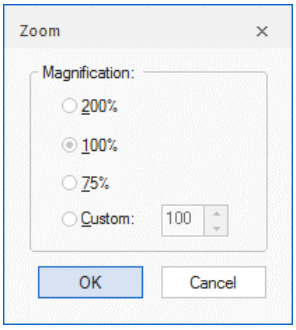
You can change the scale at which the graphics pane is viewed (i.e., zoom in and zoom out). There are two ways to do this:

- In the lower right-hand corner of the screen (the right side of the status bar) is a zoom slider:

By dragging the slider (left or right) you can adjust the scale. Clicking on the "-" or "+" increments the scale up and down in 10% increments.

If your mouse has a wheel, you can also use this for zooming. Rolling the wheel toward you while holding down the Ctrl key zooms out. Rolling the wheel away from you while holding down the Ctrl key zooms in.

- Clicking the **Current scale** (100% in the example above) opens a zoom dialog:



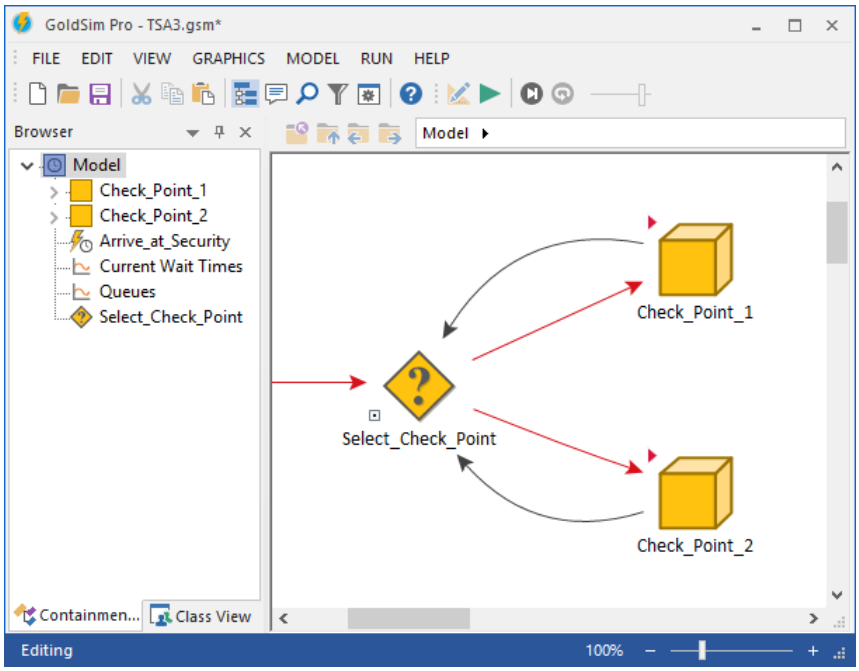
Selecting an option adjusts the zoom level accordingly.

Note: GoldSim remembers the position and scale of a Container when you leave it, so that when you return to it, it is displayed at the same scale and in the same position.

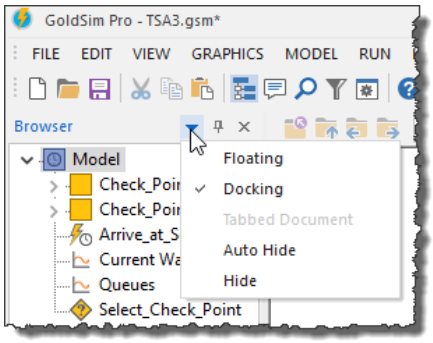
Using the Browser

For simple models containing a small number of elements with only a few subsystems (Containers), you may wish to only use the graphics pane to navigate and view your model. For most models, however, use of the browser becomes essential.

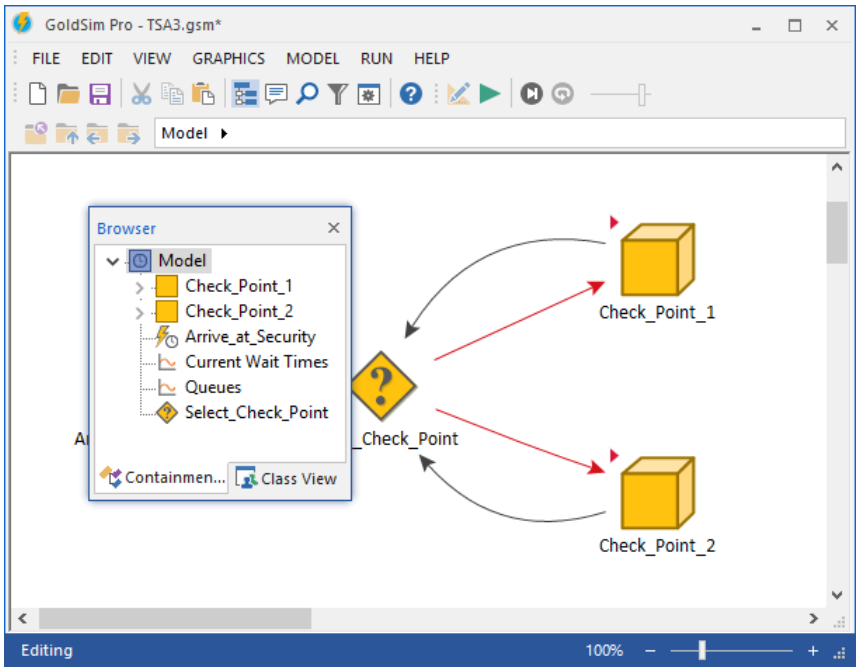
By default, the browser is activated and is initially docked on the left side of the screen:



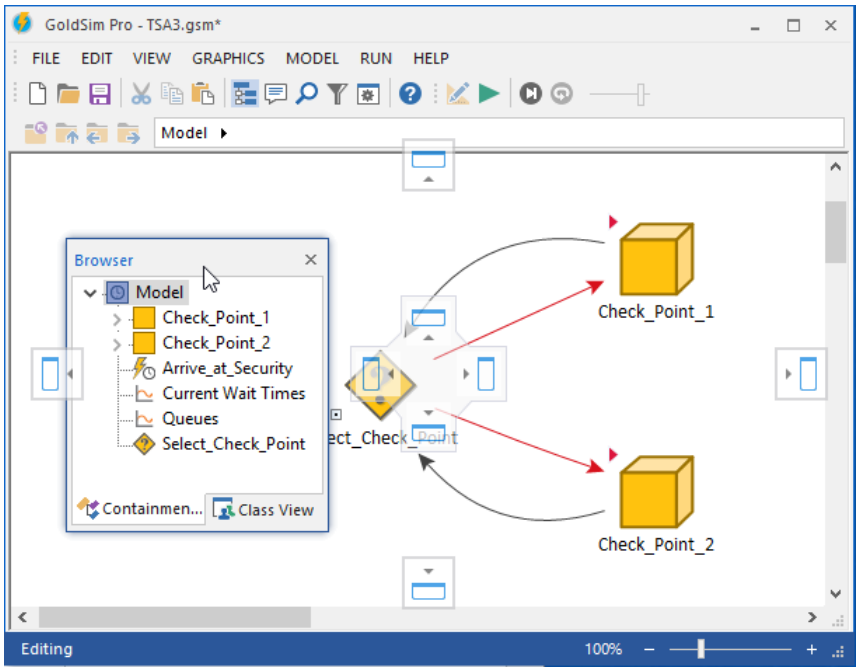
The browser can be in four different states (Floating, Docking, Auto Hide and Hide), which can be selected from the drop-list at the top of the browser:



You can make the browser become a floating window by selecting **Floating** from the browser drop-list:



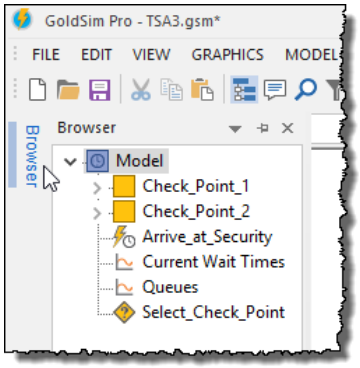
You can dock a floating browser (to any side of the screen) by starting to drag the browser. When you do so, multiple docking points appear on the screen:



Dragging to the docking point docks the browser at that location.

You can hide the browser completely by selecting **Hide** from the browser drop-list. You can also hide the browser by pressing **F6** or by pressing the browser button in the Standard toolbar:

The final option is to **Auto Hide** the browser. If you select this option, the browser is hidden until you move the cursor over the vertical section marked "Browser" on the left side of the screen:

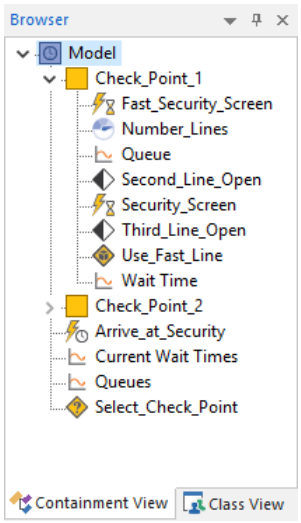


When you do so, the browser opens (and stays open until the cursor moves outside of the browser).

Hiding (or auto hiding) the browser is useful, particularly for complex models, as it allows more of the graphics pane to be visible.

The browser organizes the model into one of two views in a tree structure, which greatly facilitates navigation of complex models. The two browser views are referred to as ***Containment View*** and ***Class View***, and you toggle between these alternative views using the tabs at the bottom of the browser.

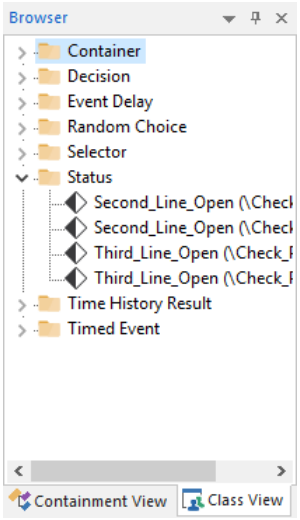
The default browser view is Containment View. In Containment View, elements are organized in a hierarchical manner (by containment), similar to the way that files and directories on a computer are organized.



In this view, elements at the same hierarchical level are listed in alphabetical order (except for Containers, which are always listed first).

Read more: Understanding Containers (page 96).

In Class View, rather than being organized by containment, the browser is organized by element type.

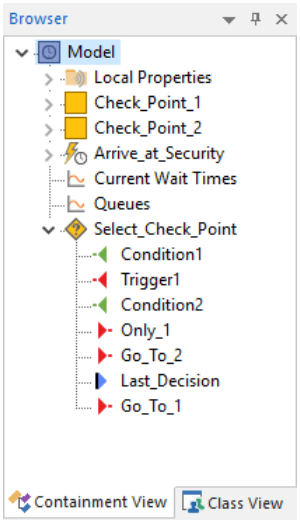


Expanding a folder shows all of the elements of that type.

All the elements of a particular type are listed together (alphabetically) in a folder labeled with the element type. This provides a very convenient way to find elements of a specific type. By default, when in Class View, the last three Containers of the path for the element is shown in parentheses next to the element ID. You can hide this path by deselecting **Show Path** in the context menu for the browser.

The browser and the graphics pane are synchronized. This means that if you click on an object in the browser, the Container in which the object resides will be opened and its contents will be shown in the graphics pane. Similarly, if you click on an element in the graphics pane, the Container in which the element resides will be expanded and that element will be selected in the browser. This synchronization facilitates navigation through the subsystems in your model.

By default, GoldSim will only display the element names in the browser. If you select **Show Element Subitems** from the context menu for the browser, press **Ctrl+I**, or press **View | Show Element Subitems** from the main menu, the element inputs and outputs will also be displayed:



When you expand an element within the browser, inputs are listed first (and represented by an arrow head pointing to the left. Outputs are listed last (and represented by an arrow head pointing to the right).

The inputs and outputs are color-coded:

- Inputs/outputs representing values are blue.
- Inputs/outputs representing conditions are green.
- Inputs/outputs representing discrete signals (transactions) are red.
- Inputs/outputs representing complex outputs (e.g., Time Series definitions) are gray.

In addition,

- An input which contains a link to another element has a dot immediately to the left of the arrow head.
- An output which is linked to another element has a dot immediately to the right of the arrow head.
- An output that is a ***state variable*** has a bold vertical line to the left of the arrow head.

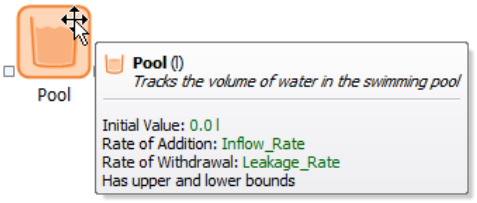
Read more: Understanding State Variables in GoldSim (page 356).

Using Tool-Tips

Elements, input objects and output objects, and input fields all display tool-tips when the cursor is placed over them.

Element Tool-Tips

Holding your cursor over an element in the graphics pane (or the browser) displays a tool-tip:



Element tool-tips display three types of information:

- Basic information
- State
- Properties

All elements display basic information regarding the element consisting of the element's name, an icon (identifying the element type), and the Description (if one is specified).

In addition to this information, other basic information about the element may also be displayed, depending on the element type, as well has how it has been defined. If the element has a primary output, the tool-tip will show the display units for the output (in parentheses). If the element is a vector or a matrix, the array label set(s) will be displayed (in brackets).

Read more: Element Inputs and Outputs (page 75); Using Vectors and Matrices (page 848).

To augment this basic information, State and Property information is also displayed for some elements. When displayed, these are separated from the basic information by a line.

State information consists of a current or initial Value for the element. Only elements that have a primary output display State information. GoldSim has three primary modes (or states) that a model can be in: Edit Mode, Run Mode and Result Mode. When in Edit Mode (prior to running the model), the current or initial value is shown in the tool-tip. This represents the value of the output prior to running the simulation.

Read more: Simulation Modes (page 67).

If an element has invalid inputs such that a current value cannot be computed, the value is reported as "undefined".

When the model has finished and has results (Result Mode), the Value shown in a tool-tip represent is the final value (i.e., the value at the end) of the final realization.

While a model is running (Run Mode), it can be paused and the model can be navigated. In this case, the Value shown in a tool-tip represents the last value that was calculated (since the simulation has not yet been completed).

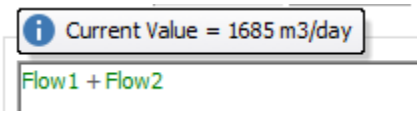
In addition to the basic information and the State (value) information, some elements will also display some of their input properties in the tool-tip. This allows you to view the key inputs for the element without having to open the dialog.

Note: You can control the number of significant figures displayed in tool-tips from the **Results** tab of the Options dialog (accessed via **Model |Options…** from the main menu).

Read more: The Results Tab of the Options Dialog (page 467).

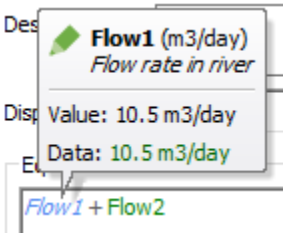
Input Field Tool-Tips

Holding your cursor over or placing your cursor into an input field in a dialog displays a tool-tip showing the computed value of the entry or expression in the input field:



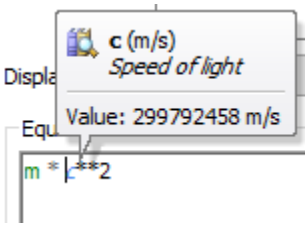
The value is computed based on the current value when in Edit Mode and the last value when in Result Mode (the final value of the final realization) and Run Mode (the last value calculated).

If you place your cursor on a link from another element and left-click, that link will be selected (and highlighted in italics), and the tool-tip will display the *value just for that link* (as opposed to the entire input field):

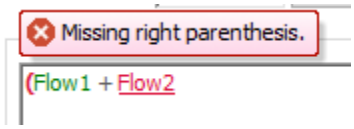


These kinds of tool-tips can be very useful when debugging and/or exploring models. Note that the icon for the link is also provided (identifying the element type).

Information regarding GoldSim's built-in constants is also displayed in expressions via tool-tips:



If the input field is invalid for some reason, the tool-tip will display an appropriate error message:



If you start typing (or move the focus to another field), the tool-tip will disappear. If you stop typing, the tool-tip will reappear.

Read more: Error Checking in Input Fields (page 94).

Note: You can control the number of significant figures displayed in tool-tips from the **Results** tab of the Options dialog (accessed via **Model |Options…** from the main menu).

Read more: The Results Tab of the Options Dialog (page 467).

Viewing Very Large and Very Small Numbers in Tool-Tips

GoldSim carries out all of its internal calculations using double precision numbers. In general, this means that GoldSim can internally handle absolute values as small as 2.2E-308 and as large as 1.8E+308. If you enter (or GoldSim calculates) a value whose absolute value is outside this range, the tool-tip for the element and the output will be displayed as 1.#INF (or –1.#INF).

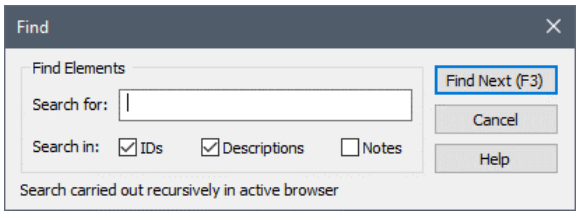
Note: Although internal calculations are carried out using double precision numbers, results are only stored as single precision numbers (in order to reduce storage requirements). This means that when results are viewed in tables or charts (see Chapter 8), the range of absolute values that can be displayed is between 1.2E-38 and 3.4E38.

Finding Elements

To assist in finding specific elements in a model, GoldSim provides a Search utility.

To start a search, press the Search button:

When you do so, the following dialog will be displayed:



(You can also open this dialog by pressing **Ctrl+F**).

Enter a string and press the **Find Next** button (or press **F3**) to find the next item in the browser that matches the search string. This will close the dialog and carry out the search. The search parameters are saved, so you can (repeatedly) press **F3** to find the next item in the browser that matches the search string.

Once you have moved through the browser tree to more than one item, you can press **Shft-F3** to jump to back to to a *previous* item (as opposed to the *next* item).

The search is not case-sensitive.

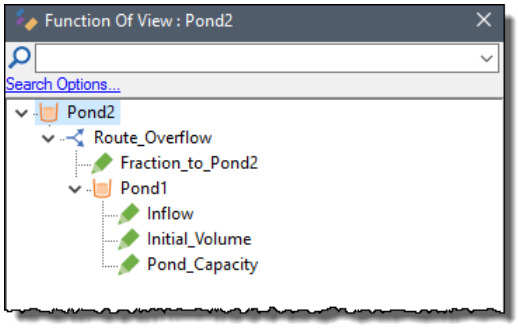
You can control where GoldSim searches selecting whether you want to search in IDs, Descriptions, and/or Notes.

Read more: Creating, Editing and Viewing Notes (page 821).

Note: These Search options are stored in the Windows Registry (so that once you change them, they will remain until you edit them again, even when editing other GoldSim files).

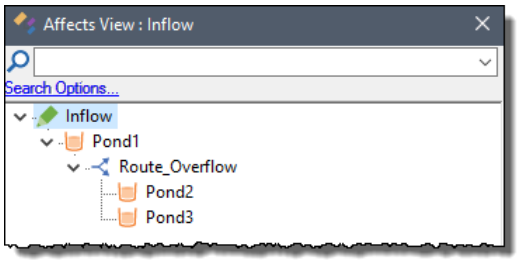
Viewing Element Dependencies

In complex models, it is often useful to explore the interdependencies of the various elements (i.e., who affects who). GoldSim provides two very powerful utilities for doing this: the ***Function Of View***, and the ***Affects View***. If you right-click on an element in either the graphics pane or the browser (to access the context menu) and select **Function Of…**, a floating window is displayed:



This is a specialized browser view of the model. It starts with the selected element, and only shows those elements which affect that element (i.e., those elements which the selected element is a *function of*). In the above example, "Pond2" is a function of one element: "Route_Overflow". "Route_Overflow", in turn, is a function of "Fraction_to_Pond2" and "Pond1". "Pond1" is a function of "Inflow", "Initial_Volume" and "Pond_Capacity".

Similarly, if you select **Affects…** from the context menu, a window like this will be displayed:



This view of the model starts with the selected element, and only shows those elements which are a function of that element (i.e., those elements which the selected element *affects*).

In the above example, "Inflow" affects "Pond1", which affects "Route_Overflow", "Pond2" and "Pond3".

Note: The **Function Of…** and **Affects…** options are only available if the element is either a function of other elements or affects other elements.

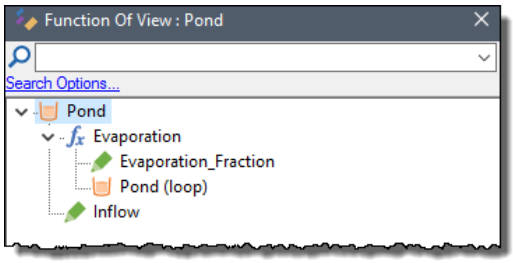
These two browser views have all the functionality of the regular browser (e.g., tool-tips, context menus). If you double-click on an element in one of these views, its property dialog is displayed.

In addition, the context menu for an item in the Function Of or Affects browser includes an option to immediately jump to the opposite view. That is, if you are viewing a Function Of list, you can right click on any element in the list, and immediately jump to the Affects list for the selected element.

By default, Function Of and Affects browser views are synchronized with the main browser (and hence the graphics pane). As a result, as you explore the interdependencies of the elements, you can simultaneously observe where they are located in the containment hierarchy.

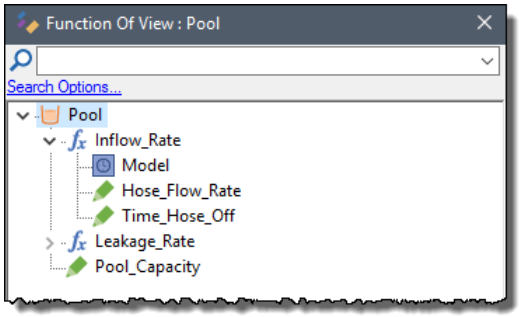
Note: If desired, you can turn off the synchronization by right-clicking on white space in the Function Of or Affects view (i.e., not on an element), and clearing the **Synchronize** option in the context menu.

Note that if you have defined a looping model, GoldSim will stop at the point of recursion. For example, if "Pond" is a function of "Evaporation", and "Evaporation" is a function of "Pond", the Function Of view for "Pond" would look like this:



Read more: Evaluating Feedback Loops (page 361).

If an element is a function of a locally-available property (such as a Run Property), the Function Of view will indicate that it is a function of the Container that "owns" the property (typically the Model Container):



In this example, Inflow_Rate is a function of ETime (a Run Property)

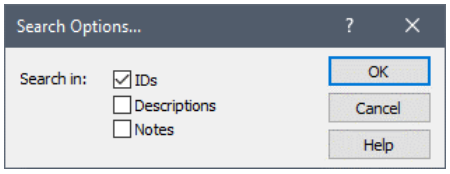
Read more: Understanding and Referencing Run Properties (page 505).

Note: Result elements do not appear in the "Affects" list for elements that they reference. This is because unlike other elements in GoldSim, when you reference an output of an element within a Result element, it is not treated as a "link". GoldSim provides other tools for navigating these kinds of connections.

Read more: Browsing Between Result Elements and Referenced Outputs (page 597).

The Function Of and Affects have a search field at the top. Enter a string and press the Search button to the left of the string (the magnifying glass) or press **F3** to find the next item in the list that matches the search string. The search is not case-sensitive.

You can control where GoldSim searches by pressing **Search Options…**, which will display a dialog for selecting whether you want to search in IDs, Descriptions, and/or Notes.



Read more: Creating, Editing and Viewing Notes (page 821).

Note: These Search options are stored in the Windows Registry (so that once you change them, they will remain until you edit them again, even when editing other GoldSim files).

This ability to search the Function Of and Affects lists for an element can be very useful for answering questions like "Is Y a function of X?" or "Is Y affected by X?".

Running a Model and Viewing Results

This section provides a very brief overview of running a model and viewing results. These topics are discussed in detail in Chapters 7 and 8. The objective of this section is to provide you with enough basic information to run and view the results of simple models.

GoldSim is a dynamic simulator, which means that your model can evolve and change with time. In order to carry out a dynamic simulation, GoldSim steps through time in discrete intervals (referred to as timesteps).

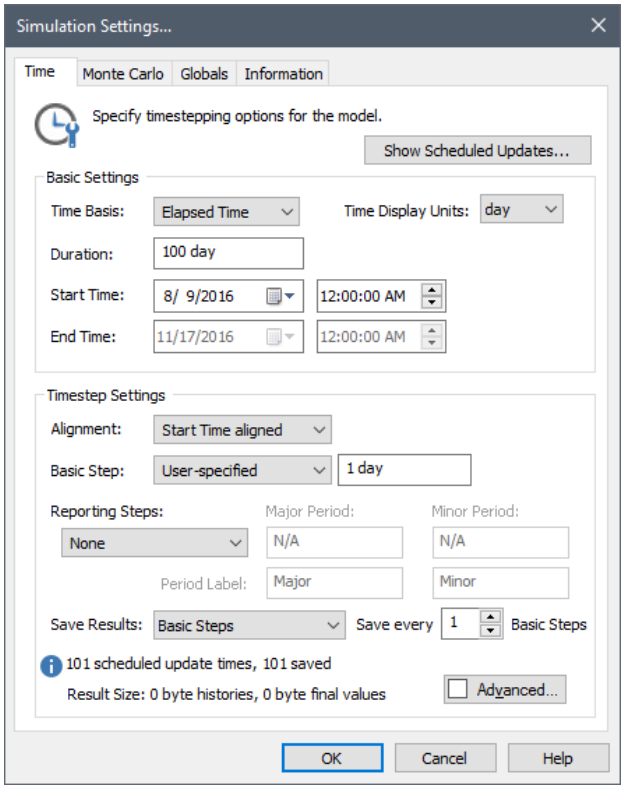
Calculations are carried out every timestep. In GoldSim, you specify the duration of the simulation (e.g., 1 year) and the length of timestep to use (e.g., 1 day).

The appropriate timestep length is a function of how rapidly the system represented by your model is changing: the more rapidly it is changing, the shorter the timestep required to accurately model the system. GoldSim allows you to change the timestep during a simulation (e.g., use short timesteps at early times when things are changing rapidly, and larger timesteps at later times).

Specifying Simulation Settings

Simulation Settings button

To run a model, you must first specify its simulation settings.When you create a new model, the simulation settings dialog is automatically displayed. After the model has been created, the simulation settings can be accessed and edited from the main menu under **Run | Simulation Settings,** or by double-clicking on the Simulation Settings button in the standard toolbar. When you do so, the following dialog is displayed:



The **Time** tab of the dialog is used to specify the duration of the simulation, the timestep length, and the units in which time will be displayed in results.

The **Monte Carlo** tab of the dialog is used to specify Monte Carlo options (how probabilistic simulations will be carried out), such as the number of realizations, and whether Latin Hypercube sampling is to be used.

Note: Appendix A provides an introduction to probabilistic simulation techniques, and introduces the basic terminology required to understand the Monte Carlo options presented in this dialog.

Read more: Simulation Settings (page 470).

Saving Results

Before you run a model, you select the results that you wish to save. With regard to saving results, there are two things that you must specify:

- *Which* specific results do you want to save (i.e., which outputs of which elements)?
- *When* do you want to save these results?

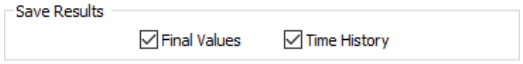
Within GoldSim, there are two fundamental types of results:

Final Value Results: These allow you to display distributions, multi-variate results (e.g., scatter plots), bar charts, column charts and pie charts (and the associated tables for these results) at specified Capture Times in a simulation. By default, "Final Value" type results are only available at the final time point in the simulation (hence, their name). In some cases, however, you may also want to view "snapshots" of results at other points in time (other than the end of the simulation). GoldSim facilitates this by allowing you to create other Capture Times (in addition to the default Capture Time at the end of the simulation) at which these results are also made available.

Read more: Creating Capture Times for Results (page 488).

Time History Results: These are saved at selected timesteps, and allow you to display how an output changes as a function of time.

All element property dialogs have check boxes (at the bottom of the dialog) to specify whether output(s) of the element are to be saved. You can save the **Final Values** (the values at the end of each realization in the simulation) and/or **Time History** (the value at selected timesteps throughout the simulation).



By default, when you create a new scalar element, the Save Results checkboxes will be checked (on). For array elements, the **Time History** checkbox defaults off.

The **Final Values** checkbox always controls whether Final Value results are saved. However, the **Time History** checkbox can be overridden. In particular, it is always applied for single realization runs, but is overridden for multiple realization runs. In particular, Time History results for multiple realization runs are only saved for outputs that are connected to Result elements.

Read more: Saving Outputs as Results (page 514).

When Time History results are saved, by default GoldSim saves the values of outputs at every Basic Step (and Reporting Period). You can instruct GoldSim to only save results at selected timesteps (e.g., every tenth Basic Step) when defining timestepping options in the Simulation Settings dialog.

Read more: Understanding Timestepping in GoldSim (page 473); Specifying When Time History Results Will Be Saved (page 482).

Running a Model

Selecting **Run | Run Model**, pressing **F5**, or pressing the **Run** button in the Run Control toolbar causes GoldSim to check the model for errors (to see if it can be run).

The second button from the left in the Run Control toolbar is the Run button.

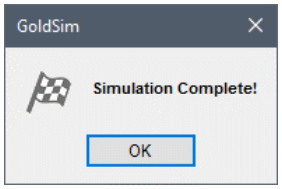
If an error is found in the model such that it cannot be run, GoldSim will display a fatal error message describing the problem. In most cases, a button on the dialog displaying the error message will allow you to jump directly to the element causing the problem.

If GoldSim does not detect any errors, the model will be placed into Run Mode and the simulation will begin. While the model is running, the status bar will display the status of the run (i.e., current realization, timestep, and elapsed time).

In addition to running the model, the Run Control toolbar can also be used to pause and resume a simulation, and/or step through the simulation one timestep or one realization at a time.

Read more: Running and Viewing the Status of a Simulation (page 517).

A small dialog will alert you when the simulation is complete:



Clicking the **OK** button in this dialog (the only button) will place the model into Result Mode.

If there were any warning messages generated during the simulation, you will immediately be given an opportunity to view the ***Run Log***. The Run Log contains basic statistics regarding the simulation (e.g., the version of the program, the date, the simulation length), and any warning or error messages that were generated.

Read more: The Run Log (page 569).

Viewing Results

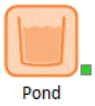
After a simulation is complete, the model will be placed in Result Mode. This will be indicated by the status bar ("Results" will be displayed on the left side of the status bar and the status bar will be green):

More importantly, editing the model's logic (i.e., the properties of model objects) will be disabled. In addition, the cursor takes on a different appearance (it turns green) to indicate that editing is disabled.

Note: In order to edit the model again, you need to return to Edit Mode. You can do so by pressing **F4** or the Edit Mode button: 

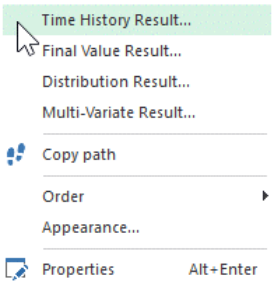
In Result Mode, an output's Last Value (the value at the end of the last realization) will be displayed in a tool-tip when the cursor is held over it in a browser (or output interface). If the output is the primary output of an element, the Last Value will also be shown in the tool-tip displayed when the cursor is held over the element itself. The Last Value is displayed in tool-tips regardless of whether results (Time Histories or Final Values) have been saved for the output.

When in Result Mode, elements which have saved results will be identified in two ways: 1) the elements (and their outputs) will be **bold** in the browser; and 2) the element output ports in the graphics pane will be green:



Read more: Understanding Input and Output Ports (page 76).

Right-clicking on an element with a primary output (in the graphics pane or browser) or on a specific output (in an output interface or a browser) which has been saved will provide a context menu for displaying results.



Depending on the type of output, the type of simulation and which results have been saved, different options will be displayed at the top of the menu.

Clicking on one of the items at the top of this menu displays the results for the selected object.

Read more: Element Inputs and Outputs (page 75).

This manner of viewing results in GoldSim is so fundamental to the GoldSim design that it bears repeating: **To view the result of an element, right-click on the element (or one of its outputs) and select the appropriate result type at the top of the menu.**

Note: Time history results may not be available in this manner, depending on the nature of the simulation. In particular, for runs with multiple realizations, extra steps must be taken to save and view time history results.

Read more: Chapter 8: Displaying Results in GoldSim (page 577).

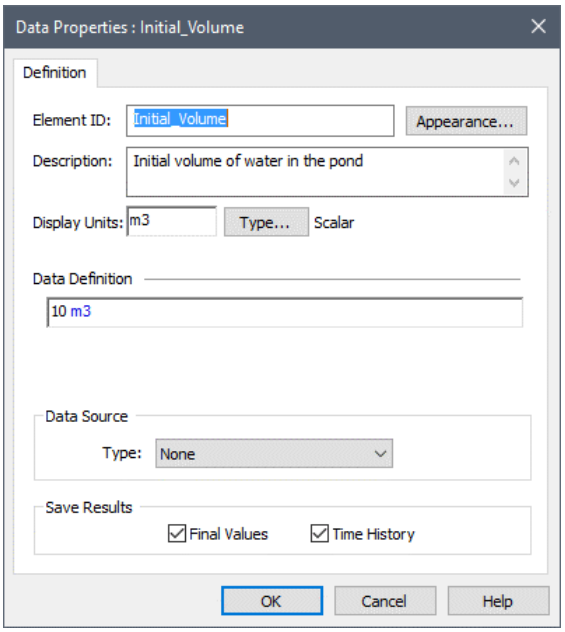
Building and Running Your First Model

We close this chapter by walking through a simple example to allow you (if you have not already done so) to build and run your first GoldSim model.

This simple example uses a Reservoir element to simulate the volume of water in a pond. The completed model file (FirstModel.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

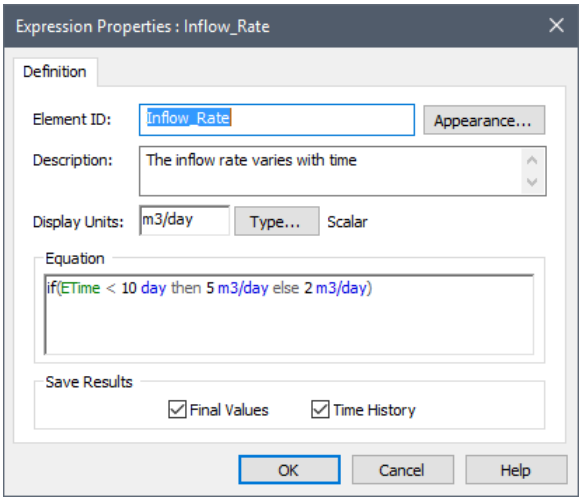
1. Open GoldSim.
2. Select New Model from the Start dialog.
3. Open the Simulation Settings by pressing **F2**.
4. In the **Time** tab of the Simulation Settings dialog, you will note that "Elapsed Time" is selected. Leave this unchanged.
5. Set the Duration to 20 days.
6. Set the **Basic Step** to 0.2 days.
7. Press **OK** to close the dialog.
8. Insert a Data element using the context-sensitive menu of the graphics pane (right-click in the graphics pane, select Insert Element, go to the Inputs category, and click on Data).
9. The element will be named Data1 by default. Change the name to Initial_Volume and give it a Description (Initial volume of water in the pond).
10. Specify the Display Units as cubic meters (m3).
11. Specify the entry in the Data Definition input field as 10 m3.

    The dialog should look like this:



12. Press **OK** to close the dialog.
13. Insert an Expression element at a point below the Data element using the context menu of the graphics pane (right-click in the graphics pane, select Insert Element, go to the Functions category, and click on Expression).
14. The element will be named Expression1 by default. Change the name to Inflow_Rate and give it a Description (The inflow rate varies with time).
15. Specify the Display Units as cubic meters per day (m3/day).

16. We will make the expression a function of time, utilizing GoldSim's *if..then* function. In particular, we will specify that for the first 10 days, the rate is equal to 5 m3/day, and it is equal to 2 m3/day afterward. To do this, enter the following into the Equation field for the Expression:



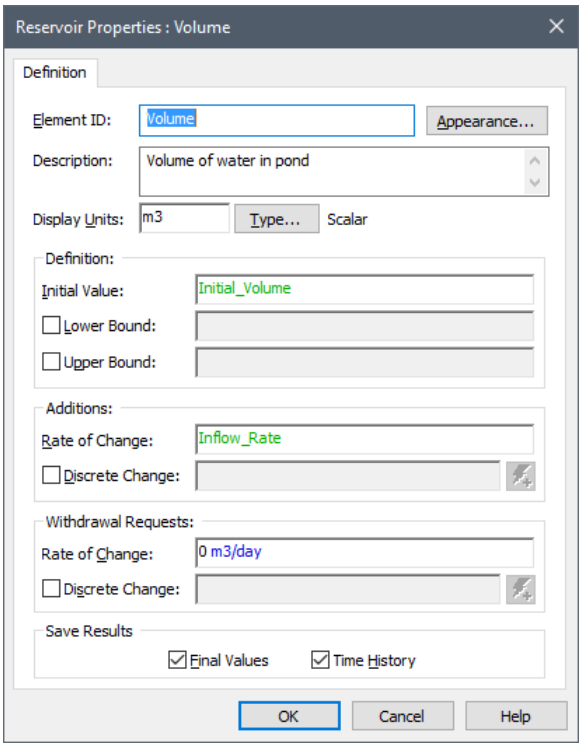
17. Press **OK** to close the dialog.

18. Insert a Reservoir element to the right of the Data and Expression elements using the context menu of the graphics pane (right-click in the graphics pane, select Insert Element, go to the Stocks category, and click on Reservoir).

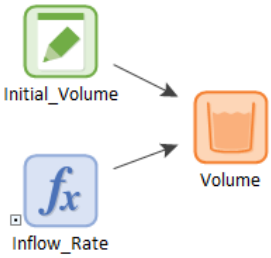
19. The element will be named Reservoir1 by default. Change the name to Volume and give it a Description (Volume of water in pond).

20. Specify the Display Units as cubic meters (m3).

21. For the Initial Value input, type Initial_Volume. In the Additions section, specify the Rate of Change as Inflow_Rate. The dialog will then look like this:

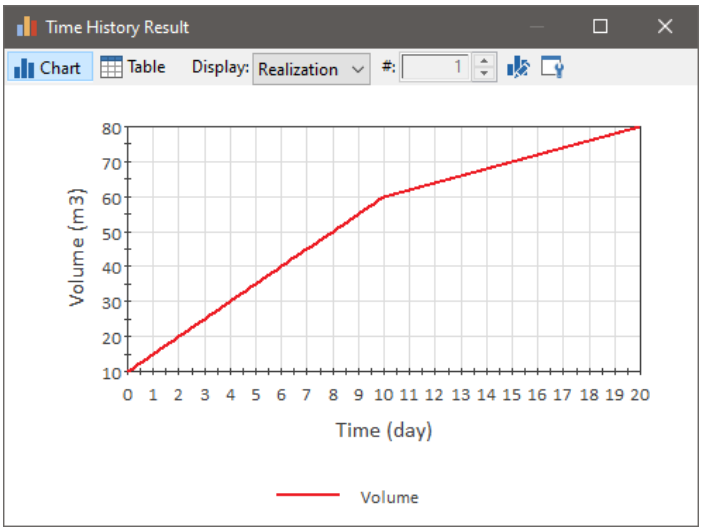


22. Press **OK**. The graphics pane should look similar to this:



If it doesn't, you can drag the elements around the graphics pane so that it does.

23. Save the file by pressing the Save button on the main menu. You will be prompted for a filename.
24. We are now ready to run the model. To do this press the **Run** button in the Run control toolbar (or press **F5**).
25. You will be presented with a dialog stating that the simulation has completed. Press **OK** to close the dialog.
26. You can now view results. To do so, right-click on Volume (the Reservoir element) and select **Time History Result…** . The following result will be shown:



Congratulations! You have built and run your first GoldSim model. The details of using the various elements, customizing the interface, running the model, viewing results and documenting your model are provided in the remaining chapters. You should certainly have enough information at this point, however, to begin to experiment with GoldSim.

Chapter 4: Using the GoldSim Elements

"The time has come," the Walrus said,
"To talk of many things:
Of shoes, and ships, and sealing wax
Of cabbages and kings
And why the sea is boiling hot
And whether pigs have wings."

Lewis Carroll

Chapter Overview

This chapter describes the details of using each of the basic GoldSim elements. After first describing the details of a topic that is applicable to all elements (entering expressions into input fields), the manner in which each of the basic GoldSim elements is defined and used is presented. A number of advanced elements are described in Chapter 10.

In this Chapter

The following topics are discussed in this chapter:

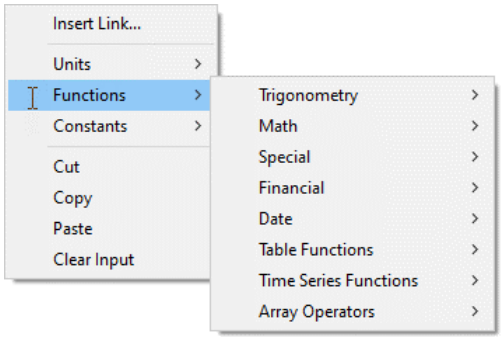
- Entering Mathematical Expressions into Element Input Fields
- Using Containers
- Overview of GoldSim Element Types
- Using Basic Input Elements
- Using Time Series Elements
- Using Stock Elements
- Using Basic Function Elements
- Using Delay Elements
- How GoldSim Carries Out its Calculations

Entering Mathematical Expressions into Element Input Fields

GoldSim provides a number of features that enable you to enter mathematical expressions into input fields. This section provides information on the use of these features. This includes a discussion of GoldSim's built-in functions and constants, and guidance with regard to creating conditional (logical) expressions and using dates in expressions.

Built-in Functions

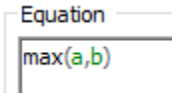
GoldSim provides a wide variety of ***built-in functions*** that can be used in expressions. These functions can be typed in directly, or inserted using the context menu of an input field:



The functions are divided into eight categories (two of the categories only appear under certain circumstances):

1. Trigonometry functions, such as sine and cosine;
2. Math functions, such as square root and logarithm;
3. Special functions, such as the Bessel function and "if,then,else";
4. Financial functions, such as present value and future value;
5. Date functions, which are specialized functions for manipulating variables that represent dates and times (e.g., extracting the day of the month from a date, determining if the simulated year is a leap year);
6. Table functions, which are specialized functions for operatibg on Lookup Table elements (this category only exists if at least one Lookup Table element exists in the model);
7. Time Series functions, which are specialized functions for operating on Time Series elements (this category only exists if at least one Time Series element exists in the model); and
8. Array operators, which are specialized functions that operate only on vectors and matrices.

An example of the use of a built-in function is shown below:



The "max" function, shown above in the Equation field, returns the maximum of a list of arguments.

The arguments to a built-in function are enclosed in parentheses, and if there are multiple arguments, they are separated by commas. The arguments to the built-

in functions can be links, constants or expressions, but typically must meet certain requirements (e.g., the arguments to a "max" must all share the same dimensions). The first seven categories of functions (and any requirements imposed on their arguments) are summarized below.

Array functions are discussed in detail in Chapter 10.

Read more: Using Vectors and Matrices (page 848).

Trigonometry Functions

GoldSim provides the following trigonometry functions:

Function	Description
sin(A)	Sine of A
cos(A)	Cosine of A
tan(A)	Tangent of A
cot(A)	Cotangent of A
sinh(A)	Hyperbolic sine of A
cosh(A)	Hyperbolic cosine of A
tanh(A)	Hyperbolic tangent of A
asin(U)	Arcsine of U. The result has dimensions of an angle.
acos(U)	Arccosine of U. The result has dimensions of an angle.
atan(U)	Arctangent of U. The result has dimensions of an angle.

A: An angle (i.e., a value). It can have angular units or no units, in which case it is assumed to be in radians. Can be a scalar or an array.
U: Must be a unitless value. Can be a scalar or an array.

Math Functions

GoldSim provides the following standard mathematical functions:

Function	Description
abs(X)	Absolute value of X
exp(U)	Exponential (e^U)
ln(U)	Natural logarithm of U
log(U)	Logarithm base 10 of U
max(X,Y,…)	Returns the maximum of a list of arguments. The first argument determines the order of the output. Arguments must either be all scalars, all arrays of the same order (and set of array labels), or a mixture of arrays of the same order and scalars (in which case the first argument cannot be a scalar).
min(X,Y,…)	Returns the minimum of a list of arguments. The first argument determines the order of the output. Arguments must either be all scalars, all arrays of the same order (and set of array labels), or a mixture of arrays of the same order and scalars (in which case the first argument cannot be a scalar).

Function	Description
mod(X,Y)	Modulus: remainder of X/Y; sign is sign of X. The first argument determines the order of the output. Arguments can be scalars, arrays of the same order (and set of array labels) or mixed (in particular, if X is an array, Y can be a scalar; if X is a scalar, however, Y cannot be an array). If X and Y have dimensions, they must have the same dimension (although the units can be different), and the result has the same dimension as X and Y.
round(U)	Rounds off U
sqrt(X)	Square root of X. Note: if X has units, they must be an even power, for example: sqrt(5 m2) is OK, but sqrt(5m) is not.
trunc(U)	Truncates U
ceil(U)	Returns the next integer that is greater than U
floor(U)	Returns the next integer that is less than U

U: Must be a unitless value. Can be a scalar or an array.
X, Y: A value. Can be a scalar or an array.

Note: Because round-off may result in a calculated integer value being slightly above or below the exact integer, GoldSim allows for a fractional error of 1e-12 when evaluating the ceil() and floor() functions. For example, although ceil(4.000001) returns 5, ceil(4.000000000001) returns 4.

Special Functions

GoldSim provides the following specialized mathematical functions:

Function	Description
erf(U1)	Gauss error function of U1
erfc(U1)	Complementary Gauss error function of U1
if(C,E,F) or if(C then E else F)	If C is true then E else F
bess(U1,U2)	Bessel function of U1 of order U2
beta(U1,U2)	Beta function of U1 and U2
gamma(U1)	Gamma function of U1
normprob(U1)	Returns a value representing the cumulative probability level for the specified number of standard deviations (U1) away from the mean for a standard normal distribution. A negative argument represents values to the left of (less than) the mean.
normsds(P)	Returns a value representing the number of standard deviations away from the mean for the specified cumulative probability level (P) for a standard normal distribution. A negative output represents a value to the left of (less than) the mean.
tdist(P,nu)	Student's t distribution for the specified cumulative probability level (P), with nu degrees of freedom.

Function	Description
tprob(X,nu)	Student's t distribution, returns the cumulative probability for value X, with nu degrees of freedom.
ImpProb(Old,Target,Width)	Used for customized importance sampling for a given target probability and probability width. Takes a probability (Old) and returns a biased probability.
ImpWeight(Prob,Target,Width)	Used for customized importance sampling for a given target probability and probability width. Takes a biased probability (produced by ImpProb) and returns a weight.
ImpOld(Prob,Target,Width)	Used for customized importance sampling for a given target probability and probability width. Takes a biased probability (produced by ImpProb) and returns the unbiased probability. This is the inverse of ImpProb.
PDF_Value(D, P1)	Returns the value of the distribution at the specified cumulative probability level P1. The output has the same dimensions as the distribution being referenced.
PDF_CumProb(D, V)	Returns the cumulative probability of the distribution at the specified value V. The output is dimensionless.
PDF_Mean(D)	Returns the mean of the distribution. The output has the same dimensions as the distribution being referenced.
PDF_SD(D)	Returns the standard deviation of the distribution. The output has the same dimensions as the distribution being referenced.
PDF_CTE(D, P1)	Returns the conditional tail expectation of cumulative probability P1 (i.e., the expected value of the output given that it lies above a specified cumulative probability P1). This result represents the mean of the worst 100(1 – P1)% of outcome. The output has the same dimensions as the distribution being referenced.
PDF_DiscreteProb(D, V)	Returns the discrete probability of the distribution at the specified value V. The output is dimensionless. This function returns 0 for continuous distributions (i.e., it should only be applied to discrete distributions).
changed(Z)	Returns a condition. True if the argument has changed since the last update (e.g., timestep). False if the argument has not changed. See Note below.
occurs(T)	Returns a condition. True if the argument has occurred this update (e.g., timestep). False if the argument has not occurred.

U1,U2: Must be a unitless value. Can be a scalar or an array.
D: A distribution output.
V: A scalar value.
X, Y: A value. Can be a scalar or an array.
E, F: A value or a condition. Can be a scalar or an array.
C: Must be a condition. C can be an array or scalar; if it is an array, then the "if" test is done on a term-by-term basis and either E or F (or both) must be an array with the same set of array labels as C. If C is scalar, E and F can be either scalar, arrays of the same

order (entire array is then selected), or one can be an array and one can be a scalar (in which case the scalar is treated as an array of identical values).
P: A value between 0 and 1, inclusive. Can be a scalar or an array.
P1, Old, Target: A scalar value between 0 and 1, inclusive.
Width: A scalar value between 10-6 and 0.5, inclusive.
nu: A positive integer. Can be a scalar or an array.
Z: A value or a condition. Must be a scalar.
T: Must be a discrete event signal.

Read more: Manipulating Arrays in Expressions Using Mathematical Operators (page 866); Specialized Functions That Operate on Distributions (page 188).

Note: If the argument to the changed() function is a Run Property that conceptually cycles (e.g., Hour), and your timestep is such that the actual value remains unchanged (e.g., Changed(Hour), with a 1 day timestep), GoldSim will still consider that the argument has changed (since the fact that it remains unchanged is simply an artifact of timestepping).

Read more: Understanding and Referencing Run Properties (page 505); Determining if an Event has Occurred (page 432).

Note: The three importance sampling functions (ImpProb, ImpWeight and ImpOld) are used to carry out customized importance sampling of Stochastic elements.

Read more: Customized Importance Sampling Using User-Defined Realization Weights (page 1089).

Financial Functions

GoldSim provides a number of built-in financial functions.

The functions below are simple compounding functions that account for the time value of money and convert between present value, future value and annuities. These are dimensionless functions that act as multiplying factors on a currency amount (e.g., $) or currency rate (e.g., $/yr).

In these functions the first argument (int. rate) is the fractional interest per period (expressed as either a fraction or a percentage), and the second argument (#periods) is the number of periods:

Function	Description	Definition
ftop(int. rate, #periods)	Factor that when multiplied by a future amount returns the present value of that future amount.	$(1+i)^{-n}$
ptof(int. rate, #periods)	Factor that when multiplied by a present amount returns the future value of that present amount.	$(1+i)^{n}$
atop(int. rate, #periods)	Factor that when multiplied by an annuity amount returns the present value of that annuity.	$\frac{(1+i)^{n}-1}{i(1+i)^{n}}$

Function	Description	Definition
atof(int. rate, #periods)	Factor that when multiplied by an annuity amount returns the future value of that annuity.	$\frac{(1+i)^n - 1}{i}$
ptoa(int. rate, #periods)	Factor that when multiplied by a present amount returns the annuity of that present amount.	$\frac{i(1+i)^n}{(1+i)^n - 1}$

int. rate (i): Must be greater than zero. Can be a scalar or an array
#periods (n): Must be a positive scalar.

These functions assume discrete compounding. That is, the functions assume compounding once per period.

Since #periods represents the number of periods in these functions, it must be a unitless value. For example, in order to compute the annuity value (the annual payment amount) for a 15 year loan of $100,000 with an interest rate of 7% per year (compounded annually), you would write the following in an expression:

100 $ * ftop(0.07, 5)

GoldSim also provides more advanced financial functions for use in conjunction with the GoldSim Financial Module. These are described in the **GoldSim Financial Module User's Guide**.

Date Functions

GoldSim inherently understands dates. For example, you can run a Calendar Time simulation (also referred to as a date-time simulation) in which you enter a Start Time and an End Time, and the simulation is then tracked in terms of the calendar time (e.g., when plotting time history results, the X-axis is plotted as dates/times).

Read more: Setting the Basic Time Options (page 471).

Because GoldSim understand dates, you can create and manipulate dates in expressions. You do so by enclosing the date in quotation marks within an expression.

Read more: Referencing Dates in Expressions (page 135).

GoldSim also provides several built-in variables (known as ***Run Properties***), such as DateTime (the simulated calendar time) and StartTime (the simulated start date) that represent dates.

Read more: Understanding and Referencing Run Properties (page 505).

To assist in using dates in your models, GoldSim provides a number of specialized functions that can be used to create dates and provide information on variables that represent dates:

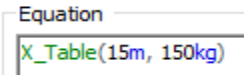
Function	Description
GetYear(Date)	Returns the calendar year (dimensionless value)
GetMonth(Date)	Returns the calendar month (dimensionless value from 1 to 12)
GetDay(Date)	Returns the day of the month (dimensionless value from 1 to 31)
GetDayofYear(Date)	Returns the day of the year (dimensionless value from 1 to 366)

Function	Description
GetHour(Date)	Returns the hour of the day (dimensionless value from 1 to 24)
GetMinute(Date)	Returns the minute of the hour (dimensionless value from 1 to 60)
GetSecond(Date)	Returns the second of the minute (dimensionless value from 1 to 60)
MakeDate(Year, Month, Day)	Returns a date built from those integer inputs
MakeDateTime(Year, Month, Day, Hour, Minute, Second)	Returns a date/time built from those integer inputs
IsLeapYear(Date) or IsLeapYear(Year)	Returns a condition (True or False)

Date: Must be a specified date/time (e.g., "17 October 2025", "21 June 2030 13:31:00") or a variable that represents a date/time (e.g., StartTime).
Year, Month, Day, Hour Minute, Second must be integer values.

Lookup Table Functions

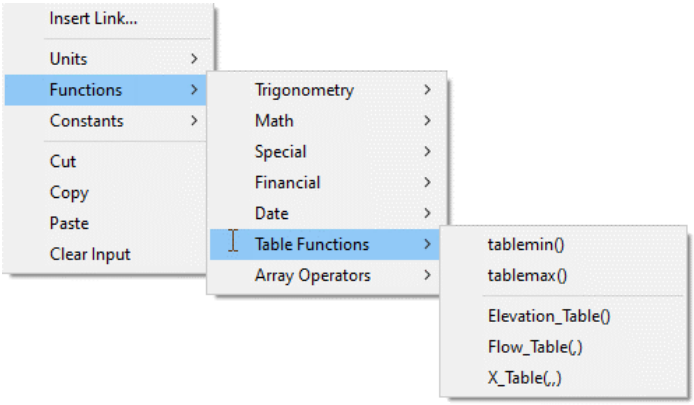
Lookup Tables in GoldSim are referenced as functions. That is, once you define a Lookup Table element, you reference it in input expressions for other elements as if it were a custom function:



This expression instructs GoldSim to use the 2-D lookup table defined by the element X_Table and compute an output value based on a value for the row variable of 15m and a value for the column variable of 150kg.

Read more: Using Lookup Table Elements (page 307).

When you create a Lookup Table, GoldSim automatically lists the table function in the Function menu that is accessible from the context menu within an input field:



In addition to the Lookup Tables you have created, there are two additional specialized functions in this list (tablemin and tablemax). Both of these functions require as their argument the name of a Lookup Table element:

Function	Description
tablemin(T)	Returns the minimum value of the dependent variable

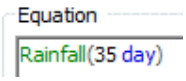
Function	Description
tablemax(T)	Returns the maximum value of the dependent variable

T: The ID of a Lookup Table elment..

Read more: Returning the Minimum or Maximum Value of the Dependent Variable (page 333).

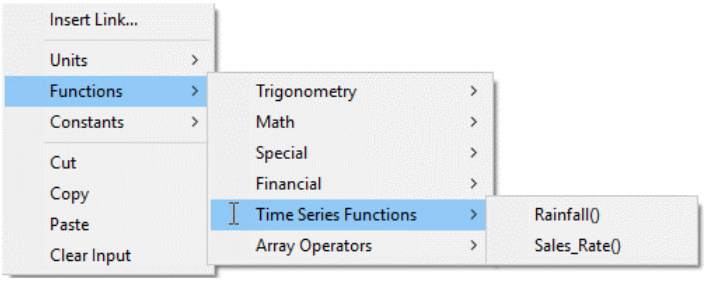
Time Series Functions

Time Series elementns in GoldSim can be referenced as functions. That is, once you define a Time Series element, in addition to referncing its output directly, you can also reference it in input expressions for other elements as if it were a custom function:



This expression instructs GoldSim to use the Time Series defined by the element named Rainfall and compute its value at time = 35 days.

Note that when you create a Time Series, GoldSim automatically lists it as a function in the Function menu that is accessible from the context menu within an input field:



Read more: Referencing a Time Series Using a Function (page 208)

Built-in Constants

GoldSim provides a number of constants that can be used in equations. The built-in constants are:

Abbreviation	Definition	Units	Value
amu	Atomic mass unit	kg	1.6605402e-027
c	Speed of light	m/s	299792458
e	Base of natural logarithms		2.71828182845905
ec	Elementary charge (electron)	s-amp	1.60217733e-019
Eps0	Permittivity of vacuum	s4-amp2/kg-m3	8.85418781762039 e-12
ev	Electron-volt	kg-m2/s2	1.60217733e-019
G	Gravitational constant	m3/kg-s2	6.67259e-011
gee	Acceleration of gravity	m/s2	9.80665
h	Planck's constant	kg-m2/s	6.6260755e-34

Abbreviation	Definition	Units	Value
HgDens	Density of mercury	kg/m3	13595.08
k	Boltzmann constant	kg-m2/s2-K	1.380658e-23
me	Electron mass	kg	9.1093897e-31
mn	Neutron mass	kg	1.6749286e-27
mp	Proton mass	kg	1.6726231e-27
Mu0	Permeability of vacuum	kg-m/s2-amp2	1.25663706143592e-06
N	Avogadro's constant	1/mol	6.0221367e+23
pi	Pi		3.14159265358979
R	Gas constant	kg-m2/s2-K-mol	8.31451
sigma	Stefan-Boltzmann constant	kg/s3-K4	5.67051e-008
Stemp	Standard temperature	K	273.15
Vmol	Molar gas volume at STP	m3	0.0224140972760918
WatDens	Density of water at STP	kg/m3	999.95
WatWt	Unit weight of water at STP	kg/m2/s2	9806.16

Warning: If there is an element name which conflicts with (i.e., is identical to) a constant name, the element name always has precedence. Hence, if you type an expression such as 3*R, and an element named R exists in the same scope, GoldSim will try to create a link to the element rather than using the built-in constant R, even if the element's dimensions are incompatible (such that the expression becomes invalid).

Creating Conditional Expressions

GoldSim provides a number of operators and functions which allow you to create ***conditional expressions***. As used here, a conditional expression is an expression (or part of an expression) which evaluates to (produces) a condition (rather than a value). A condition has two states: True or False.

The following expressions are all conditional expressions:

A>B
A=B
A>5 AND A<10
!A

The operators that can be used in conditional expressions, along with their precedence, are summarized below:

Precedence Level	Type	Operators
Highest	parentheses	()
	logical NOT	!, NOT
	relational	>, <, >=, <=
	equality, inequality	= (or ==), <>
	logical AND	&&, AND
Lowest	logical OR	||, OR

Conditional expressions are very useful, because they allow you to add if…then logic to your model. This can be accomplished by using GoldSim's if function in an expression. For example, the expression

if(ETime>10 yr and ETime<20 yr then 33 else 44)

would be interpreted as "If the elapsed time is between 10 years and 20 years, the value is equal to 33, otherwise it is equal to 44".

Read more: Built-in Functions (page 126).

Complex if…then logic can be defined by nesting this function, or by using a Selector element. Conditional expressions are also of great use when modeling discrete events and consequences.

Read more: Selector Elements (page 285); Specifying Triggering Events (page 370).

Warning: The equality operator (= or ==) should be used with caution. In particular, you should generally not use this operator when comparing calculated values in your model (which could be affected by small round-off errors). Note that both ETime and Time are calculated values (since they are always represented internally in seconds) and hence they are also potentially susceptible to small roundoff errors if used in conjunction with the equality operator.

Note: Tool-tips for conditional outputs by default display true or false. You can specify what is displayed (e.g., on/off, yes/no, etc.) by editing the "Show condition result outputs as" field in the Results tab of the Options dialog (accessed from the main menu via **Model|Options…**)

Referencing Dates in Expressions

GoldSim allows you to reference dates in expressions by enclosing the date in quotation marks within an expression. The format for referencing a date is determined by the Regional and Language time/date settings specified by the operating system. For example, for a computer in the US, the following formats would all be valid ways for referencing October 1, 2009:

"10/1/2009"
"10-1-2009"
"October 1, 2009"
"1 October 2009"

Note: You can include the time of day by adding hours:minutes:seconds to the string (e.g., "1 October 2009 13:30:00" would be 1:30 PM on 1 October 2009).

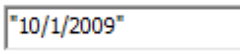
Note: GoldSim provides two special units for displaying dates. If "date" or "datetime" are the assigned display units for an element, the value is displayed as a date (or a date and a time).

Read more: Display Units for Dates (page 465).

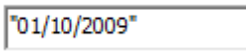
However, if you entered the same expressions on an Australian or European computer, although the last two examples would be interpreted as the 1st day in October, the first two examples ("10/1/2009" and "10-1-2009") would be interpreted as the 10th day in January. Similarly, on a German computer, "1 October 2009" would not even be recognized (GoldSim would display an error), but "1 Oktober 2009" would be correctly recognized and interpreted.

A date is internally converted and stored as a Julian time (in particular, the time since December 30, 1899 00:00:00). Hence, a date has dimensions of time.

Because dates are stored in this way, an expression could appear differently depending on the regional settings on the computer on which GoldSim is running. For example, if you entered a date (say October 1, 2009) into GoldSim on a computer with US settings like this:

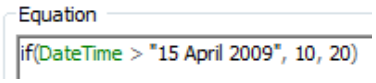


and then saved the file and subsequently opened the file on a computer with Australian or European settings, the same expression would appear like this:



In both cases, GoldSim would interpret the date as October 1, 2010.

You would typically reference a date in conjunction with DateTime, as shown below:



DateTime is a Run Property, and represents the simulated calendar time.

Read more: Understanding and Referencing Run Properties (page 505).

Warning: You should take extra care when exchanging date information with other programs, such as Microsoft Excel, since they may treat Julian date references differently than GoldSim. Microsoft Excel, for example, actually uses a Julian reference date of December 31, 1899 00:00:00, but mistakenly adds an extra day into its calendar that did not actually exist (February 29, 1900). Fortunately, as a result of this, the effective Julian date reference for all times after March 1, 1900 in Excel is actually the same as that used by GoldSim, December 30, 1899 00:00:00.

Read more: Exchanging Date Information with a Spreadsheet (page 1003).

Warning: If you enter a date using only two digits for the year (e.g., "10/1/09"), GoldSim interprets years less than or equal to 29 as being in the 21st century, and years greater than 29 as being in the 20th century. To avoid confusion, it is strongly recommended that you always use four digits to specify the year.

Read more: Setting the Basic Time Options (page 471).

Using Containers

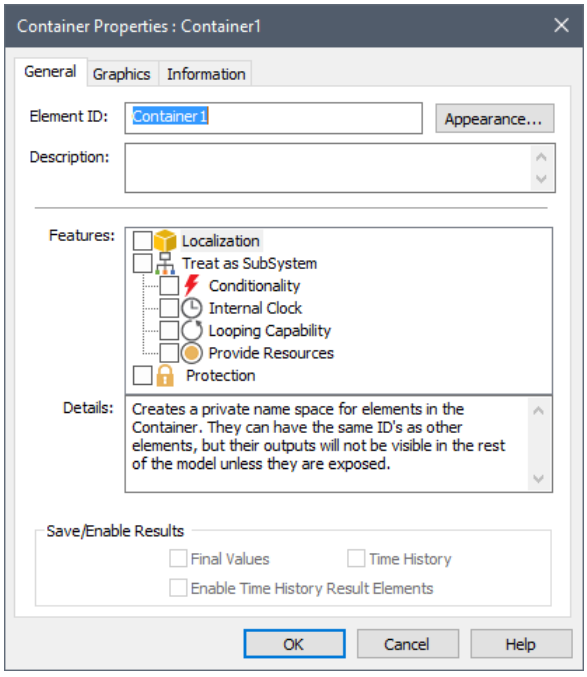
Containers are perhaps the most important element type in GoldSim, because they allow you to create hierarchical, "top-down" models. This section provides the basic information required to use Containers in your models.

The example model BasicContainer.gsm in the General Examples/Containers folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) presents the basic concepts associated with the use of Containers.

Read more: Understanding Containers (page 96).

The Container Properties Dialog

Like any element in GoldSim, you can edit the properties of a Container by double-clicking on it either in the graphics pane or the browser, or right-clicking anywhere inside the graphics pane when inside the Container, and selecting **Properties…**. The properties dialog looks like this:



By default, a Container has three tabs: **General**, **Graphics**, and **Information**.

Note: If you turn on some of the other features for a Container, additional tabs are added.

Within the **General** tab (shown by default), the top part of the dialog allows you to enter and edit the ID, Description and Appearance of the element.

Within the middle portion of the **General** tab, you can select which **Features** you would like the Container to have. By default, it has none of these features (it is a simple Container). If you click on the name of a feature, a brief description of the feature will appear in the **Details** window. Features are added and removed using the checkboxes to the left of the feature name.

Read more: Container Options and Features (page 138).

At the bottom of the **General** tab are options to **Save/Enable Results**. By default, a Container does not have any outputs of its own, and the first two checkboxes are grayed out. Under some conditions (e.g., making the Container conditional), it does have outputs, and in this case, these checkboxes become available for editing. The third option (to **Enable Time History Result Elements**) will be grayed out unless the Container includes some Time History Result elements (in which case it will be checked on). This allows you to globally disable all Time History Result elements inside the Container.

Read more: Controlling Result Flags for Elements in the Container (page 146).

The **Graphics** tab of the Container provides access to options for controlling the appearance of elements inside the Container (e.g., size of the graphics pane, and the manner in which the influences between elements are drawn).

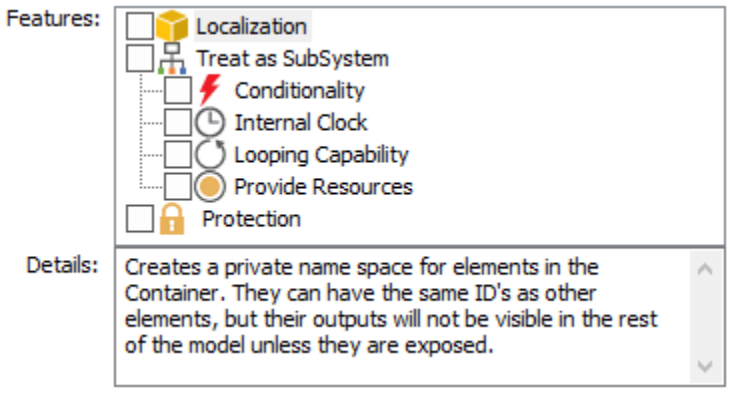
Read more: Controlling the Appearance of the Graphics Pane in a Container (page 144).

The **Information** tab of the Container provides summary information for the Container, such as the total number of elements it contains, and the size of the results being saved inside the Container. It also provides the ability to recursively turn off result saving for all elements inside the Container.

Read more: Summary Information for a Container (page 145); Controlling Result Flags for Elements in the Container (page 146).

Container Options and Features

Within the middle portion of the **General** tab of the Containers dialog, you can select which **Features** you would like the Container to have:



By default, it has none of these features (it is a simple Container).

If you click on the name of a feature, a brief description of the feature will appear in the **Details** window. Features are added and removed using the checkboxes to the left of the feature name. Each of the available features is discussed in more detail in the sections below.

The default appearance of the Container changes depending on its features:

Image	Features
	Simple (global) Container
	Localized Container
	SubSystem Container
	Conditional Container
	Container with Internal Clock
	Looping Container
	Conditional Container with Internal Clock
	Conditional Looping Container

Note: If SubSystems (conditional, looping, and internal clock Containers) are also localized, this is indicated by displaying the triangle in the upper left hand corner of the Container's symbol in the graphics pane in red (instead of blue)

Local and Global Containers

Each Container in a model is either global or local. The contents of a global Container can be "seen" (referenced) by any other element in the model. The contents of a local Container can typically only be referenced by other elements inside the Container.

By default, Containers are global. Containers can be localized by selecting the **Localization** feature in the Container dialog, or by right-clicking on the Container and selecting **Localize**. In addition, when you paste a Container, GoldSim will localize it if the names of elements inside the pasted Container conflict with element names at the location where it is being pasted.

You can recognize a localized Container in three ways:

- The triangle in the upper left hand corner of the Container's symbol in the graphics pane is red (instead of blue).
- The icon for the Container in the browsers and the default symbol for the Container in the graphics pane is a closed box (rather than an open box):

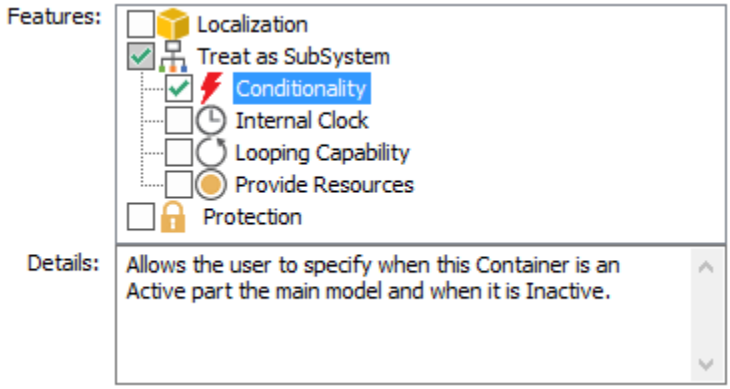
  This symbol is only used for simple Containers. Localized SubSystems use a different symbol but retain the red triangle.

- The tool-tip for the Container shows that it is Localized.

Read more: Localizing Containers (page 1018).

Treating a Container as a SubSystem

One of the advanced options for a Container is to treat it as a SubSystem. If you select the **Conditionality**, **Internal Clock**, **Looping Capability** or **Provide Resources** feature for a Container, it will automatically be treated as a SubSystem (these features require this to be the case):



*In this example the **Conditionality** feature is selected, and therefore the **Treat as SubSystem** feature is also automatically selected (and grayed out so it cannot be changed).*

SubSystems are specialized Containers that are completely "self-contained" so that from the outside, they behave like a single element. What is meant by "self-contained" requires a somewhat detailed understanding of the order in which GoldSim carries out its calculations, and such an understanding is not required for the majority of users.

Read more: How GoldSim Carries Out Its Calculations (page 355).

For most users, it is sufficient to note that being "self-contained" enables a SubSystem to take on some useful features and properties (e.g., conditionality, having an internal clock, and being able to loop). However, it also imposes some limitations with regard to how the SubSystem can be incorporated into certain types of systems (i.e., feedback loops).

Read more: Limitations on the Use of SubSystems in Feedback Loops (page 363).

For most users, there will be no need to treat a Container as a SubSystem.

Experienced users who would like to utilize advanced features such as Conditionality, Internal Clocks and Looping, or to more directly control the order in which GoldSim carries out its calculations, should make sure they clearly understand the limitations that SubSystems impose.

Conditional Containers

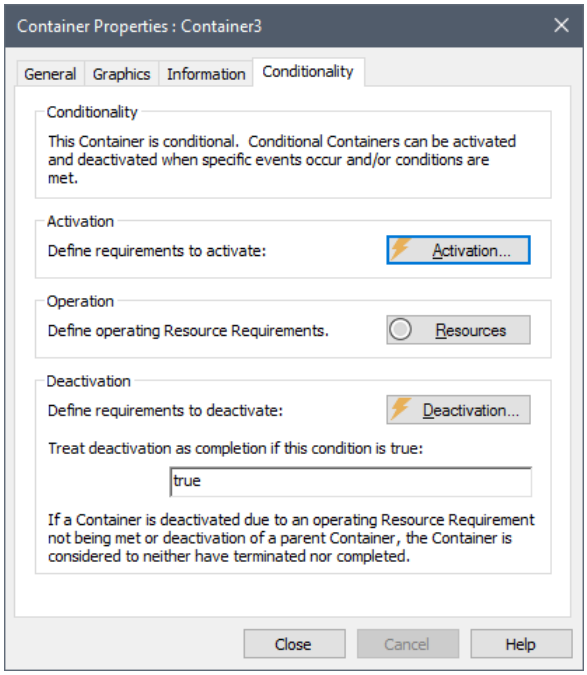
Conditionality is an advanced feature of GoldSim which allows parts of your model to dynamically activate and deactivate. By default, Containers are not conditional.

Containers can be made conditional by selecting the **Conditionality** feature in the Container dialog.

Warning: When you make a Container conditional, the **Treat as SubSystem** feature is also automatically selected (and cannot be deselected unless you first turn off **Conditionality**). That is, a Conditional Container, by definition, is treated as a SubSystem. Because a Conditional Container is treated as a SubSystem, this puts certain limitations on how Conditional Containers can be used.

Read more: Treating a Container as a SubSystem (page 140).

When you make a Container conditional, a **Conditionality** tab is added to the Container dialog:



In addition, when a Container is made conditional, a number of inputs and outputs are added to the Container element itself. As a result, the Save Results checkboxes for the Container are no longer grayed out in the General tab (since a conditional Container has its own specific outputs).

Read more: Using Conditional Containers (page 968).

Containers with Internal Clocks

In some situations, you may wish to use different timesteps in different portions of your model. This is useful, for example, if the processes represented in one portion of your model occur rapidly and hence require a small timestep to model accurately, while processes represented in the rest of your model occur much more slowly, such that a larger timestep can be used.

GoldSim allows you to assign a timestep that is smaller than the "global" timestep to one or more Containers. For example, your model could have a 10 day "global" timestep, but you could assign a 1 day timestep to a specific Container in your model that represents a system that changes rapidly and hence requires a smaller timestep to simulate accurately.

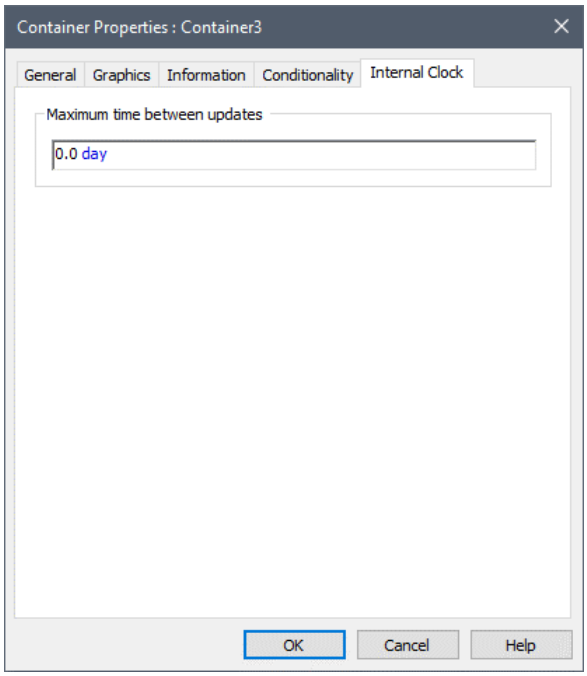
You can specify smaller timesteps for a Container by assigning the Container an "internal clock". Containers can be assigned internal clocks by selecting the **Internal Clock** feature in the Container dialog.

Note: When you specify a Container as having an **Internal Clock**, you cannot also define it as having **Looping Capability** (these two options are mutually exclusive).

Warning: When you assign an internal clock to a Container, the **Treat as SubSystem** feature is also automatically selected (and cannot be deselected unless you first turn off **Internal Clock**). That is, a Container with an internal clock, by definition, is treated as a SubSystem. Because a Container with an internal clock is treated as a SubSystem, this puts certain limitations on how these Containers can be used.

Read more: Treating a Container as a SubSystem (page 140).

When you assign an internal clock to a Container, an **Internal Clock** tab is added to the Container dialog, and the field in this tab is used to define the manner in which GoldSim timesteps within the Container:



Read more: Specifying Containers with Internal Clocks (page 493).

Looping Containers

In some models, you may want to carry out an iterative calculation at each timestep. This might be useful, for example, if you have a coupled system of nonlinear equations that must be solved every timestep by iterating.

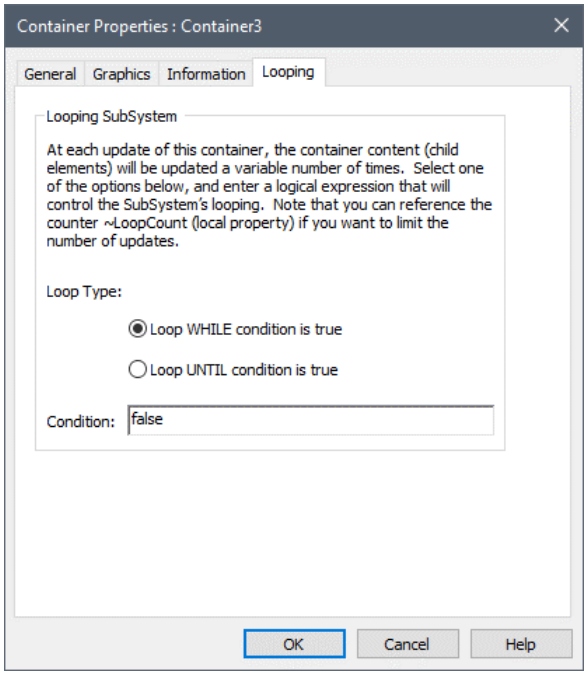
You can define a Container as a looping Container by selecting the **Looping Capability** feature in the Container dialog.

Note: When you specify a Container as having **Looping Capability**, you cannot also define an **Internal Clock** for the Container (these two options are mutually exclusive).

Warning: When you specify a Container as a looping Container, the **Treat as SubSystem** feature is also automatically selected (and cannot be deselected unless you first turn off **Looping Capability**). That is, a looping Container, by definition, is treated as a Subsystem. Because a looping Container is treated as a SubSystem, this puts certain limitations on how these Containers can be used.

Read more: Treating a Container as a SubSystem (page 140).

When you specify a Container as a looping Container, a **Looping** tab is added to the Container dialog, and the fields in this tab are used to control how the Container carries out its loops:



Read more: Using Looping Containers (page 1036).

Providing Resources for Containers

Providing Resources within a Container is an advanced feature of GoldSim. A ***Resource*** is something that has a limited supply (e.g., spare parts, fuel, skilled personnel, money) and is required in order for specified elements within the Container to carry out certain actions.

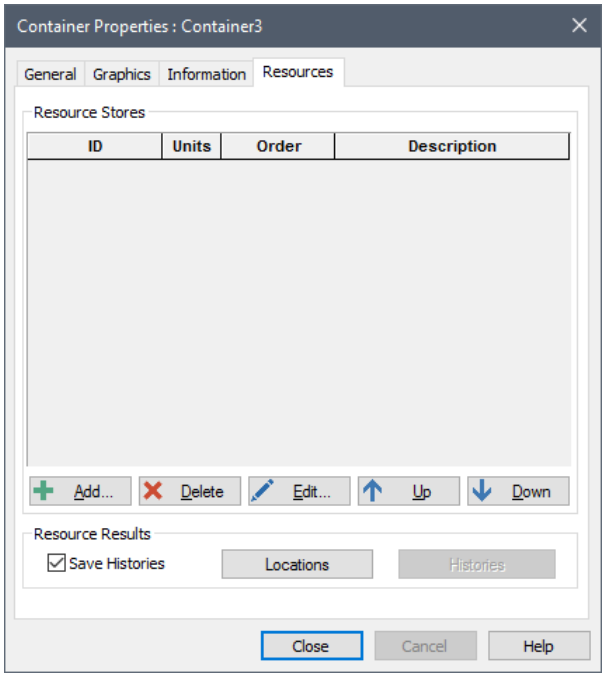
Read more: Using Resources (page 906).

Resources can be provided to a Container by selecting the **Provide Resources** feature in the Container dialog.

Warning: When you provide Resources for a Container, the **Treat as SubSystem** feature is also automatically selected (and cannot be deselected unless you first turn off **Provide Resources**). That is, a Container with Resources, by definition, is treated as a SubSystem. Because a Container with Resources is treated as a SubSystem, this puts certain limitations on how the Containers behave.

Read more: Treating a Container as a SubSystem (page 140).

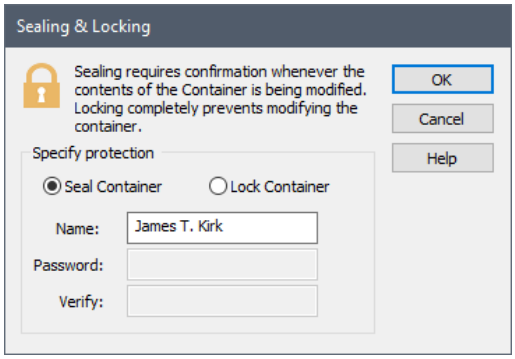
When you provide Resources to a Container, a **Resources** tab is added to the Container dialog:



Protected Containers

In some cases, you may want to protect the contents of a Container from being modified. GoldSim provides two options (sealing and locking) for doing so. Sealing a Container causes a warning message to be displayed whenever you attempt to modify the contents of the Container. Locking a Container completely prevents you from editing or modifying the contents of the Container. A password is required to unlock a Container.

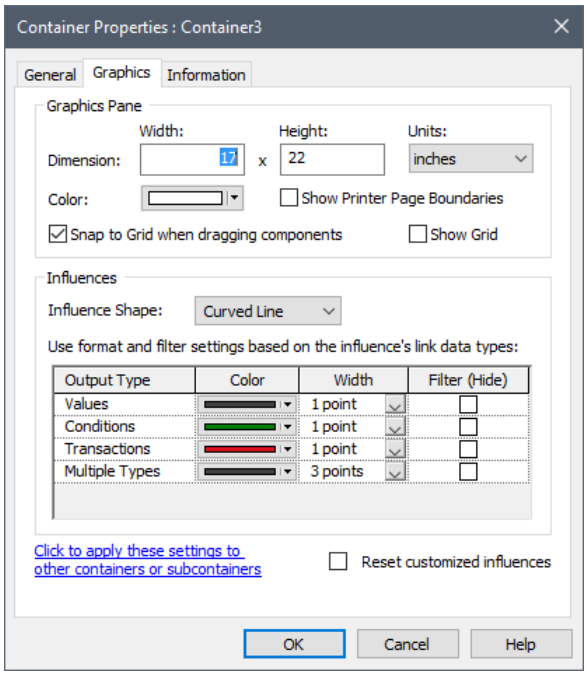
You can protect the contents of a Container by selecting the **Protection** feature in the Container dialog. When you do so, the following dialog for specifying how you would like to protect the Container is displayed:



Read more: Sealing and Locking Containers (page 148).

Controlling the Appearance of the Graphics Pane in a Container

The **Graphics** tab of the Container dialog provides access to options for controlling the appearance of elements inside the Container:



The top portion of the dialog (the Graphics Pane section) is used to define the size of the graphics pane, a background color for the graphics pane, and whether or not a grid is displayed.

Read more: Adjusting the Size of the Graphics Pane (page 444); The Graphics Pane Grid and Background (page 442).

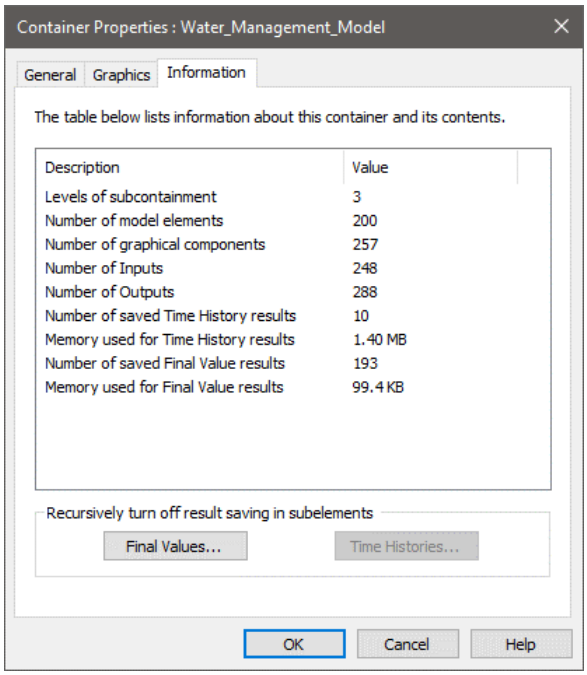
The bottom portion of the dialog (the Influences section) is used to specify the default shapes for influences in the Container, and to define whether and in what manner influences within the Container are filtered (hidden). The options in this portion of the dialog are quite important, as they can be used to ensure that your models are easier to view and understand.

Read more: Links and Influences (page 81); Editing the Appearance of Influences (page 445); Filtering Influences (page 448).

Note: The graphical properties are of particular interest for the Model Container, as they allow you to control the appearance of the entire model. You can view the properties of the Model Container by double-clicking on it in the browser or by right-clicking anywhere in the graphics pane (when viewing the Model Container) and selecting **Properties…**.

Summary Information for a Container

The **Information** tab of the Container dialog provides access to summary information regarding the Container:



The dialog provides some useful summary statistics for the Container, including the number of model elements, the number of inputs and outputs associated with the elements, the number of graphical components and the degree of subcontainment. Note that the number of levels of subcontainment does not refer to the number of Containers; it refers to the number of hierarchical levels of Containers. For example, if A contained Containers B and C, A would have 1 level of subcontainment; if A contained B, and B contained C, A would have 2 levels of subcontainment.

Note: These properties are of particular interest for the top-level container (the Model Container), as they tell you the size (and memory requirements) of the entire model. You can view the properties of the Model Container by double-clicking on it in the browser.

The dialog also indicates the total size of the results being saved for all elements within the Container. This information can be very useful in helping you to manage the size of the model file.

The bottom of the dialog contains some advanced options to allow you to deactivate the results flags for all elements contained within the Container.

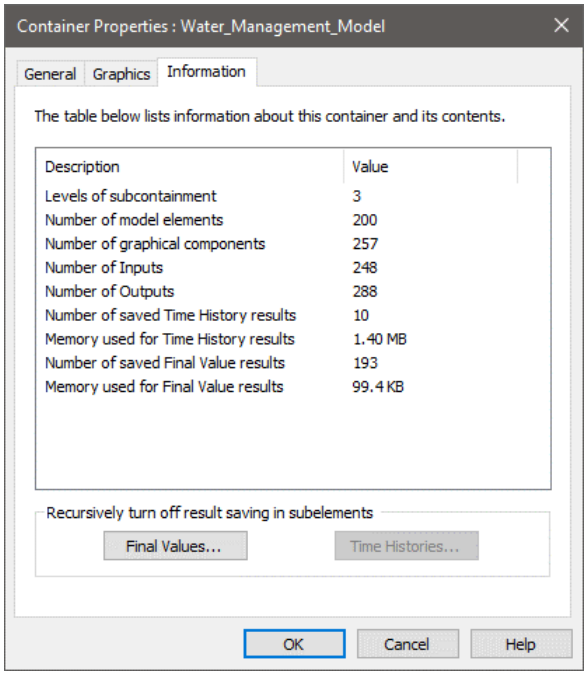
This is described in detail in the next section.

Controlling Result Flags for Elements in the Container

Before you run a model, you select the results that you wish to save. You can save **Final Values** (the values at the end of each realization in the simulation) and/or **Time History** (the value at selected timesteps throughout the simulation). Typically, these are specified by separately setting flags for each element (and each output).

In some cases, however, you may want to change these settings for *all* the elements in a Container at once (i.e., globally deactivate the result flags for all elements inside the Container).

You can do this using the two buttons located at the bottom of the **Information** tab or the Container dialog:



Note: The **Time Histories** button is only available if you are running a single realization. If you are running multiple realizations, the state of each element'sTime History flags are determined by whether or not the element is referenced by an active Time History Result element. If it is, the flag is turned on. If it is not, the flag is turned off. In both cases, the flag is grayed out and cannot be manually changed.

Read more: Specifying Results to be Saved (page 514).

To globally turn off saving of all of the results of a particular type in a Container, simply press the button. A dialog will be displayed asking you to confirm that you wish to turn off the results.

Of course, once you turn off results in a Container, you can subsequently enter the Container and set some of the elements' results flags back on.

Note: This capability is of particular interest for the Model Container, as it can be used to globally turn off all result options for the entire model.

By default, you cannot turn off results for outputs which are linked to Result elements (unless the Result element is a Time History Result element that has been disabled). That is, any output linked to a Result element is automatically saved, even if you choose to turn off results using the buttons described above. This behavior can be changed in Time History Result elements (so the outputs linked to the Result element are not automatically saved) by disabling the element.

Read more: Disabling a Time History Result Element (page 658).

You can choose to globally disable all Time History Result elements in a Container by clearing the **Enable Time History Result Elements** checkbox at the bottom of the **General** tab of the Container dialog.

Sealing and Locking Containers

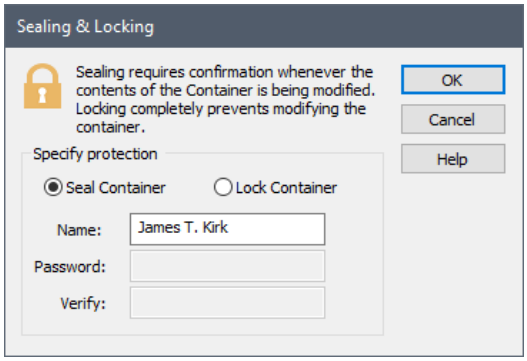
GoldSim provides two options to protect the contents of a Container from being modified: sealing a Container and locking a Container.

Sealing a Container is the weakest of the two methods. Sealing causes a warning message to be displayed whenever you attempt to modify the contents of the Container, but does not prevent you from modifying the contents if you choose to "break" the seal. Locking a Container completely prevents you from editing or modifying the contents of the Container without providing a password.

Sealing a Container

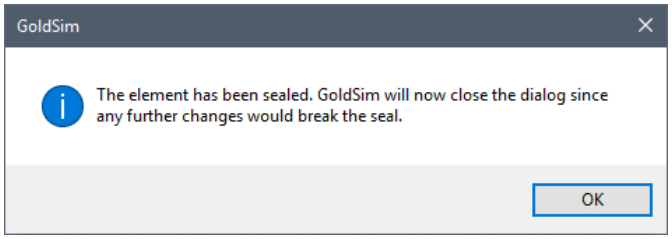
Sealing is the lowest level of protection you can place on a Container. Sealing a Container causes a warning message to be displayed whenever you attempt to modify the contents of the Container, but does not prevent you from modifying the contents if you choose to "break" the seal. It is typically used simply to remind users that a particular Container has been verified and/or checked in some manner and hence should not be edited. It also can be used to verify that the contents of a particular Container has not been modified.

You can seal the contents of a Container by selecting the **Protection** feature in the Container dialog. When you do so, the following dialog for specifying how you would like to protect the Container is displayed:



Your Windows user name will be inserted by default into the **Name** field (which you can subsequently edit).

By default, the option to **Seal Container** will be selected. The Container can then be sealed by pressing the **OK** button. Upon doing so, the following dialog will be displayed:



When a Container is sealed, the Container and all of its contents appear grayed out when viewed in a browser. In addition, the tool-tip for the Container indicates that it is sealed, and the **Details** section for the Container dialog displays the name of the person who sealed the Container, along with the date and time that the Container was sealed.

Once a Container has been sealed, you can make "cosmetic" changes to the contents (moving elements around in the graphics pane, adding text, graphics or images to the Container), but if you try to make any other kind of change (e.g., changing the inputs to an element, adding an element) GoldSim will provide a message warning you (twice!) that the seal will be "broken" if you continue.

Once a seal is broken, this new status (along with who broke the seal and when it was broken) is also displayed in the **Details** section of the dialog for the Container.

Once a seal is broken, you can choose to seal the Container again (by pressing the **Protection** checkbox again).

You can remove (as opposed to break) the seal from a Container by pressing the **Protection** checkbox.

Warning: If a seal is removed (rather than broken), no record of this is written to the **Details** section of the dialog for the Container.

Note: If you seal a Container which contains other Containers, all of the Containers within the parent Container are also sealed. If you then remove the seal from the parent Container, however, the other Containers within it remain sealed.

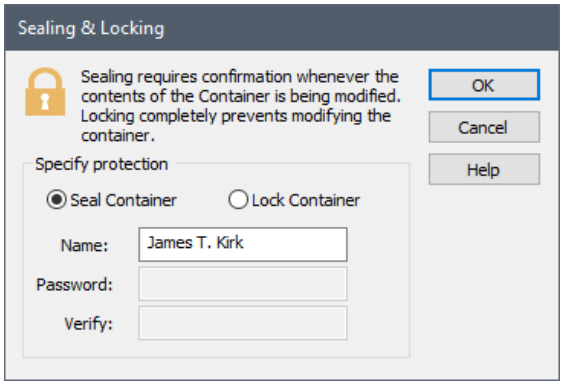
Warning: The values of Data elements that are located within a sealed Container and are controlled via a Dashboard control can be changed via the control without breaking the seal. Dashboard controls are discussed in the **GoldSim Dashboard Authoring Module User's Guide**.

Locking a Container

If you need to protect the contents of a Container such that they cannot be edited at all, you should lock the Container.

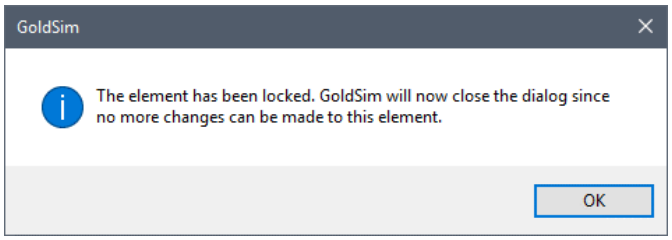
Locking is the highest level of protection you can place on a Container. Locking a Container completely prevents the user from editing or modifying the contents of the Container without providing a password.

You can lock the contents of a Container by selecting the **Protection** feature in the Container dialog. When you do so, the following dialog for specifying how you would like to protect the Container is displayed:



Your Windows user name will be inserted by default into the **Name** field (which you can subsequently edit).

By default, the option to **Seal Container** will be selected. To lock the Container, select the **Lock Container** radio button. When you do so, the **Password** and **Verify** fields will become editable. To lock the Container, enter a password, verify it, and press the **OK** button. Upon doing so, the following dialog will be displayed:

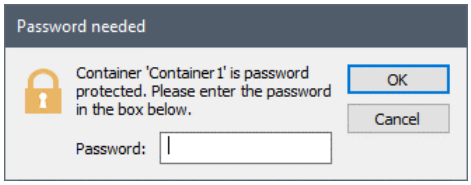


Lock Cursor

When a Container is locked, the Container and all of its contents appear grayed out when viewed in a browser. In addition, the tool-tip for the Container indicates that it is locked, and the **Details** section for the Container dialog displays the name of the person who locked the Container, along with the date and time that the Container was locked. Moreover, whenever you are inside a locked Container, the cursor is changed to the "Lock Cursor", to remind you that the Container is locked.

Note also that checkboxes on the property dialog are grayed out (except for the **Protection** checkbox). In fact, the property dialogs of all elements within a locked Container will also be uneditable. In addition, when viewing the contents of a locked Container, most menus are disabled. This is because you cannot make any changes at all to the contents of a locked Container (or to the properties of the locked Container itself). You can view the contents of a locked Container (and all the properties of the elements within the Container), but the contents of the Container cannot be edited until the Container is unlocked.

To unlock a locked Container, click on the **Protection** checkbox on the properties dialog for the Container. You will be prompted for a password.



Enter the password and press **OK**. The Container and its contents will then be available for editing.

Note: When you lock a Container, you can choose not to specify a password (leave the password blank). If you do this, the Container will unlock as soon as you press the **Protection** checkbox (without prompting you for a password).

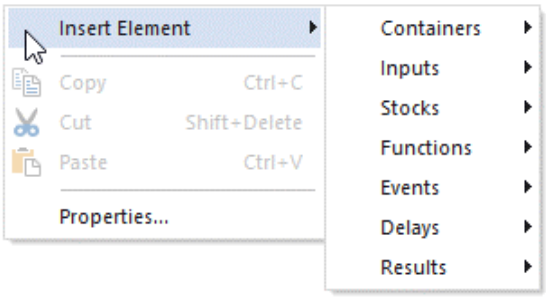
Note: The Properties page for Result elements in locked Containers cannot be edited. However, when displaying a result via a Result element that is inside a locked Container, you can edit the style (e.g, headers, axes titles) via the Edit Style button on the display page.

Warning: The values of Data elements that are located within a locked Container and are controlled via a Dashboard control can be changed via the control without unlocking the Container. Also, the values of Data elements that are located within a locked Container and are specified as being Scenario Data can be changed via the Scenario Manager without unlocking the Container. Dashboard controls are discussed in the **GoldSim Dashboard Authoring Module User's Guide**.

Read more: Creating and Using Result Elements (page 593); Scenario Data: Defining Inputs for Different Scenarios (page 527).

Overview of GoldSim Element Types

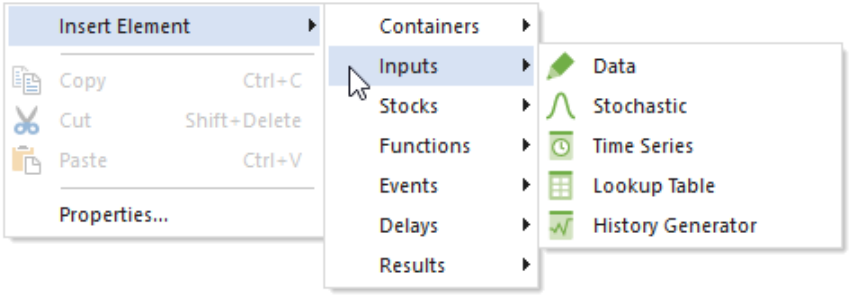
GoldSim provides a wide variety of elements from which you can build your models. These elements can be divided into a number of categories. When you choose to insert an element into GoldSim, the Insert menu sorts the elements into these categories.



The various categories are discussed in general terms below. Most of the elements are then discussed in detail in the remainder of this chapter. Several of the more advanced elements are discussed in subsequent chapters.

Input Elements

Input elements define the inputs to your model. There are five input elements in GoldSim: Data, Stochastic, Time Series, Lookup Table and History Generator.



Data elements allow you to specify a single scalar value (e.g., the discount rate) or an array of related values (e.g., the salaries of each individual in a group). Stochastic elements allow you to specify that a particular value is uncertain by defining it as a probability distribution. Time Series elements allow you to specify a time series of a value (e.g., monthly rainfall rates, quarterly cashflows). Lookup tables allow you to create response surfaces. History Generators provide a mechanism for creating stochastic time series based on statistical inputs.

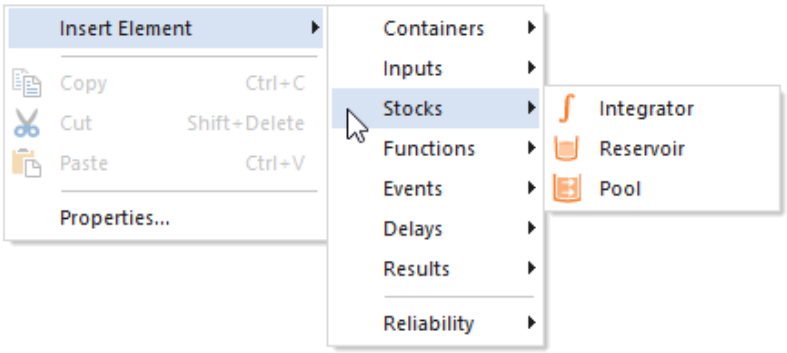
Read more: Using Basic Input Elements (page 156); Using Time Series Elements (page 192); Using Lookup Table Elements (page 307); Generating Stochastic Time Histories (page 893).

Stock Elements

Stocks are elements that impart inertia and memory to a system, and hence are responsible for internally generating the dynamic behavior of many systems. In GoldSim, Stocks, a second element category called Delays, and a special function element (Convolution) are collectively referred to as dynamic elements.

Mathematically, Stocks are time integrals (i.e., they integrate flows or signals over time). As a result, they have the property that their outputs are determined by the historical (integrated) value of their inputs.

GoldSim provides three Stock elements: Integrators, Reservoirs and Pools.



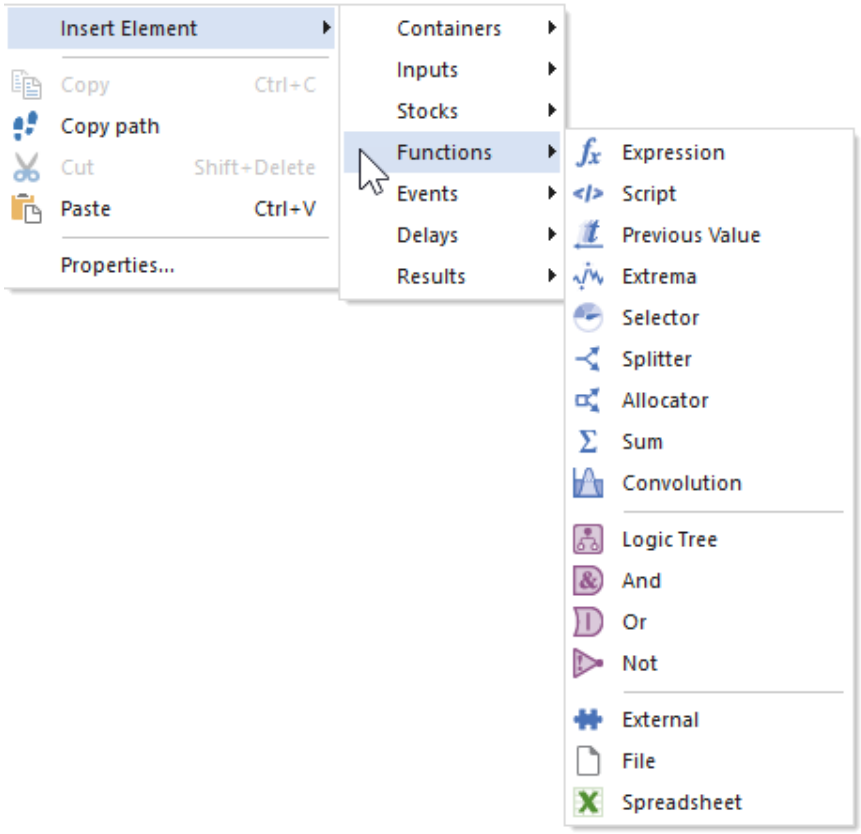
Pools and Reservoirs are intended to accumulate flows of materials (e.g., cash, water, widgets). Integrators simply integrate signals (e.g., the height of a thrown ball could be computed by integrating the velocity of the ball).

Read more: Using Stock Elements (page 233).

Function Elements

Functions compute outputs based on the current (instantaneous) values of their inputs. Hence, unlike Stocks, Functions do not impart inertia or memory to a system. Rather, they instantaneously transform or convert inputs to outputs.

GoldSim provides a wide variety of Function elements.



As can be seen in the menu, Function elements are subdivided into three types: Standard Functions, which include Expressions and Selectors, Logical Functions for manipulating logical expressions, and External Application Functions for linking external applications such as spreadsheets into GoldSim.

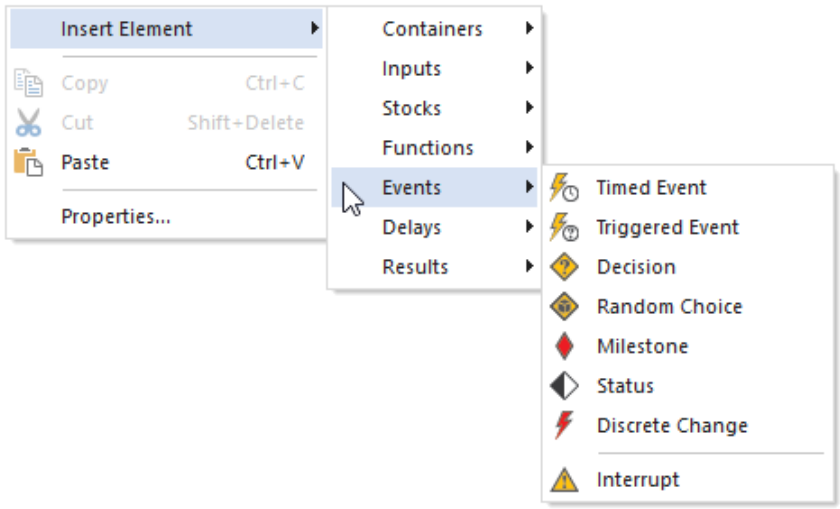
Read more: Using Basic Function Elements (page 281); Script Elements (page 929); Solving Convolution Integrals (page 884); Using External Application Elements (page 982).

Event Elements

Event elements allow you to superimpose the occurrence and effects of discrete events onto continuously varying systems.

This allows for the realistic simulation of such things as financial transactions, accidents, system failures, storms, labor strikes and lawsuits.

There are ten elements that can be used to create and react to discrete events. Eight of these are available under the Events submenu. Two additional elements are available under the Delays submenu.



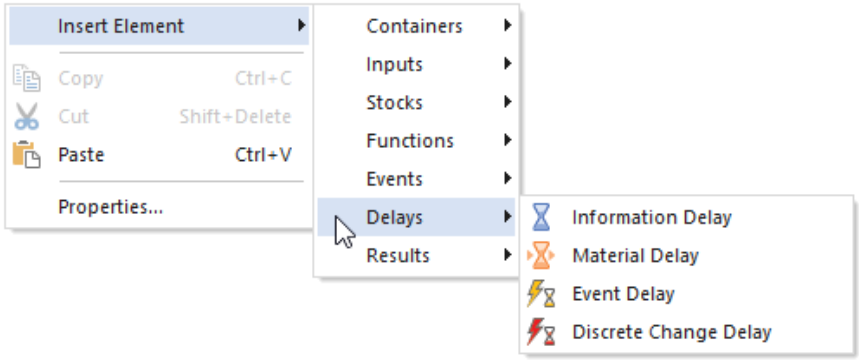
Read more: Chapter 5: Simulating Discrete Events (page 365).

Delay Elements

Delay elements simulate processes that delay continuous or discrete signals and flows. That is, their outputs lag their inputs. Therefore, like Stocks, their outputs are computed based on the historical values of their inputs.

As a result, Delays also impart inertia and memory to a system, and can internally generate dynamic behavior within a system.

There are four Delay elements in GoldSim: Material Delays delay continuous flows of material; Information Delays delay continuous flows of information; Event and Discrete Change Delays delay discrete signals.



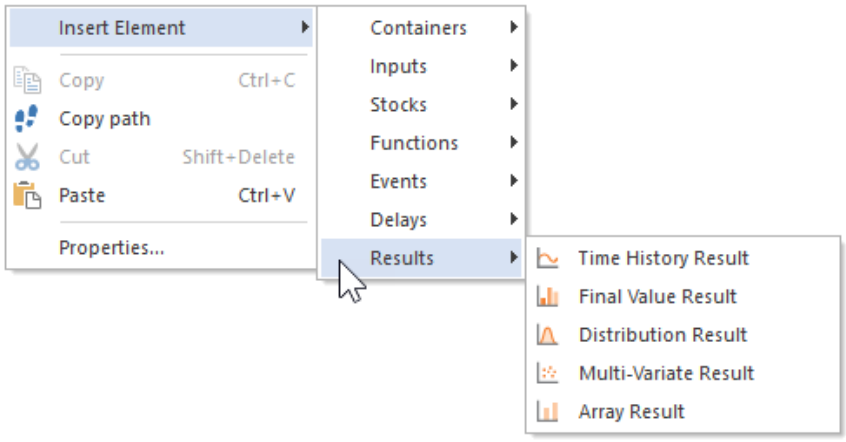
Read more: Using Delay Elements (page 334); Chapter 5: Simulating Discrete Events (page 365).

Result Elements

Result elements provide a convenient way to collect, analyze and display results. While you can look at the results associated with any element by finding the element and right-clicking on it, Result elements provide a mechanism for making key results readily accessible in a location separate from the element itself.

Read more: Viewing Results (page 119).

GoldSim provides five types of Result elements, one for each of the basic types of results that can be displayed in GoldSim.



Read more: Creating and Using Result Elements (page 593).

Differentiating Between Material and Information Flow

The purpose of any dynamic model is to describe the movement, evolution and/or transformation of materials and/or information. Material can be thought of as "stuff": things that are tangible, like widgets, water, dirt, buildings or cash. Information is intangible, and represents things like temperature, interest rates, prices, or a person's perceptions.

Many models simulate the movement or transformation of materials. A water resources model simulates the movement of water through a system. A financial model simulates the movement and transformation of assets (e.g., cash, property) within a system. Other models simulate the evolution of information (e.g., the status of a project, a person's perception of or degree of belief in something, the price of a commodity).

Many models simulate both material and information flows. For example, a supply chain model simulates the movement and transformation of parts and products (materials) as well as the perceptions of purchasing managers and other individuals (information).

Although the movement/evolution/transformation of materials and information within a system are similar in many respects, they have an important difference. In particular, material is conserved as it moves through a system, while information generally is not. Treating material and information flows in the same manner within a model can lead to conceptual and mathematical errors. It can also add to the complexity (and lack of transparency) in a model.

As a result, GoldSim explicitly distinguishes between the movement/evolution/transformation of material and information by providing separate elements that are intended only to operate on a particular type of input. This ability facilitates the construction of internally-consistent and transparent models.

GoldSim provides this differentiation for two kinds of elements:

Stocks: GoldSim provides three basic Stock elements. Reservoirs and Pools are intended to integrate/accumulate material flows, and represent things such as reservoirs of water, account balances, and inventories. Integrators are intended to simply integrate information. For example, integrating a time series of the velocity of a projectile using an Integrator would yield the distance that the projectile had traveled.

Delays: GoldSim provides two Delay elements for delaying continuous signals. Material Delays are intended to accept flows of material (e.g., gal/day or $/yr), and conserve the material in transit, outputting a flow. An

Information Delay element accepts any kind of signal (which is generally not a flow), and does not enforce conservation of the signal.

While building your models, you should think carefully about whether you are operating on material or information, and use the appropriate element. As a general rule, if it is tangible (i.e., can be quantified in terms of mass, volume, or number of items), it is a material.

Note: Energy, although it is not tangible, should also be treated as a material, since it is always conserved. An example is a model that simulates heat transport through a system. In this case, the transport of heat is analogous to the transport of mass, and hence heat (energy) should be treated as a material within GoldSim. The dimensions of energy are $ML^2 T^{-2}$.

Note: Even though their value is not necessarily conserved (e.g., due to currency fluctuations or fluctuating market values), cash and other assets such as stocks should always be thought of as materials (since they represent quantities of bills or shares, which are conserved). That is, the quantity of shares that you own is a material; the value of those shares is information.

Using Basic Input Elements

This section describes the two basic input elements: Data elements and Stochastic elements. The three other types of input elements (Time Series, Lookup Table and History Generator) are described separately.

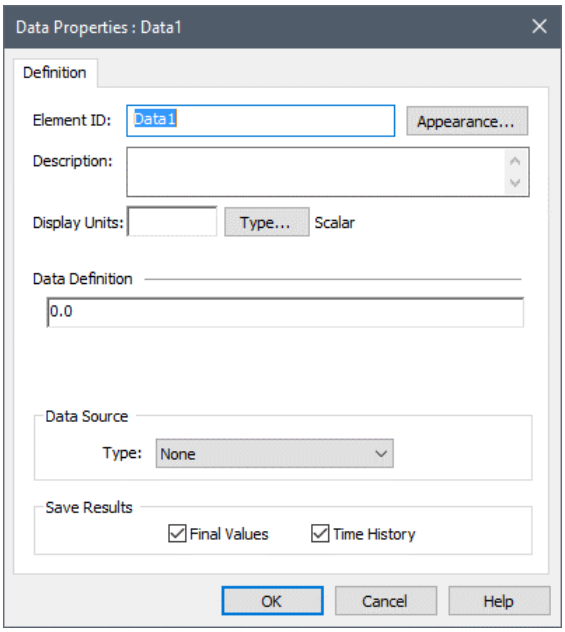
Read more: Using Time Series Elements (page 192); Using Lookup Table Elements (page 307); Generating Stochastic Time Histories (page 893).

Data Elements

Data elements are intended to represent the constant inputs in your model.

A Data element can represent both values and conditions (i.e., True/False), and can represent a single scalar datum, or an array of data.

The properties dialog for a Data element looks like this:



As can be seen, the dialog is very simple. Other than the **Element ID**, **Description** and **Display Units**, the Data element property dialog has only a single input field (labeled **Data Definition**). Because Data elements are meant to represent constants in your model, typically you will enter a number into this field.

If you specify that the output of the Data element is a vector or a matrix, the dialog will be slightly modified (in order to allow you to define the members of the array). Instead of displaying an input field, it displays a button for defining the array:

Read more: Using Vectors and Matrices (page 848).

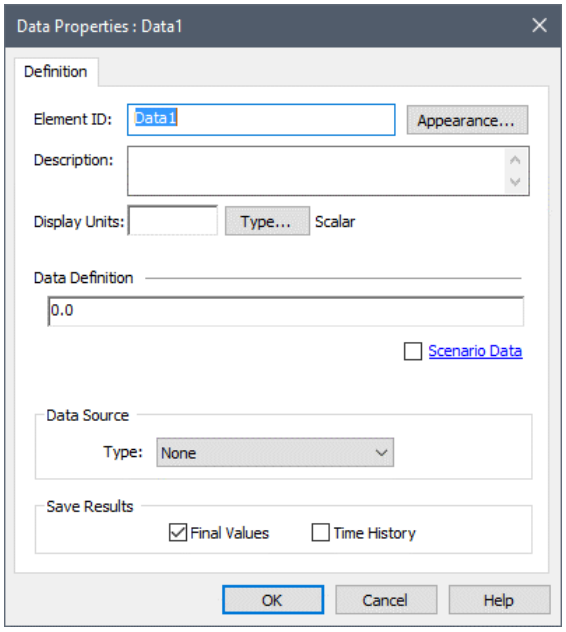
Note: Although you can enter expressions (with links) into the **Data Definition** field for a Data element, it is generally recommended that you only enter numbers in this field (and use an Expression element when you need to define equations with links to other elements). Doing so helps to make your models more transparent, since the Data symbol will visually indicate to anyone viewing the model that the element represents a constant.

Data elements have a single output, which can be a value or a condition, and can be specified as a scalar, a vector or a matrix. You can specify these attributes by pressing the **Type…** button. By default, a new Data element is a scalar, dimensionless value.

Data elements also have a **Data Source** field that allows you to download data directly from an ODBC-compliant database.

Read more: Linking Elements to a Database (page 1107).

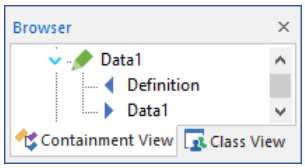
If you are using GoldSim's advanced scenario feature, and have defined at least one scenario, Data elements include an additional field that allow you to define the element as Scenario Data:



Read more: Creating, Running and Comparing Scenarios (page 525).

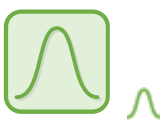
You can save the results for a Data element by clicking **Final Values** and/or **Time Histories**.

As shown below, the browser view of a Data element shows a single input (referred to as the Definition), and a single output:



Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

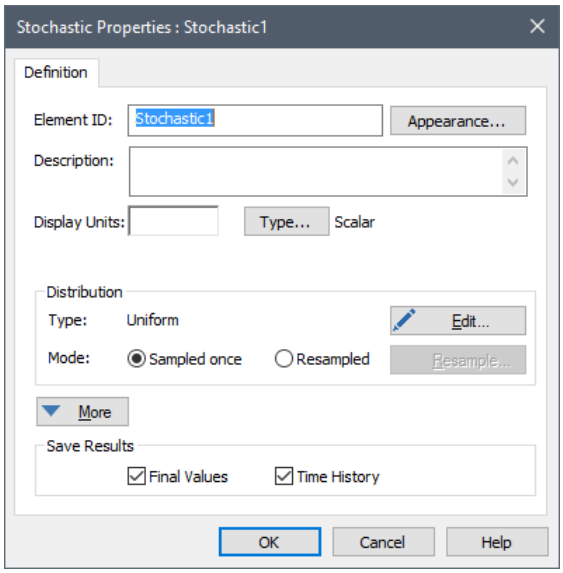
Stochastic Elements



Stochastic elements allow you to explicitly represent uncertainty in the input data for your model. GoldSim uses the Monte Carlo method to sample Stochastic elements in order to carry out probabilistic simulations.

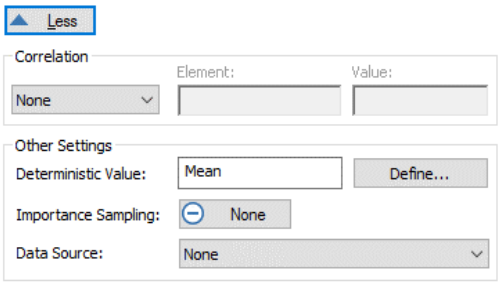
The probabilistic simulation techniques used by GoldSim are discussed in general terms in Appendix A "Introduction to Probabilistic Simulation". If you are unfamiliar with probabilistic modeling, you should read this appendix before using a Stochastic element.

The dialog for a Stochastic element looks like this:



The **Edit…** button is used to define the distribution type and specify its parameters. The two **Mode** radio buttons are used to control when a Stochastic element is sampled.

The **More** button expands the dialog to provide access to a number of advanced features:



The advanced options include correlating one Stochastic to another, directly specifying a percentile level to use (rather than random sampling), modifying the sampling algorithm (importance sampling), linking the element to a database, and specifying how the Stochastic is to be evaluated when running deterministic simulations.

Read more: Linking Elements to a Database (page 1107).

Note: The **More** button becomes a **Less** button when the dialog is expanded. If any of these options are selected, the **Less** button is removed (the dialog remains expanded) the next time you open it.

Stochastic elements have four outputs:

- the realized (sampled) value, which is the primary output (and hence has the same name as the element);
- the probability density of the realized value (Probability_Density);
- the cumulative probability of the realized value (Cumulative_Probability); and

- a complex output representing all the distribution information (Distribution).

The first three outputs of Stochastic elements are always scalar or vector values (unless the Stochastic is defined as a Boolean, in which case the primary output is a condition). By default, a new Stochastic element is dimensionless. You specify the dimensions (display units) of the primary output of a Stochastic element in the **Display Units** field. The dimensions of the Probability_Density output are the inverse of those of the primary output (e.g., if the primary output has units of meters, the Probability_Density has units of inverse meters). The Cumulative_Probability output is dimensionless.

The fourth output of a Stochastic element (Distribution) is a complex output that represents all the statistical information necessary to define a probability distribution. It can only be used in several specialized locations (e.g., SubModel Interface, inputs to specialized distribution functions, inputs for an Externally-defined distribution, specialized input to Timed Events and Event Delays). It can also be viewed directly in a Distribution Result display in order to display the analytical form of the distribution.

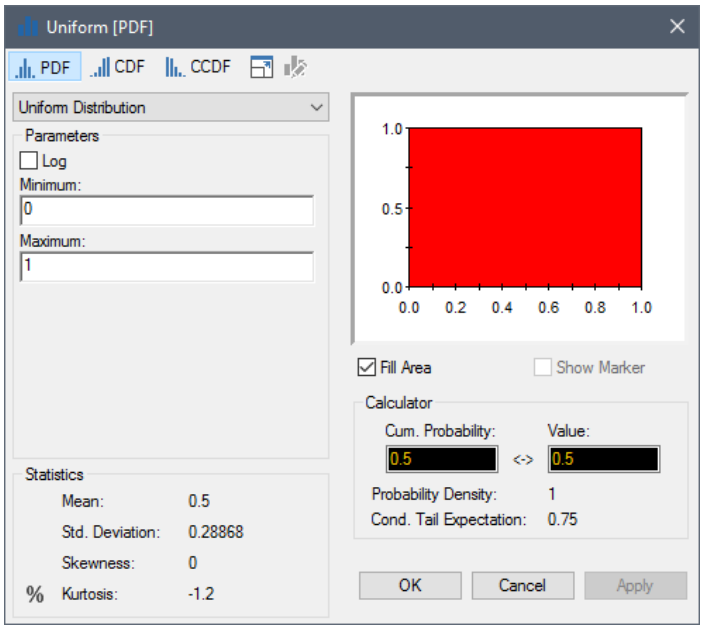
Read more: Creating the Input Interface to a SubModel (page 1055); Specialized Functions that Operate on Distributions (page 188); Externally-Defined Distribution (page 172); Timed Event Elements (page 379); Modeling Event Delays with Dispersion (page 394); Adding a Distribution Output to a Distribution Result (page 686).

You can save the results for a Stochastic element by clicking **Final Values** and/or **Time Histories** in the properties dialog. Checking one of these causes all three outputs to be saved as results. If you wish to save only one or two of these as results, you can use the context menu of the output (accessed via a right-click in the browser) to turn on or off one or more of the three outputs. In this case, the checkbox in the properties dialog will become a box instead of a check (indicating that only some of the results will be saved). Note that in order to see outputs in the browser you must first ensure that **Show element subitems** is selected by right-clicking anywhere in the browser.

Stochastic elements are discussed in detail in the sections below.

Specifying the Distribution for a Stochastic Element

The **Edit …** button on the Stochastic dialog accesses a dialog for specifying the probability distribution defining the element.



The drop-list in the upper left-hand corner of the dialog contains a list of all of the distributions provided by GoldSim.

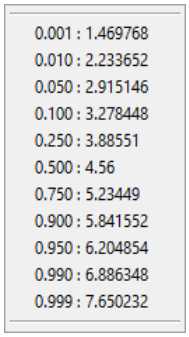
Directly below this field, you enter the parameters defining the selected distribution (the parameters differ depending on the distribution type). These can be constants, links or expressions.

A preview of the distribution chart is displayed in the upper right-hand corner of the dialog. Note that after edited the distribution parameters, you must press **Apply** to update the chart.

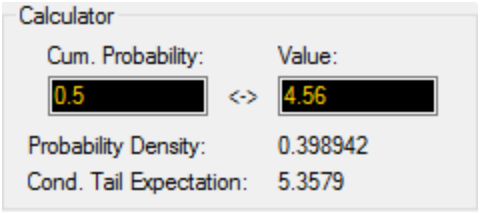
The statistics for the distribution (***Mean***, ***Standard Deviation***, ***Skewness,*** and ***Kurtosis***) are shown directly below the distribution's parameters. The significance of these four statistics is described in Appendix A, "Introduction to Probabilistic Simulation".

Percentile button

The Percentile button displays the percentiles of the distribution:



The Calculator section of the dialog allows you to compute the value associated with a particular percentile or the percentile associated with a particular value:



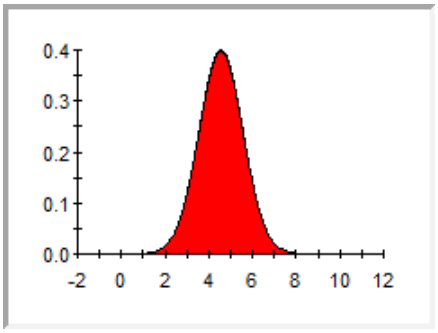
Enter the percentile in the Cum. Prob. field and the corresponding value will be displayed in Value OR Enter the value in the Value field and the corresponding percentile will be displayed in Cum. Prob.

The Calculator also displays the Probability Density and the ***Conditional Tail Expectation*** for the specified Cumulative Probability/Value pair. The Conditional Tail Expectation is the expected value of the output given that it lies above a specified Cumulative Probability. That is, it represents the mean of the worst 100(1 - α)% of outcomes, where α is the specified Cumulative Probability.

Note: Calculation of the Conditional Tail Expectation is discussed in detail in Appendix B.

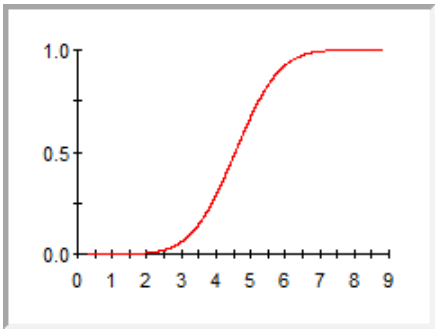
The toolbar at the top of the dialog is used to control the distribution plot. The functions of the various buttons are as follows:

Button	Action
PDF	Display the preview as a PDF (probability density function):



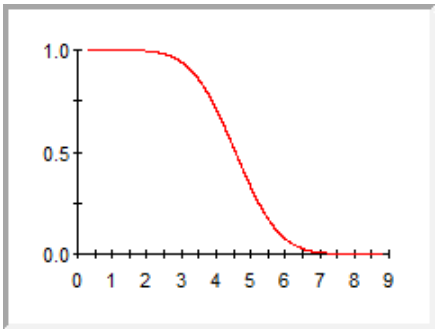
Note that if **Fill Area** is checked below the preview, the area below the PDF line is filled in (this applies to CDF and CCDF previews also).

Button	Action
CDF	Display the preview as a CDF (cumulative distribution function):



Note that for a CDF, if Show Marker is checked below the preview, the particular value/percentile entered in the Calculator section is indicated on the plot.

CCDF — Display the preview as a CCDF (complementary cumulative distribution function):



Display a full chart of the distribution. (You can also display the full chart by double-clicking on the preview or pressing **Ctrl+Shft+T**). (When viewing the full chart, pressing the button again returns to the Distribution dialog.) A full chart can be customized to a much greater degree than a preview chart (e.g., you can add headers and footers; axis labels, etc.).

Read more: Viewing a Distribution Chart (page 670).

Note: You can toggle through the three types of distribution displays (PDF, CDF, CCDF) using the **PgUp** and **PgDn** keys.

Stochastic Distribution Types

The types of probability distributions supplied by GoldSim are summarized below:

Distribution Type
Beta
Generalized Beta
BetaPERT
Binomial

Distribution Type
Boolean
Cumulative (and log-Cumulative)
Discrete
Exponential
Externally-defined
Extreme Probability
Extreme Value
Gamma
Log-Normal
Negative Binomial
Normal
Pareto
Pearson Type III
Poisson
Sampled Results
Student's t
Triangular (and log-Triangular)
Uniform (and log-Uniform)
Weibull

The fields that appear in the Parameters section of the dialog will change with the distribution type. As a general rule, you should not specify the parameters of a distribution as a function of time, since GoldSim does automatically resample the distribution unless you specifically instruct GoldSim to do so.

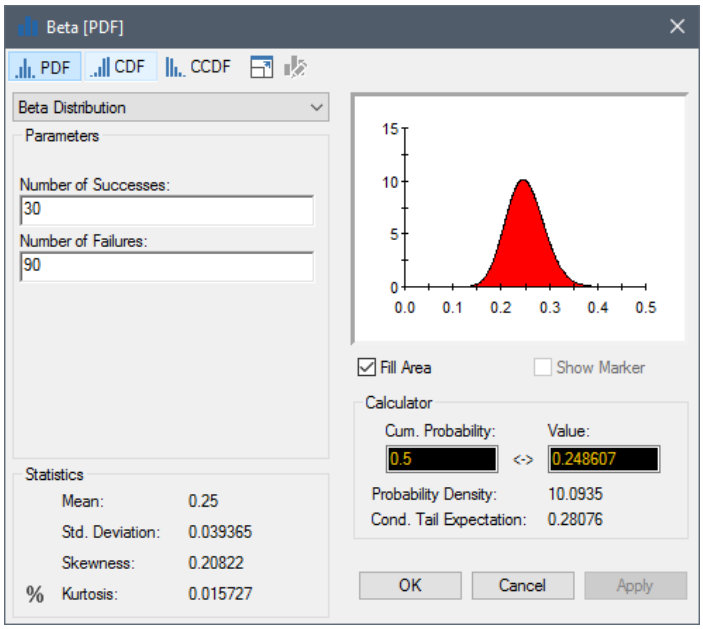
Read more: Controlling When a Stochastic Element is Sampled (page 183).

The required inputs for each of the distributions types are summarized below. An example file which uses all of the Stochastic elements (Distributions.gsm) is in the General Examples/Stochastic folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu). The mathematical details of each of the distributions are provided in Appendix B.

Beta Distribution

The Beta distribution is a continuous distribution used to represent the uncertainty in the probability of occurrence of an event given some data regarding observations of the event occurrence in previous experiments. As such, the Beta distribution represents the probability distribution of a frequency, and therefore always ranges between 0 and 1.

It is defined by specifying results of an experiment or a number of trials (e.g., a coin flip) in terms of **Number of Successes** and **Number of Failures**:



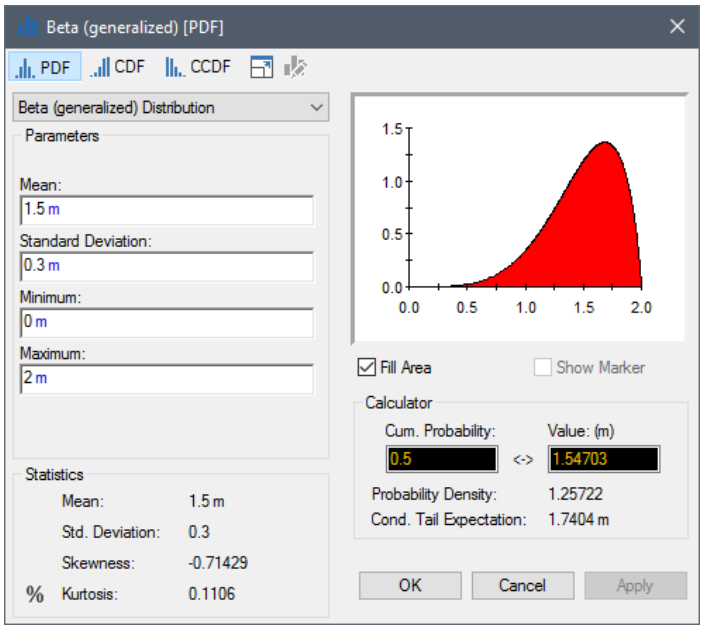
Both inputs must be positive values. The displayed distribution represents the underlying probability of a Success. For example, in the screen shown above, if we define Success as heads on a coin flip, and Failure as tails, the distribution represents the uncertainty in the probability of obtaining heads on the next flip of the coin. If the number of trials is small, the uncertainty is high. As the number of trials increases, the uncertainty in the outcome decreases (and in the example of a coin flip, if the coin is unbiased, the probability of heads would collapse to 0.5).

Note: The Beta distribution must always be dimensionless, as it represents a frequency (otherwise GoldSim will display an error). However, GoldSim also provides a generalized form of the Beta (described below) that allows you to specify a distribution's dimensions (e.g., time). Such a distribution is defined in a different way (using a mean, standard deviation, minimum and maximum). The Generalized Beta distribution therefore provides a flexible way to specify a probability distribution over a particular range.

Generalized Beta Distribution

The Generalized Beta distribution provides a flexible way to specify a probability distribution over a particular range (i.e., with a specified minimum and maximum). It is commonly used within project management simulations to represent the time to complete a task.

It is defined by specifying a **Mean**, **Standard Deviation**, **Minimum** and **Maximum**:



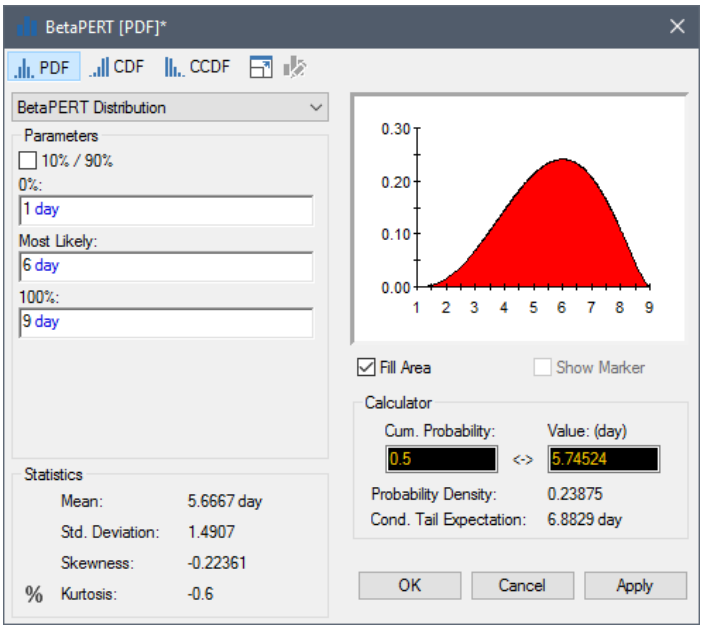
Note: The theoretical maximum standard deviation (SD) for a beta distribution (ranging from 0 to 1) is equal to sqrt[mean*(1-mean)]. However, with such a high SD, the beta distribution would have a "spike" of probability density at both its upper and lower bounds. With a somewhat lower SD, there will only be a spike at the limit closest to the mean. GoldSim restricts the SD to 0.6 of the maximum theoretical value in order to avoid having any spikes in the density function. If you need probability distributions that combine discrete spikes with continuous curves, you should construct this explicitly (by combining multiple distributions using an Expression, or by using a Cumulative distribution.

Read more: Cumulative Distribution (page 169).

BetaPERT Distribution

The BetaPERT distribution is a specialized version of the Beta distribution and is often used for project risk analysis. Mathematically, it is a Beta distribution. While a Generalized Beta Distribution requires four parameters, a BetaPERT requires only three. A particular formula (inherent to the BetaPERT) determines the mean of the distribution (and hence its shape).

By default, it is defined by specifying either a **Minimum (0th percentile)**, **Most Likely** and **Maximum (100th percentile)**:



Alternatively, if you check the **10% / 90%** checkbox, you can specify the 10th percentile, Most Likely and 90th percentile.

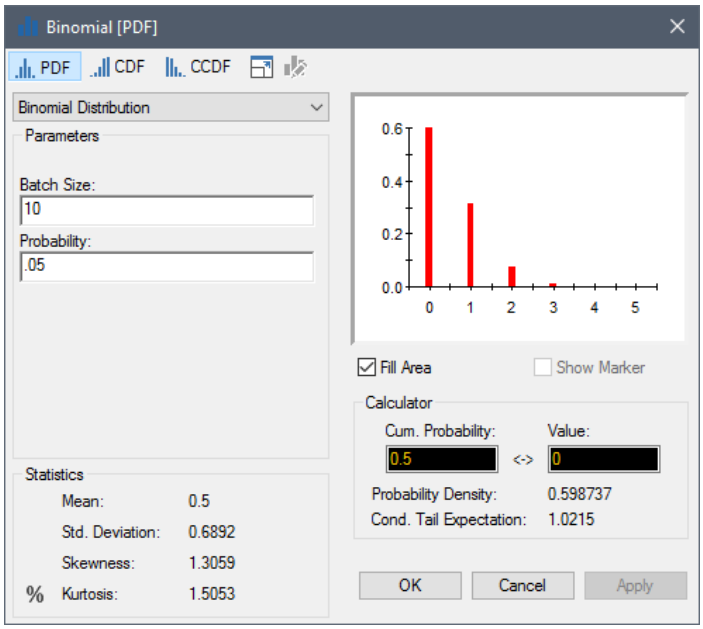
Read more: Generalized Beta Distribution (page 165).

Binomial Distribution

The Binomial distribution describes the probability of a certain number of instances, given a (dimensionless) batch size and a probability of occurrence. As such, by definition, a Binomial distribution is dimensionless.

For example, you could use a Binomial distribution to define a probability distribution for the number of defective widgets produced, given a particular batch size (e.g., 10) and the probability of any given widget being defective (e.g., 0.05).

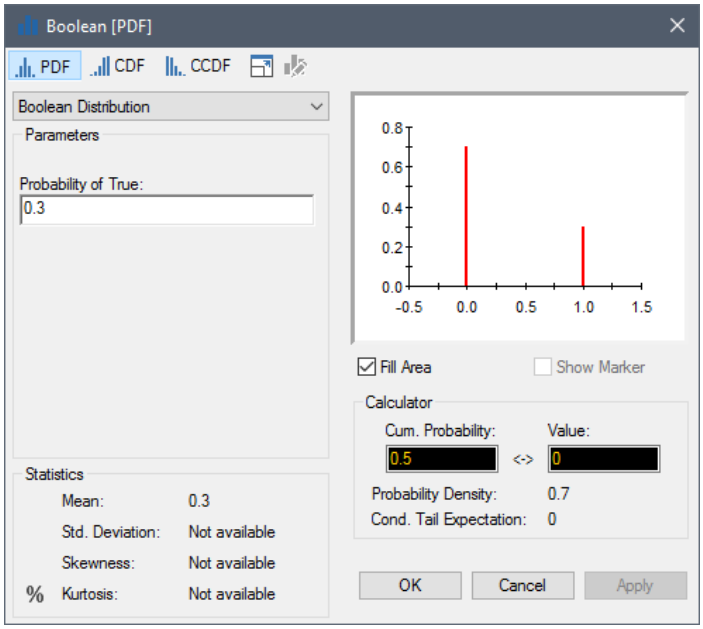
It requires two inputs, the **Batch Size** (which should be an integer) and the **Probability**. Like the Poisson distribution, it is a discrete distribution containing only integer numbers.



Note: Since this is a discrete distribution, the PDF view does not actually display a ***probability density function***. Instead, it displays a ***probability mass function***.

Boolean Distribution

The Boolean distribution takes on one of two values: True or False. It requires a single input, **Probability of True**. It is useful for representing binary systems which have a given probability (e.g., flipping a coin):

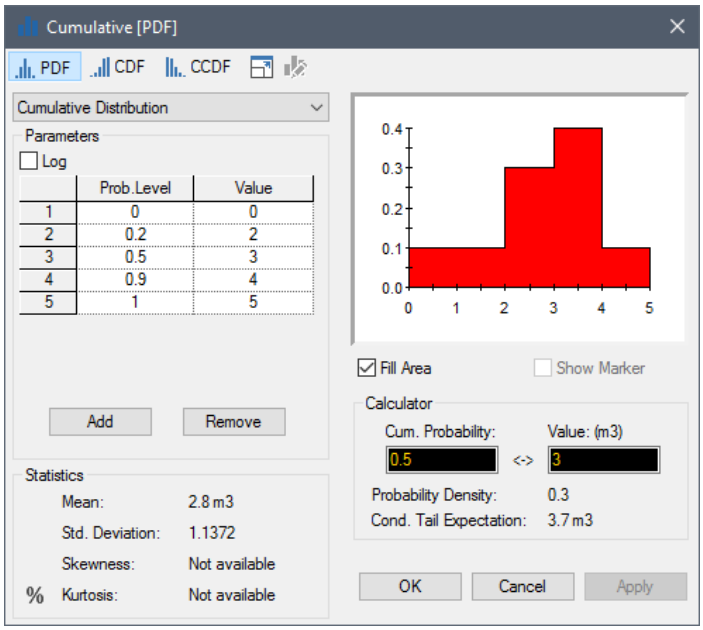


Note that when plotted, GoldSim shows a True condition as 1, and a False condition as 0.

Note: Since this is a discrete distribution, the PDF view does not actually display a ***probability density function***. Instead, it displays a ***probability mass function***.

Cumulative Distribution

The Cumulative distribution is used to define custom continuous distributions. You define the distribution by specifying [cumulative probability, value] pairs. A given pair (defined by a **Prob. Level** and a **Value**) implies that the cumulative probability of the **Value** is equal to the specified **Prob. Level**:



In this example, the cumulative probability of the value being less than or equal to 4 is 90%.

You add and remove pairs using the **Add** and **Remove** buttons (new pairs are inserted below the selected pair). In addition, if you place the cursor in the grid, the following hotkeys can be used:

Keys	Action
Ctrl+Enter	creates a new row below the cursor
Ctrl+Shift+Enter	creates a new row above the cursor
Ctrl+Backspace	deletes the current row

By definition, the first cumulative probability specified must be 0 and the last cumulative probability specified must be 1. The **Prob. Level** and the **Value** of the pairs cannot decrease as you move downward through the list. If the Prob. Levels decrease as you move down the table, GoldSim will sort the rows so that they are in increasing order when you close the dialog or press **Apply**. If the Values decrease as you move downward, GoldSim will warn you and ask you to fix the distribution.

Note: Specifying two or more Prob Levels with the same number results in a horizontal line in the CDF. Specifying two or more Values with the same number results in a vertical line in the CDF (and an infinite spike in the PDF).

You can also define the distribution as a log-cumulative (by checking the **Log** box). Whereas in a cumulative distribution, the density between values is constant (i.e., the distribution between values is uniform), in a log-cumulative, the density of the *log* of the value is constant (i.e., the distribution between values is log-uniform). If **Log** is checked, all **Values** for the distribution must be positive. Log-Cumulative distributions are often applied to quantities with large (order-of-magnitude) uncertainties.

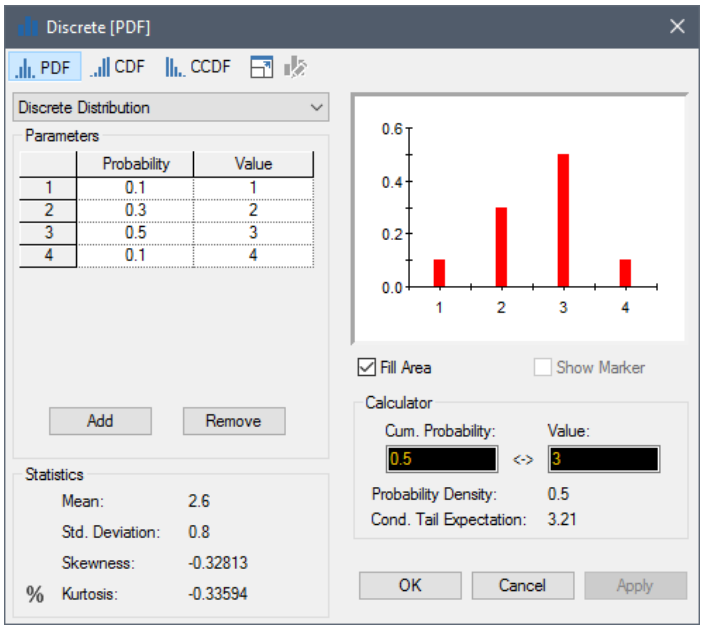
Note: The values and cumulative probabilities must be entered as numbers and cannot be specified using links or expressions. The values are assumed to be entered in the Display Units for the element.

Note: You can copy and paste the entries for a Cumulative distribution from a spreadsheet. To do so, select the two columns in the spreadsheet (Probability Level and Value), and copy them to the clipboard. Then place the cursor in the upper left-hand corner of the grid (i.e., the first Probability Level) and paste (by pressing **Ctrl+V**).

Discrete Distribution

A Discrete distribution is used to specify a discrete (as opposed to continuous) probability density function. In a Discrete distribution, probabilities are assigned to discrete values. The probability of a value between the specified values is zero.

You define the distribution by specifying [probability, value] pairs. A given pair (defined by a **Probability** and a **Value**) implies that the probability of the **Value** is equal to the specified **Probability**:



In this example, the probability of the value being equal to 3 is 50%.

You add and remove pairs using the **Add** and **Remove** buttons (new pairs are inserted below the selected pair). In addition, if you place the cursor in the grid, the following hotkeys can be used:

Keys	Action
Ctrl+Enter	creates a new row below the cursor
Ctrl+Shift+Enter	creates a new row above the cursor
Ctrl+Backspace	deletes the current row

By definition, the probabilities must sum to one. The **Values** do not need to be in any particular order (GoldSim will automatically sort them in increasing order when the data is applied). However, if the Probabilities do not sum to one, GoldSim will warn you and ask you to fix the distribution.

Note: The values and probabilities must be entered as numbers and cannot be specified using links or expressions. The values are assumed to be entered in the Display Units for the element (which are displayed in the header for the editing grid).

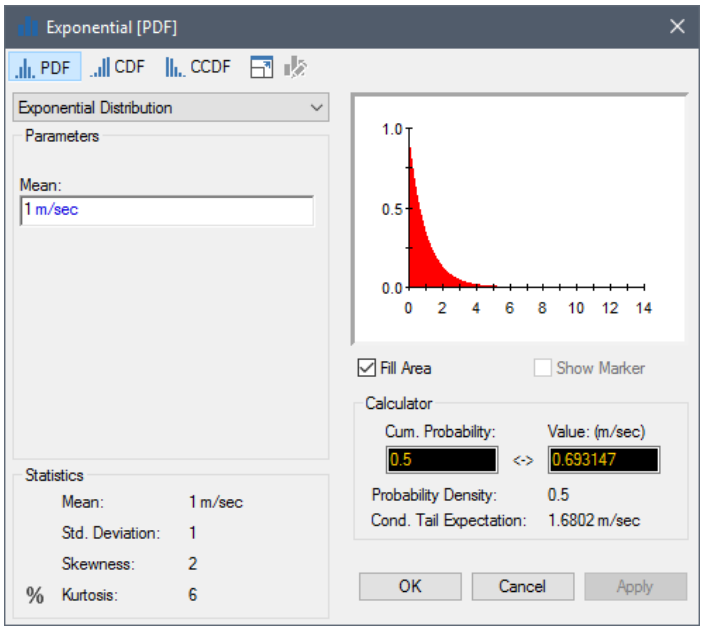
Note: You can copy and paste the entries for a Discrete distribution from a spreadsheet. To do so, select the two columns in the spreadsheet (Probability and Value), and copy them to the clipboard. Then place the cursor in the upper left-hand corner of the grid (i.e., the first Probability) and paste (by pressing **Ctrl+V**).

Note: Since this is a discrete distribution, the PDF view does not actually display a ***probability density function***. Instead, it displays a ***probability mass function***.

Exponential Distribution

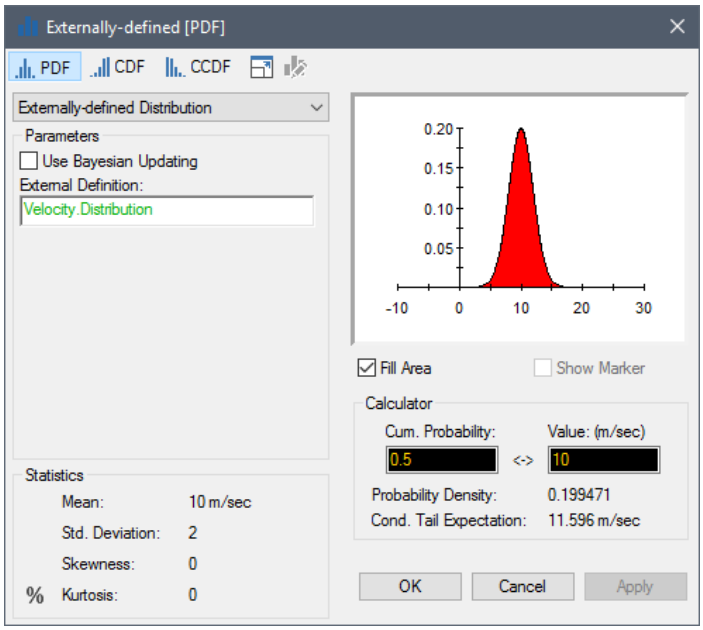
The Exponential distribution is a continuous distribution, typically used to model the time to complete a task or reach a milestone.

It is defined by a single parameter: the **Mean** of the distribution (which must be positive).



Externally-Defined Distribution

The Externally-defined distribution is a specialized distribution that is defined externally by a Distribution output:



The **External Definition** field only accepts a Distribution output. Distribution outputs are complex outputs that represent all the statistical information necessary to define a probability distribution. They can only be produced by another Stochastic element, a Spreadsheet element, or a SubModel.

The primary purpose of this distribution type is to connect a Stochastic to a distribution that has been imported via a Spreadsheet element.

Read more: Importing Stochastic Element Definitions from a Spreadsheet (page 991).

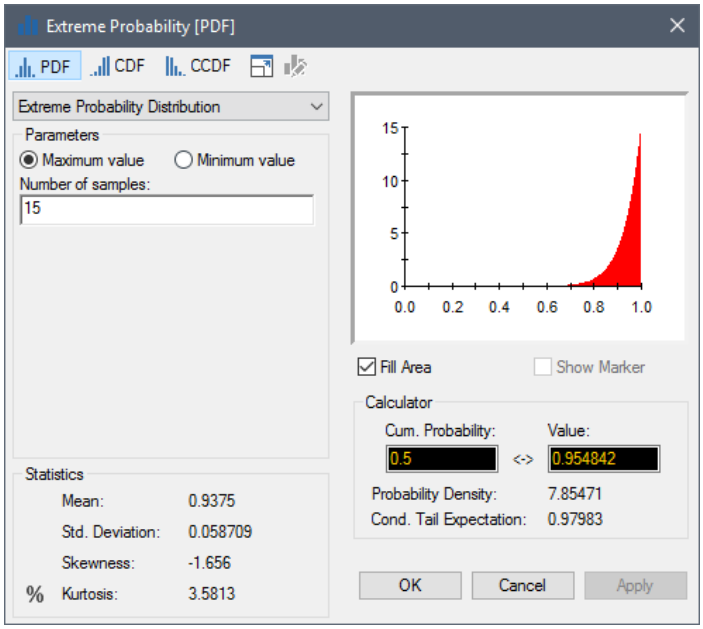
However, there are also several other specialized uses, such as exchanging distribution information with a SubModel, and to support dynamically revising distributions using simulated Bayesian updating.

Read more: Creating the Input Interface to a SubModel (page 1055); Creating the Output Interface to a SubModel (page 1059); Dynamically Revising Distributions Using Simulated Bayesian Updating (page 1092).

Extreme Probability Distribution

The Extreme Probability distribution is a continuous distribution used to represent the uncertainty in the highest or lowest probability level if any given distribution is sampled N times. As such, the Extreme Probability distribution represents the probability distribution of a probability level, and therefore always ranges between 0 and 1.

It is defined by specifying the **Number of samples**, and whether you are interested in the probability level for the **Maximum value** or the **Minimum value**:



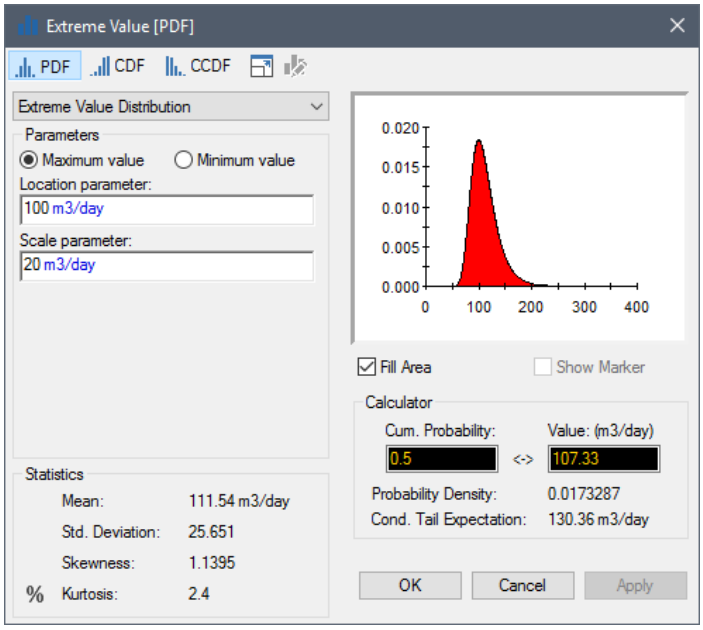
The input must be a positive value. The displayed distribution represents the probability of the maximum or minimum value corresponding to a particular probability level given a specified number of samples. For example, in the screen shown above, the distribution represents the uncertainty in the probability level of the maximum value assuming 15 samples. It indicates that the expected value of the maximum probability level is 0.9375.

Note: The Extreme Probability distribution must always be dimensionless, as it represents a probability level (otherwise GoldSim will display an error).

Extreme Value Distribution

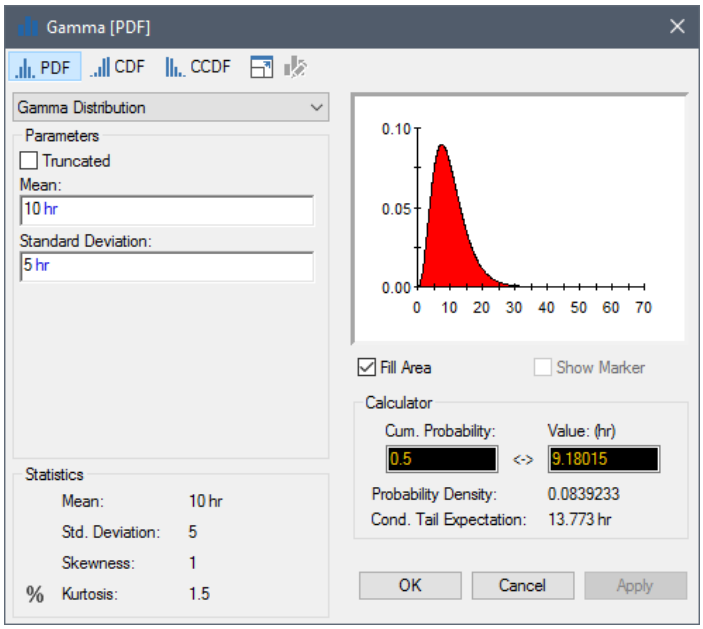
The Extreme Value distribution (also referred to as the Gumbel distribution) is a continuous distribution used to describe the maximum (or the minimum) observed values for a variable. For example, you could use this distribution to specify the probability of the maximum flow rate in a river in a particular year by fitting a list of the maximum values observed for each of the past 25 years to this distribution. It is therefore commonly used to predict the chance of extreme events such as earthquakes or floods.

It is defined by specifying two parameters: a **Location parameter** and a **Scale parameter**. You must also specify whether you are interested in the **Maximum value** or the **Minimum value**:



Gamma Distribution

The Gamma distribution is similar to a Log-Normal, but is less positively-skewed. Because it mathematically represents the time required for the occurrence of a specified number of Poisson events, it is often used to represent the time required to complete a particular task or reach a particular milestone. It is defined by a **Mean** and a **Standard Deviation**:



If desired, a Gamma distribution can be **Truncated**, in which case you must specify a **Minimum** and **Maximum** value. Note that in this case, the Mean and Standard Deviation inputs refer to the statistics prior to truncation.

Note: If the Mean and Standard Deviation are identical, the Gamma distribution collapses to an exponential distribution.

Log-Normal Distribution

The Log-Normal distribution is used to describe quantities in which the logarithm of the value is normally distributed. The Log-Normal is typically used to represent physical quantities which must be non-negative and are positively skewed. This distribution is often used to represent quantities with large (order-of-magnitude) uncertainties.

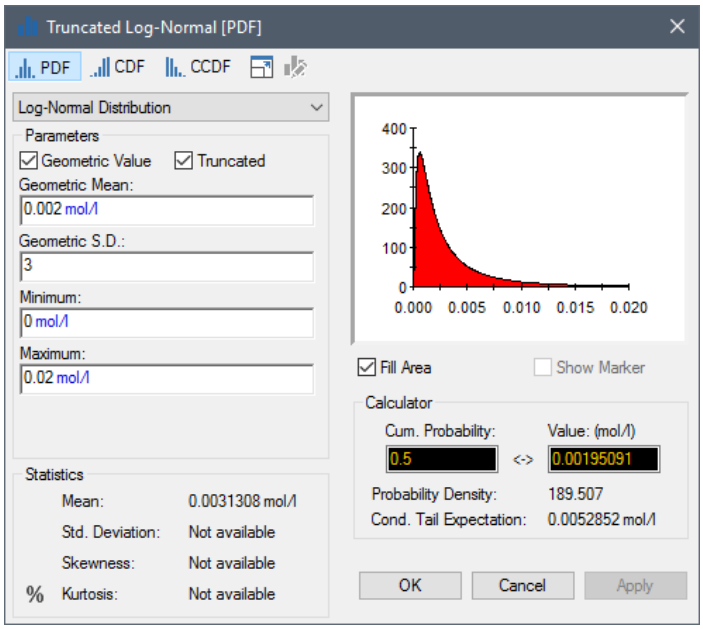
Log-Normal distributions can be entered in two ways: 1) by entering the **Geometric Mean** and the **Geometric S.D.**; or 2) by entering the **True Mean** and the **True S.D.** If **Geometric Value** is checked, the former method is used. When one option is chosen, the other set of parameters are computed internally by GoldSim and are grayed out.

With regard to a set of data points, the **Geometric Mean** is equal to the exponentiated mean of the logs (i.e., 10^X, where X is equal to the mean value of the logarithms of the data points). With regard to a set of data points, the **Geometric S.D.** is the exponentiated standard deviation of the logs (i.e., 10^Y, where Y is equal to the standard deviation of the logarithms of the data points). Note that the Geometric S.D. is always dimensionless, and must be greater than 1.

The **True Mean** and the **True S.D.** refer to the true (arithmetic) mean and S.D. (i.e., in linear space).

A Log-Normal distribution can be **Truncated**. Note that in this case, the inputs (i.e., Mean and Standard Deviation) refer to the statistics prior to truncation.

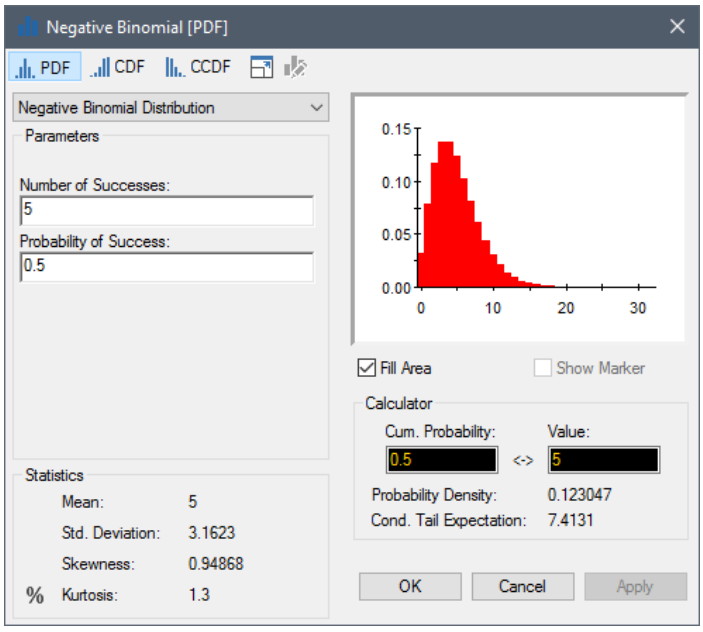
All inputs for a Log-Normal must be positive values.



Negative Binomial Distribution

The Negative Binomial distribution describes the distribution of the number of failures in order to achieve a specified number of successes, with a specified probability of success for each attempt. As such, by definition, it is dimensionless. It is frequently used in actuarial models.

The distribution requires two inputs, the **Number of Successes** (which must be a dimensionless positive integer) and the **Probability of Success**. Like the Poisson distribution, the Negative Binomial is a discrete distribution consisting of only integer values.

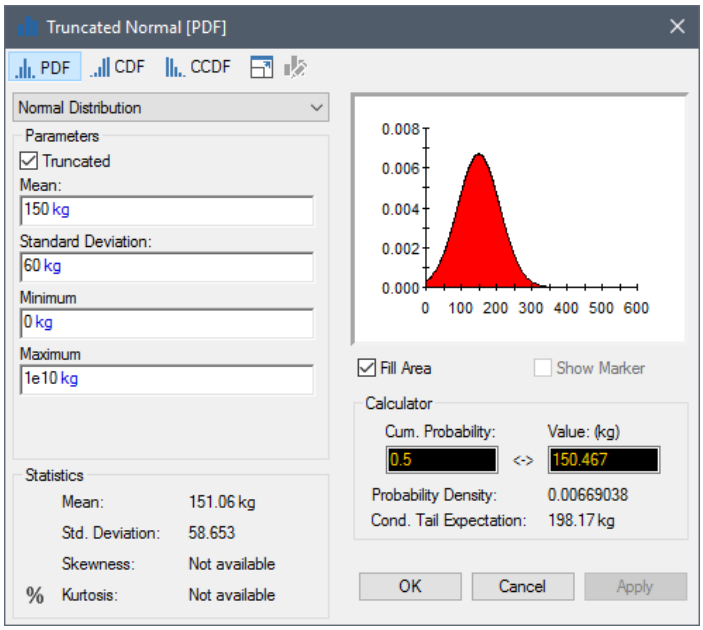


Note: Since this is a discrete distribution, the PDF view does not actually display a ***probability density function***. Instead, it displays a ***probability mass function***.

Normal Distribution

The Normal distribution is perhaps the most commonly used probability distribution. It can be used, for example, to represent uncertainties resulting from unbiased measurement error, and (because of the ***central limit theorem***) the value of a sum of other variables.

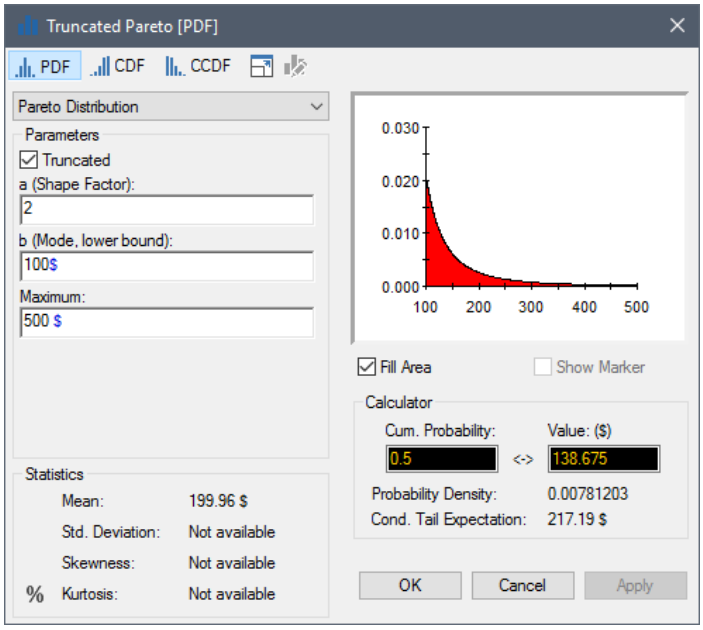
The Normal distribution is defined by a **Mean** and a **Standard Deviation**. GoldSim also allows you to truncate the distribution by checking the **Truncated** box and specifying a **Minimum** and a **Maximum**:



Pareto Distribution

The Pareto distribution is a continuous, long-tailed distribution that is commonly used to model traffic patterns in network modeling, the size of insurance claims, and income levels in economic modeling.

It requires two inputs, a shape parameter (**a)** and a scale parameter (**b**), which defines the lower bound and mode of the Pareto distribution. Both of these parameters must be positive numbers.

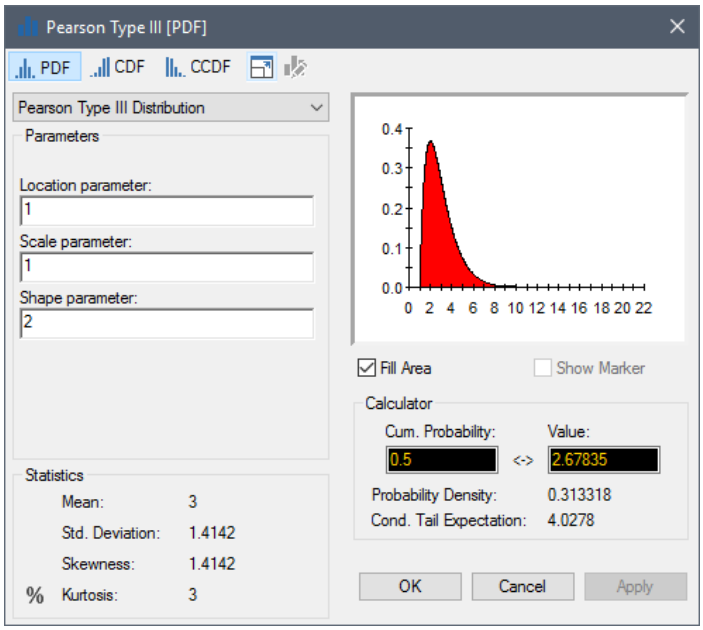


GoldSim also allows you to truncate the distribution by checking the **Truncated** box and specifying a **Maximum.**

Pearson Type III Distribution

The Pearson Type III distribution is a continuous distribution that is used for representing skewed observations. It is widely used in hydrological applications (often for the log of the underlying variable, such as a flood flow).

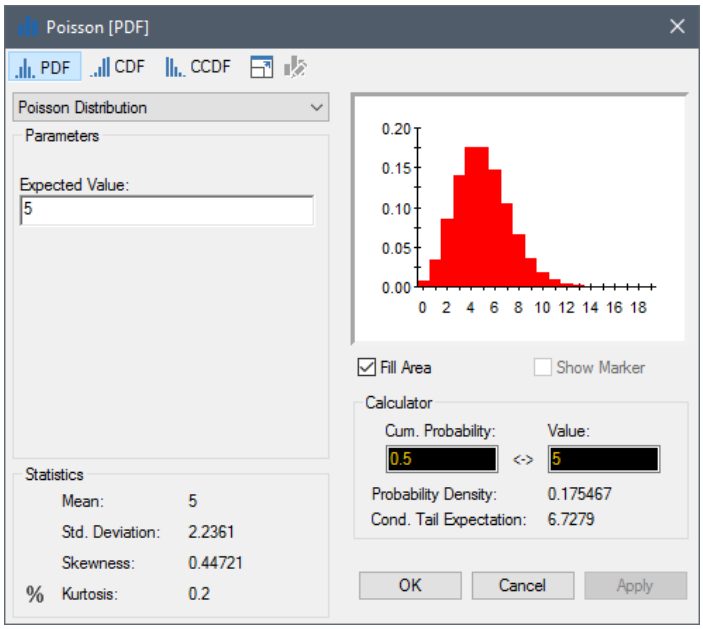
It is defined by specifying three parameters: a **Location parameter**, a **Scale parameter**, and a **Shape parameter**:



Poisson Distribution

The Poisson distribution is used to represent the number of occurrences or instances of a particular event (e.g., number of storms during a year, number of defects in a length of a pipe).

It is a discrete distribution containing only integer numbers. It is defined by a single value, the **Expected Value** of the number of occurrences or instances (which must be positive):



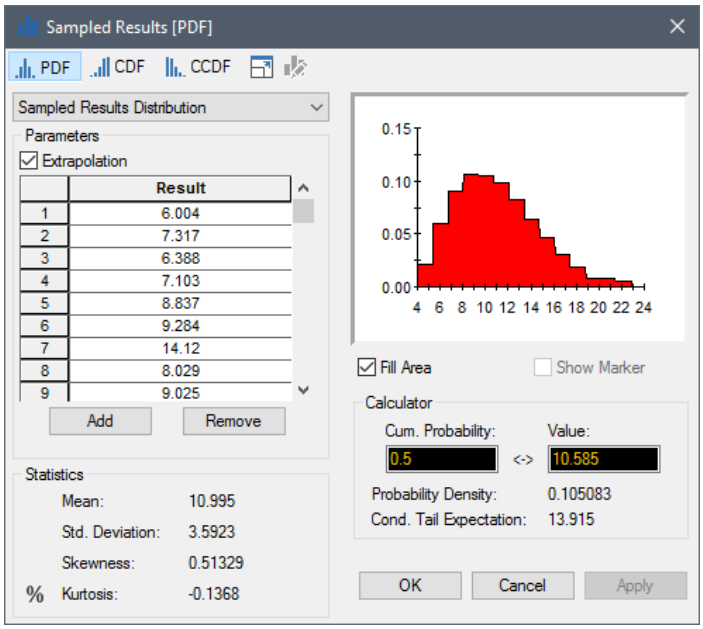
Note: Since this is a discrete distribution, the PDF view does not actually display a ***probability density function***. Instead, it displays a ***probability mass function***.

Sampled Results Distribution

The Sampled Results distribution provides a flexible way to create a non-parametric distribution using a list of sampled (observed) results. GoldSim generates a CDF by sorting the observations and assuming that a cumulative probability of 1/(Number of Observations) exists between each data point. If there are multiple data points at the same value, a discrete probability equal to N/(Number of Observations) is applied at the value, where N is equal to the number of identical observations.

In addition to providing the list of observations, you also specify whether or not GoldSim should extrapolate at the ends of the data set. If the **Extrapolation** option is cleared, a discrete probability of 1/(2*Number of observations) is assigned to the minimum and maximum values. When the **Extrapolation** option is selected, GoldSim extends the generated CDF to cumulative probability levels of 0 and 1 by extrapolating existing observations.

A simple example (using 200 data points) is shown below:



Typically, a Sampled Results distribution would only be used with a fairly large number of data points (50 or more). With fewer data points, in most cases, it would be more appropriate to fit the data to a known parametric distribution.

Note: You can copy and paste the entries for a Sampled Results distribution from a spreadsheet. To do so, select the column of data points in the spreadsheet, and copy them to the clipboard. Then place the cursor in the first field in the GoldSim dialog, and paste (by pressing **Ctrl+V**).

Student's t Distribution

The Student's-t distribution is most commonly used to represent the distribution of an uncertain population mean, given a sample mean and standard deviation. It is characterized by one parameter, the number of degrees of freedom, which equals the number of samples minus one. The t distribution is symmetric.

The t distribution is often used as follows:

$$p(\mu > X + t_c \frac{s_x}{\sqrt{n}}) = c$$

where:

μ = the population mean;

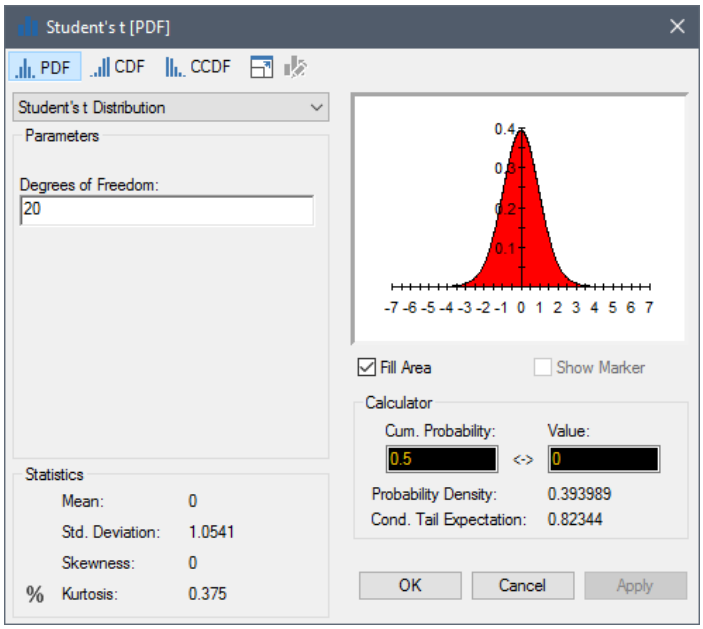
X = the sample mean;

t_c = the t-distribution for n-1 degrees of freedom, at a cumulative value of c;

s_x = the sample standard deviation;

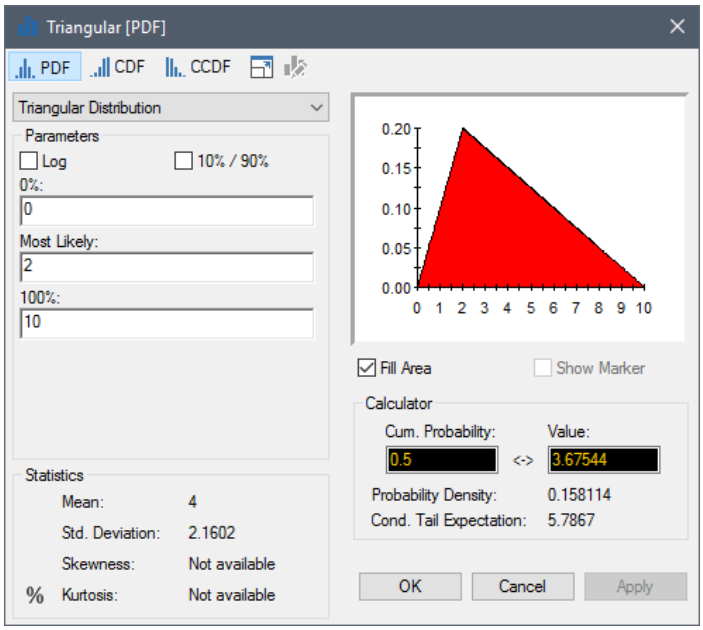
n = the number of samples; and

c = the desired confidence level.



Triangular Distribution

The Triangular distribution is useful in situations where you may have little information about a value, but can provide upper and lower bounds, as well as a "best guess" or most likely value. By default, it is defined by specifying either a **Minimum (0th percentile)**, **Most Likely** and **Maximum (100th percentile)**:

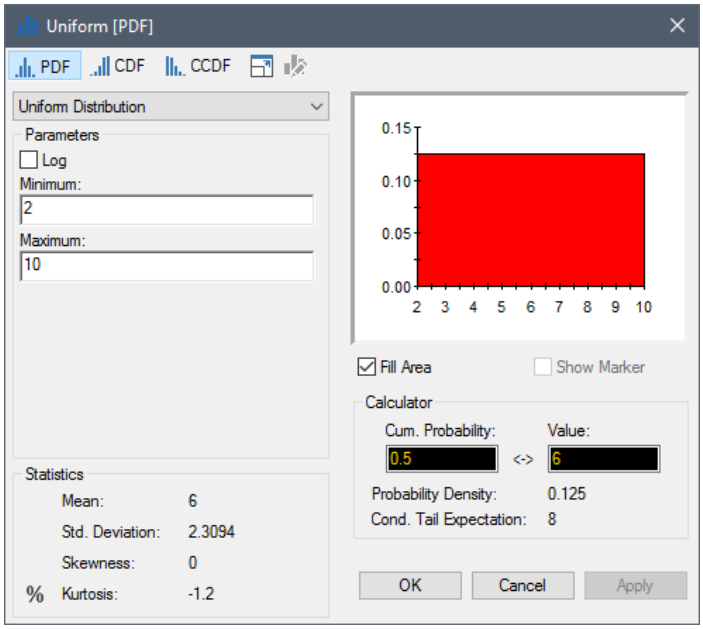


Alternatively, if you check the **10% / 90%** checkbox, you can specify the 10th percentile, Most Likely and 90th percentile.

You can also specify that the logarithms of the values have a triangular distribution (by checking the **Log** box). In this case, all inputs to the distribution must be positive values. Note that for a Log-Triangular distribution, the Most Likely input represents the value whose logarithm is most likely. Log-Triangular distributions are often applied to quantities with large (order-of-magnitude) uncertainties.

Uniform Distribution

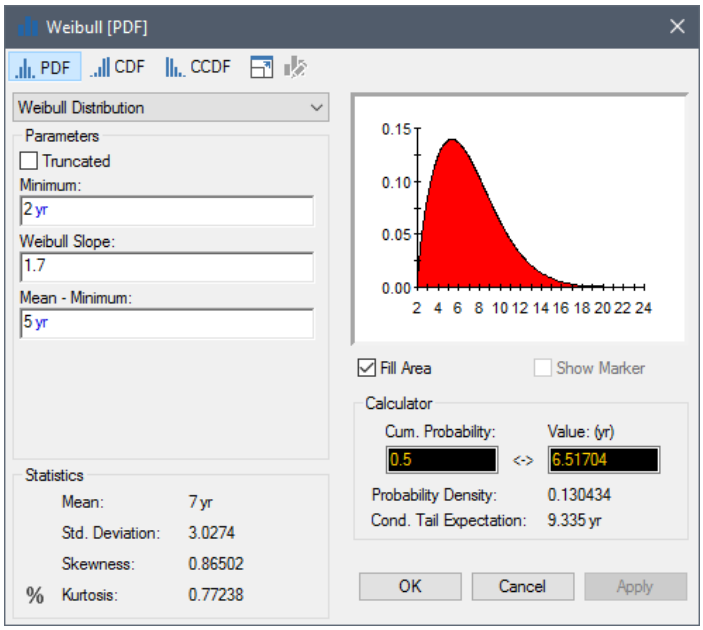
The Uniform distribution is useful for defining quantities that vary uniformly between two values. You enter a **Minimum** and a **Maximum**:



You can also specify that rather than the values being uniformly distributed, the logarithms of the values are uniformly distributed (by checking the **Log** box). In this case, the **Minimum** and **Maximum** must be positive values. Log-Uniform distributions are often applied to quantities with large (order-of-magnitude) uncertainties.

Weibull Distribution

The Weibull distribution is often used to represent the distribution of failure times in reliability models (e.g., the distribution of lifetimes for light bulbs). It is defined by a **Minimum**, a **Slope**, and **Mean-Minimum**. If desired, it can be **Truncated** at its upper end by defining a **Maximum**:



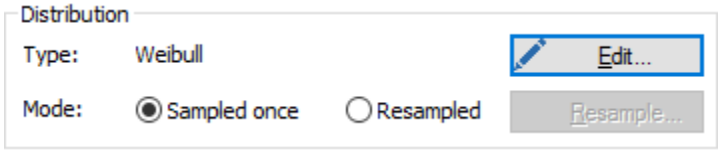
Note: The Slope of the Weibull is always dimensionless. If it is specified as 1, the distribution collapses to an exponential distribution.

Controlling When a Stochastic Element is Sampled

By default, Stochastic elements are sampled once per realization (typically at the beginning). Hence, if you specify the parameters describing a Stochastic as a function of time, unlike other GoldSim elements, Stochastic elements are not updated (resampled) if the parameters change.

GoldSim does provide a mechanism, however, to force a Stochastic to either 1) be sampled at a specified time; or 2) be resampled multiple times during a simulation. In particular, you can define one or more *triggers* for the Stochastic which specify when (or under what circumstances) the Stochastic is resampled.

How a Stochastic is resampled is controlled by the **Mode** specified on the dialog:



The default is for the Stochastic to be **Sampled once**. However, if **Resampled** is selected, the **Resample…** button in the dialog becomes available, and this allows you to force the Stochastic to be resampled (triggered) at other points in the simulation.

Read more: Triggering a Stochastic (page 421).

Note: You cannot specify triggers to resample a Stochastic if it is correlated to a second Stochastic (see below). However, if a Stochastic is correlated to a second Stochastic, and that second Stochastic is resampled, the correlated Stochastic will also automatically be resampled (even though no resampling triggers are specifically defined, and the Mode is set to **Sampled once**).

Conditional Containers can also be used to control when Stochastic elements are resampled.

Read more: Using Conditional Containers (page 968).

An example file which illustrates how a Stochastic is sampled (BasicStochastic.gsm) is in the General Examples/Stochastic folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Correlating Stochastic Elements

Frequently, parameters describing a system will be correlated (inter-dependent) to some extent. For example, if one were to plot frequency distributions of the height and the weight of the people in an office, there would likely be some degree of positive correlation between the two: taller people would generally also be heavier (although this correlation would not be perfect).

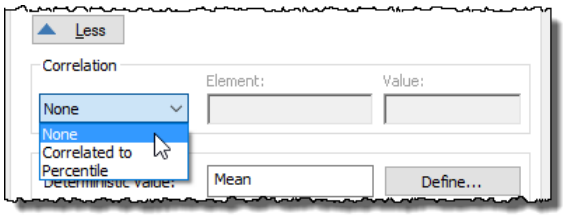
The degree of correlation can be measured using a correlation coefficient, which varies between 1 and -1. A correlation coefficient of 1 or -1 indicates perfect positive or negative correlation, respectively.

A positive correlation indicates that the parameters increase or decrease together. A negative correlation indicates that increasing one parameter decreases the other. A correlation coefficient of 0 indicates no correlation (the parameters are independent of each other).

The preferred method to represent a correlation is to explicitly model the cause of a dependency. For example, the height and weight of children are correlated primarily due to a common dependency on age (both increase with age). In such a situation, the best way to represent this correlation would be to explicitly define the mean and standard deviation of the height and the weight as functions of the primary parameter causing the dependency (age).

In many cases, however, specifying such a dependency may be difficult. Therefore, GoldSim provides a mechanism to specify a statistical correlation.

To do so, you must use the Correlation section of the Stochastic dialog (accessed via the **More** button). You will note that in that section, GoldSim provides three options for correlation:



None. This is the default. The Stochastic is not correlated.

Correlated to: This allows you to correlate one Stochastic to another Stochastic. You must specify the Element (it must be a Stochastic element), and the Value (the correlation factor). The Value represents a *rank correlation coefficient*. It must be a value between –1 and 1, inclusive (1 being a perfect positive correlation, and –1 being a perfect negative correlation). It can be entered as a number, a link or an expression.

The algorithm used to implement the correlations is described in Appendix B.

Note: If a Stochastic is correlated to a second Stochastic, and that second Stochastic is resampled, the correlated Stochastic will also automatically be resampled.

Read more: Controlling When a Stochastic Element is Sampled (page 183).

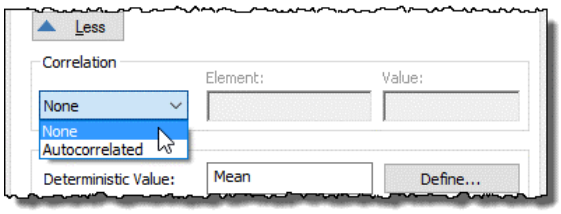
Percentile. This allows you to specify a percentile of the distribution. For example, specifying 0.95 would return the 95% percentile. Among other applications, by using this with multiple elements, you could force a particular correlation scheme. An important point should be noted: when the Correlation is specified in this way, the Stochastic is automatically resampled whenever the specified Percentile *or any other input parameter for the distribution* is changed.

GoldSim also allows you to ***autocorrelate*** a Stochastic element (i.e., correlate a Stochastic to its previously realized value). This is useful, for example, when you are sampling a Stochastic multiple times in a realization (e.g., once a month), and this month's value is correlated to last month's value.

In order to autocorrelate a Stochastic, you must first instruct GoldSim to resample the Stochastic (since autocorrelation only has meaning if a Stochastic is resampled).

Read more: Controlling When a Stochastic Element is Sampled (page 183).

After you do so, you will note that in the Correlation section of the Stochastic dialog, GoldSim provides two options for correlation:



None. This is the default. The Stochastic is not autocorrelated.

Autocorrelated. In this case, the Element is autocorrelated (correlated to its previous value). You must specify the Value (the correlation factor). The Value represents a *rank correlation coefficient*. It must be a value between –1 and 1, inclusive (1 being a perfect positive correlation, and –1 being a perfect negative correlation). It can be entered as a number, a link or an expression.

If you specify autocorrelation, GoldSim will correlate the next update (sample) of the Stochastic to the previous update of the Stochastic. Hence, if you trigger the Stochastic to be sampled every day, it will correlate today's value to yesterday's value.

When using autocorrelation, it is important to remember that the correlation factor (Value) should actually be a function of the resampling period. That is, if you resample every 1 minute, the Value should obviously be larger (closer to 1) than if you resample every day. Therefore, when you define a correlation factor for autocorrelation, you should define it with the resampling period in mind.

If you know the autocorrelation coefficient for one resampling period, you can compute it for a different sampling period using the following equation:

$$C2 = \exp[\ln(C1) * (DT2/DT1)]$$

where C1 is the coefficient for sampling period DT1, and C2 is the coefficient for sampling period DT2. Note that if you are resampling every timestep (OnChanged Etime), and need to compute an appropriate value for C2, DT2 should be specified as Timestep_Length (as it may change during the simulation).

The above discussion relates to correlating Stochastics that are defined as scalars. Stochastics can also be defined as vectors (arrays), and in that case, it is possible to specify a correlation matrix to define how the items of the vector are correlated. Stochastic vectors cannot be autocorrelated. They can be correlated to other vectors (in which chase the correlation is term-by-term) or to scalars.

Read more: Creating a Stochastic Vector (page 189).

An example file which illustrates correlation of Stochastics (Correlation.gsm) is in the General Examples/Stochastic folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

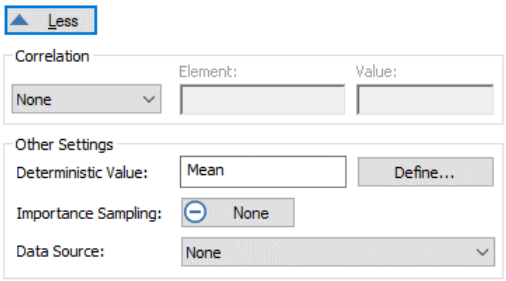
Specifying a Deterministic Value for a Stochastic

In some cases, you will want to run a deterministic simulation (i.e., a single realization which does not try to represent the uncertainty in inputs), even though the model contains some Stochastic elements. For these kinds of simulations, it is necessary to specify the value that a Stochastic element takes on during the simulation.

In order to run a deterministic simulation, you must open the Simulation Settings dialog, go to the **Monte Carlo** tab, and select the **Deterministic Simulation** radio button.

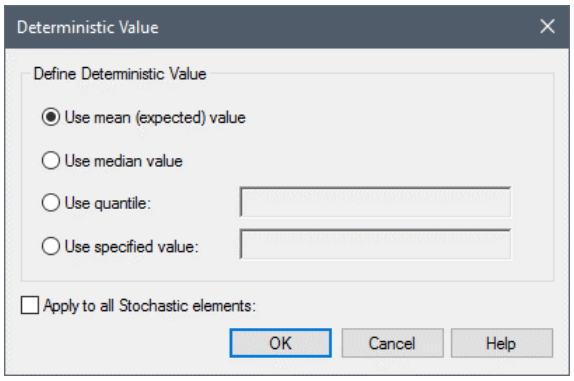
Read more: Deterministic Simulation Options (page 501).

For each Stochastic, you must then define the **Deterministic Value** to be used when a deterministic simulation is carried out:



*To access this portion of the dialog, you may need to press the **More** button on the Stochastic dialog.*

The default is for the mean (expected) value of the Stochastic to be used as the Deterministic Value. By pressing the **Define…** button, however, you can specify other values:



The other options are to use the median value, use a specified quantile (e.g., 0.95), or to use a specified value (e.g., 3.7 m).

If you select one of the first three options in the dialog, you can choose to apply the selection to all Stochastics in the model (by checking the **Apply to all Stochastic elements** box).

If you select the fourth option (a specified value), you must specify the units when you enter the value.

Within the Simulation Settings dialog, when running a deterministic simulation, you can choose to use these individually specified deterministic values, or override them all and use the mean or a specified quantile.

Note: When you define a specified value, GoldSim remembers it, so that if you switch to a mean value, a median value or a quantile, and then switch back to a specified value, GoldSim retains that value (and you do not have to enter it again).

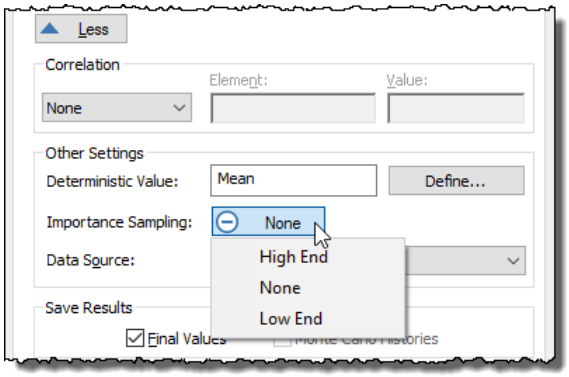
Note: A specified value can be outside the defined range of the distribution.

Applying Importance Sampling to a Stochastic Element

For risk analyses, it is frequently necessary to evaluate the low-probability, high-consequence end of the distribution of the performance of the system. Because the models for such systems are often complex (and hence need significant computer time to simulate), it can be difficult to use the conventional Monte Carlo approach to evaluate these low-probability, high-consequence outcomes, as this may require excessive numbers of realizations.

To facilitate these type of analyses, GoldSim allows you to utilize an ***importance sampling*** algorithm to modify the conventional Monte Carlo approach so that the tails of distributions (which could correspond to high-consequence, low-probability outcomes) are sampled with an enhanced frequency. During the analysis of the results that are generated, the biasing effects of the importance sampling are reversed. The result is high-resolution development of the high-consequence, low-probability "tails" of the consequences, without paying a high computational price.

Importance sampling is specified by selecting an option from the **Importance Sampling** button (the default is "None"):



If you select "High-End", GoldSim will preferentially bias toward the high end of the distribution; if you select "Low-End", it will preferentially bias toward the low end of the distribution.

It is important to understand that you should use importance sampling sparingly (i.e., only for those elements that really need it). This is because the degree of biasing for distribution tails that GoldSim can apply decreases with the number of elements for which importance sampling is applied.

The importance sampling algorithm is discussed in detail in Appendix B.

Note: Importance sampling cannot be applied if the Stochastic is resampled during a realization.

Read more: Controlling When a Stochastic Element is Sampled (page 183).

Note: In addition to the importance sampling method described here (in which you can choose to force importance sampling on either the low end or high end of a Stochastic element's range), GoldSim also provides an advanced feature that supports custom importance sampling that can be applied over user-defined regions of the Stochastic element's range.

Read more: Customized Importance Sampling Using User-Defined Realization Weights (page 1089).

Specialized Functions That Operate on Distributions

GoldSim provides several specialized functions that can be used to reference the Distribution output type and return properties of the distribution. The Distribution output is a complex output representing all the distribution information. It can be produced by a Stochastic element, a Spreadsheet element, or a SubModel.

These functions all require as the first argument a Distribution output. Some require an additional output:

PDF_Value(Distribution, P): The value of the distribution at the specified cumulative probability level P. The output has the same dimensions as the distribution being referenced.

PDF_CumProb(Distribution, V): The cumulative probability of the distribution at the specified value V. The output is dimensionless.

PDF_Mean(Distribution): The mean of the distribution. The output has the same dimensions as the distribution being referenced.

PDF_SD(Distribution): The standard deviation of the distribution. The output has the same dimensions as the distribution being referenced.

PDF_CTE(Distribution, P): The conditional tail expectation of cumulative probability P (i.e., the expected value of the output given that it lies above a specified cumulative probability P). This result represents the mean of the greatest 100(1 - P)% of outcomes. The output has the same dimensions as the distribution being referenced.

Note: Calculation of the Conditional Tail Expectation is discussed in detail in Appendix B.

PDF_Density(Distribution, V): The probability density or discrete probability of the distribution at the specified value V. If the distribution is continuous, the result is the probability density of the specified value. The dimensions are the inverse of the distribution itself. If the distribution is discrete, the result is the discrete probability of the specified value, in which case it is dimensionless.

Note: For Boolean distributions, the value argument V must be a condition. Note, however, that if a condition-type result is passed out through a SubModel interface, it must be either 1 or 0.

Note: In some cases, GoldSim cannot compute a direct solution for a statistic (e.g., computing the standard deviation for a truncated Weibull). In this case, the function returns an error.

Since these functions simply return the key properties of a probability distribution, in most cases, there would be no value in using these functions directly on Stochastic elements. However, there are two primary applications for these functions:

- When the definition of a Stochastic distribution is changing dynamically during a simulation (either by making the defining parameters functions of time, or via simulated Bayesian updating), these functions can be used to query the current shape and characteristics of the distribution.

Read more: Dynamically Revising Distributions Using Simulated Bayesian Updating (page 1092).

- When exporting a distribution result from a Monte Carlo SubModel, these functions can be used to query the current shape and characteristics of the distribution in the parent model.

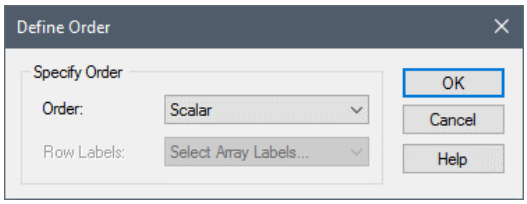
Read more: Creating the Output Interface to a SubModel (page 1059).

Creating a Stochastic Vector

GoldSim allows you to define a Stochastic element as a vector of data. If you define your element as a vector, rather than inputting a single probability distribution, you specify a set of distribution parameters (one for each item of the vector).

Read more: Using Vectors and Matrices (page 848).

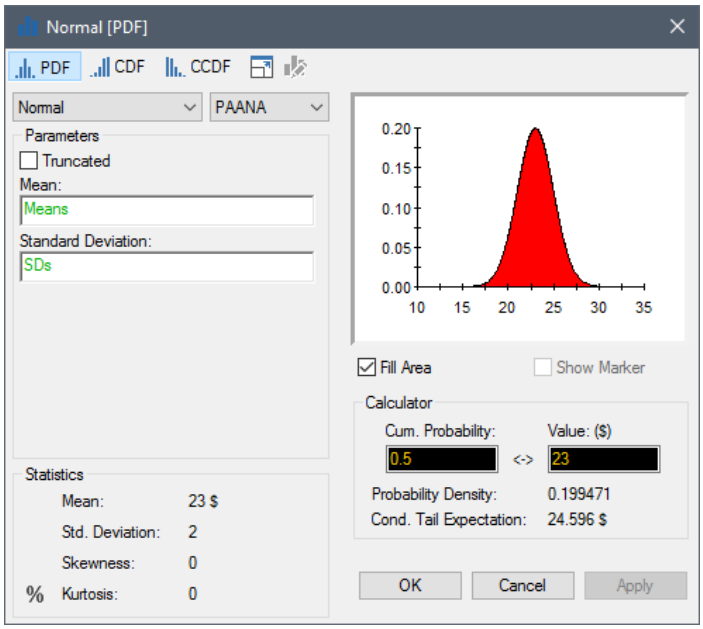
To define your element as a vector, press the **Type…** button on the dialog. The following dialog will appear:



From the **Order** drop-list select "Vector (1-D Array)". You will then need to specify a set of **Row Labels**.

Read more: Understanding Array Labels (page 849).

If you specify the Stochastic as a vector, the dialog for defining the distribution (accessed via the **Edit Distribution…** button) will look similar to this:



This dialog is identical to the standard dialog for a scalar Stochastic, with two exceptions:

- The input fields for the parameters for the distribution must be vectors. Hence, when you create a Stochastic vector, all of the items of the vector have the same distribution type, but may have different values for the input parameters for the distribution.
- You view the distribution and the statistics for a particular item of the vector by selecting the item from the drop-down list at the top of the dialog (immediately to the right of the distribution type).

Note: If the distribution type is Cumulative, Discrete or Sampled Results, you cannot enter vectors into the grids defining the distribution. That is, the grids only accept numbers. As a result, all items of the vector would be identical. If you want to create a vector of Stochastics that consists of Cumulative, Discrete or Sampled Results distributions, you can do so by creating a separate Stochastic for each item, and then using a Data element (defined as a vector) to reference each separate item.

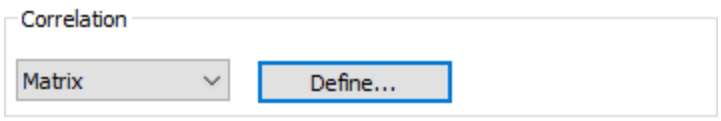
A Stochastic vector cannot be autocorrelated. It can, however, be correlated to another Stochastic. If the other Stochastic is a vector, the correlation is term-by-term. If the other Stochastic is a scalar, all terms are correlate to the scalar value.

You can also specify correlations *between members* of the vector via a correlation matrix. A correlation matrix specifies the correlations between variables, and generally has the following form:

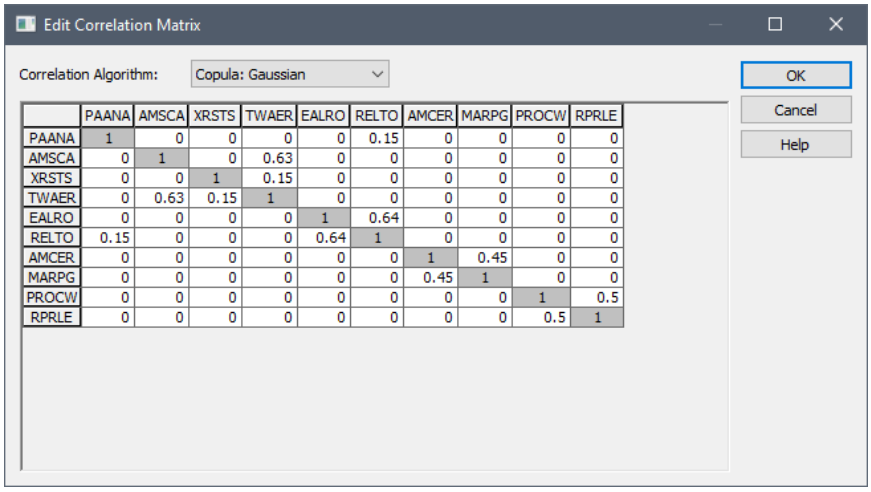
	Alpha	Beta	Gamma
Alpha	1	0.1	0.1
Beta	0.1	1	0.99
Gamma	0.1	0.99	1

Note that by definition, a correlation matrix is symmetric around its diagonal (since the cross diagonal terms define the same correlation coefficient).

If you specify that a Stochastic is a vector, then the drop-list in the Correlation section of the dialog provides an option called "Matrix". If this option is selected, a button is provided (**Define…**) to define the correlation matrix:



This button provides access to a dialog for specifying the correlation matrix:



	PAANA	AMSCA	XRSTS	TWAER	EALRO	RELTO	AMCER	MARPG	PROCW	RPRLE
PAANA	1	0	0	0	0	0.15	0	0	0	0
AMSCA	0	1	0	0.63	0	0	0	0	0	0
XRSTS	0	0	1	0.15	0	0	0	0	0	0
TWAER	0	0.63	0.15	1	0	0	0	0	0	0
EALRO	0	0	0	0	1	0.64	0	0	0	0
RELTO	0.15	0	0	0	0.64	1	0	0	0	0
AMCER	0	0	0	0	0	0	1	0.45	0	0
MARPG	0	0	0	0	0	0	0.45	1	0	0
PROCW	0	0	0	0	0	0	0	0	1	0.5
RPRLE	0	0	0	0	0	0	0	0	0.5	1

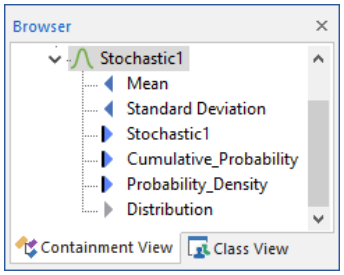
As pointed out above, by default, all off-diagonal correlation coefficients are zero. The matrix is symmetrical, so you need only define one of the cross-diagonal terms. The value represents a rank correlation coefficient, and must vary between -1 and 1. It must be a number (i.e., you cannot specify a link).

Note: When you define a correlation matrix, it is important to ensure that it is internally consistent. For example, if you specified that A was positively correlated to B, and B was positively correlated to C, but that A was negatively correlated to C, the correlation matrix would be inconsistent (since in this case, A should also be positively correlated to C). When this occurs, GoldSim will produce a fatal error message.

GoldSim provides several different algorithms for correlating the members of the vector. These are selected from the **Correlation Algorithm** drop-list at the top of the dialog. The various correlations algorithms are discussed in detail in Appendix B.

Browser View of a Stochastic Element

The browser view of a Stochastic element is shown below:



Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

All Stochastic elements have four outputs.

Note that the Distribution output has a different icon than the other outputs. This is because the Distribution output is a complex output that represents all the statistical information necessary to define a probability distribution. It can only be used in several specialized locations.

The number of inputs is a function of the distribution type. If the Stochastic is correlated, it has a **Correlated To** input, as well as a **Factor** input (the correlation factor).

Note: If you have specified a quantile or a specified value for the Deterministic Value, this also appears as an input in the browser. In addition, if the Stochastic is explicitly triggered, a number of additional inputs related to triggering also appear.

Using Time Series Elements

Time Series elements are a type of input element that provide a very flexible and powerful way to input external time histories of data into GoldSim (i.e., a table showing how a variable changes as a function of time).

You can use a Time Series element to input the predefined histories of things like interest rates, commodity prices, temperature, rainfall rates, sales rates, cash flows, or the condition (reliability, strength) of a machine or a material. A Time Series element represents an exogenous (external) "driver" that can directly or indirectly influence the dynamic behavior of the system being modeled.

Note: Time Series elements are for time series that are known in advance of the simulation. If you want to generate random (stochastic) histories *during* your simulation, you should use a History Generator element instead.

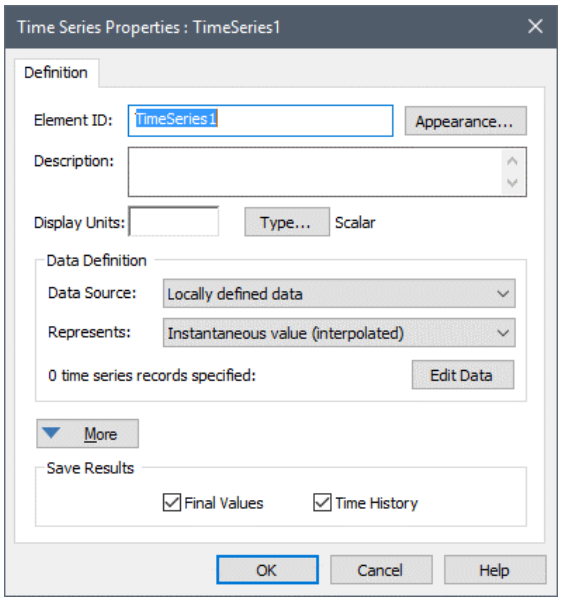
Read more: Generating Stochastic Time Histories (page 893).

To define a Time Series element, you input a set of time series records (i.e., a table of times and values) and specify what the data represent (e.g., instantaneously measured values at specified times). Note that the time values in the input time series do not have to coincide with the model's timesteps.

You then specify what the output of the element should be (e.g., the average value of the variable over each timestep). GoldSim then carries out the appropriate calculations in order to convert the input data into the specified output.

For example, if the input data is specified as a series of instantaneous values, GoldSim interpolates between the time series records to produce the output time series.

The dialog for a Time Series element looks like this:



Note: A number of advanced options are initially hidden by the **More** button.

There are five steps involved in defining a Time Series element:

1. Define the type (scalar, vector, or matrix; value or discrete change) and units for the time series;
2. Specify the source for the input data (e.g., defined directly, imported from spreadsheet);
3. Specify what the time series input represents (e.g., instantaneous values at specific times, constant values over specified intervals);
4. Define the time series itself (if specified directly) or the location of the data source (if imported); and
5. Specify the output types to be computed for the element (e.g., instantaneous values at each timestep, average values over a timestep).

Each of these steps, as well as some example files and advanced options, are described below.

Note: In addition to inputting pre-defined histories, one of the advanced options for a Time Series element is to use it to record (and subsequently play back) a history computed by another GoldSim element.

Read more: Using a Time Series Element to Record and Play Back a History (page 226).

Several files are provided within the TimeSeries subfolder of the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) that include examples on the use of Time Series elements.

Defining the Data Type and Units for a Time Series

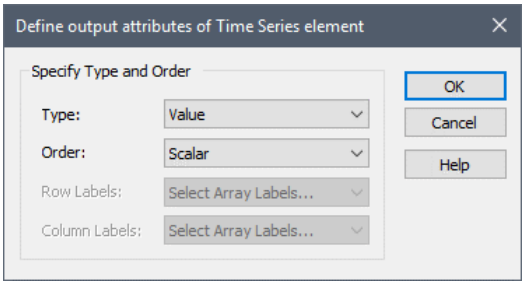
The first step involved in defining a Time Series element is to define the data type and units for the time series.

Units are specified in the **Display Units** field. This defines the dimensions of the input and primary output. By default, a Time Series is dimensionless.

Like all GoldSim elements, the data type is specified by pressing the **Type…** button.

In most applications, your time series will represent a set of scalar values (one value at each specified time point). Because this is the default, in most situations, there is no need to edit the **Type**.

If you do press the **Type…** button, the following dialog is displayed:



The **Type** can be defined as a Value (the default) or a series of Discrete Change Signals.

Read more: Generating Discrete Changes Using Time Series Elements (page 430).

The **Order** can be defined as a Scalar (the default), a vector or a matrix. Defining time series of vectors or matrices (i.e., in which each time point is defined in terms of an array of data, rather than just a single datum) is useful in some situations (e.g., defining a time series for the concentrations of a set of chemicals, or the prices for a set of securities).

Read more: Specifying Time Series Data as Vectors or Matrices (page 205).

After the data type and units are defined, the next step is to define the source of the input data for the Time Series.

Specifying the Source of the Input Data for a Time Series

Time Series elements can be defined in four ways. The two most common ways to define a Time Series are as follows:

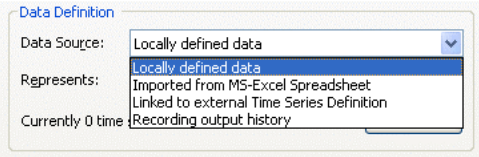
- You can define the series locally by entering the data directly; or
- You can import the data by linking to a spreadsheet.

In addition, GoldSim provides two advanced options for defining Time Series elements:

- You can read the output of any other element in GoldSim, and "record" the results, and then "play them back" in a subsequent run of the model. Among other applications, this allows you to use the results from one model as input to another model.
- You can link to a "time series definition" that was output by another Time Series element within an embedded SubModel or from an external function (a DLL). The primary application of this advanced option is to transfer time series between SubModels.

  Read more: Using SubModels to Embed Models Within Models (page 1047).

The way that the input data are defined is specified in the **Data Source** drop-list:



Locally defined data. This is the default. You enter the data directly into a table using the **Edit Data** button.

Read more: Viewing and Editing Time Series Inputs (page 196).

Imported from MS-Excel Spreadsheet. You import the data from an Excel spreadsheet. When you select this option, a new tab appears (**Excel**) from which you can specify the spreadsheet filename and other required information. You can import the data immediately, or wait until the simulation begins (the data will always be automatically imported when you start a simulation). The **View Data** button allows you to view the imported data (it cannot be edited unless you switch back to "Locally defined data").

Read more: Importing Data into a Time Series from a Spreadsheet (page 199).

Linked to external Time Series Definition. In this advanced option, you read a "time series definition" that was output by another Time Series element (within a separate SubModel) or from an external element. When you select this option, a new tab appears (**Linked**) from which you specify the link from the other element.

Read more: Referencing a Time Series Definition Output (page 230).

Recording output history. In this advanced option, you can select an output of any other element in GoldSim, and "record" the results (in order to "play them back" in a subsequent run of the model). When you select this option, a new tab appears (**Recording**) from which you specify the link from the other element, as well as several additional options regarding how the output is recorded.

Read more: Using a Time Series Element to Record and Play Back a History (page 226).

After specifying the source of the input data for the Time Series, the next step is to specify what the input to the Time Series represents.

Specifying What the Input to a Time Series Represents

The input to a Time Series element is always a set of time series records (i.e., a table consisting of time/value pairs). However, since a time series can represent several different kinds of data (e.g., values, rates), the first (and most important) step in defining a Time Series element (prior to actually defining the records) is to specify what these records represent. GoldSim provides several different ways for you to define the inputs to Time Series elements.

In particular, you can specify the input to a Time Series as representing one of six kinds of data:

- The **instantaneous value** of a variable at specified times: Examples include the price of a commodity (e.g., gold), the price of an asset (e.g., a stock), or the height of a projectile.

  Read more: Example: Time Series Inputs Represent Instantaneous Values (page 210).

- The **constant value** of a variable **over the next time interval** or the **constant value** of a variable **over the previous time interval.** In some cases, a value is assumed to be constant over a specified interval (i.e., follow a "stair-step" function from interval to interval). In some instances, this may reflect the fact that the variable actually is held constant over each interval. More commonly, it may be an artifact of how the data was recorded (e.g., it may have only been recorded in terms of an average value over the interval). GoldSim provides two options for entering this kind of data (one is forward-looking, and one is backward-looking).

  Read more: Example: Time Series Inputs Represent Constant Values Over Specified Intervals (page 211).

- The (uniform) **change** (increment) in a variable **over the next time interval** or the (uniform) **change** (increment) in a variable **over the previous time interval**: These options are usually used to output cumulative values (e.g., cumulative sales, cumulative rainfall) and/or rates (e.g., sales rates, rainfall rates) that are specified by defining incremental changes in a variable (e.g., monthly sales, monthly rainfall) over specified intervals. *When this option is selected, the Primary Output of the Time Series is not the specified time series itself; rather, it is the cumulative value of the variable at each point in the simulation* (assuming that the specified changes occur uniformly over each interval).

  Good examples of this type of time series data are rainfall and sales rates. In these cases, what is actually measured and recorded are totals (e.g., rainfall in mm or sales in $) over a particular interval (e.g., 31 days). Based on this data, you could then use GoldSim to compute the cumulative rainfall and sales (over the entire simulation), as well as the average daily rainfall or sales *rate* for each interval (e.g., month). GoldSim assumes that the variable (e.g., cumulative rainfall or sales) changes uniformly over the time period, which means that the rate of change is constant over the interval (i.e., it "stair-steps"). GoldSim provides two options for entering this kind of data (one is forward-looking, and one is backward-looking).

  Read more: Example: Time Series Inputs Represent Changes Over Specified Intervals (page 214).

- **Discrete changes** to a variable at specified times. In some cases, your time series may not represent the current value of a variable, but a series of discrete changes (additions and subtractions) to a variable. An example of this kind of time series deposits and withdrawals from an account that happen discretely. Note that this option is only available if the Data Type has been defined as a Discrete Change Signal with an Add instruction.

  Read more: Example: Time Series Inputs Represent Discrete Changes (page 216); Defining the Data Type and Units for a Time Series (page 194).

Prior to defining the time series records, you must select one of these four options from the drop-list labeled **Represents**.

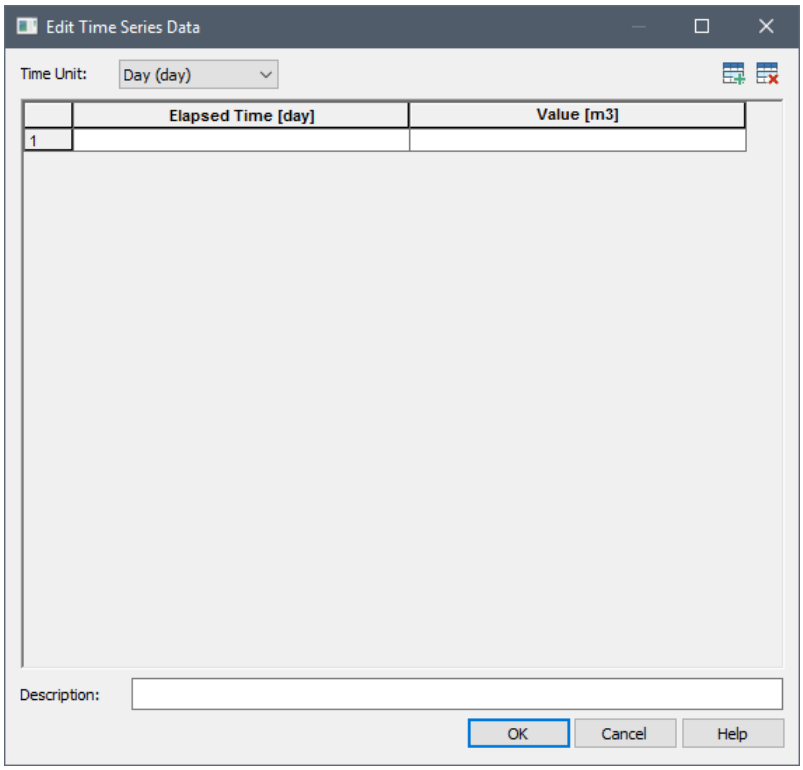
After specifying what the input to the Time Series represents, the next step is to define the actual Time Series input data.

Viewing and Editing Time Series Inputs

The data for your time series are viewed and edited by pressing the **Edit Data…** (or, in some cases, the **View Data…** button) in the main Time Series dialog.

Note: Time series data can only be edited if the **Data Source** is defined as "Locally defined data". If any other Data Source is specified, the data can only be viewed (and cannot be directly edited) in this dialog.

When you press the **Edit Data…** (or **View Data…**) button, the following dialog is displayed:



You can enter an optional **Description** at the bottom of the dialog to help document the time series data.

***Add Row** button*

If you are defining the data locally, you can add rows to the table using the **Add Row** button. If you hold down the **Ctrl** key when you press this button, you will be prompted for the number of rows to add (otherwise, a single row will be added).

You can also add rows by pasting in a block of data from the Windows clipboard.

***Remove Row** button*

To delete one or more rows, select them and press the **Remove Row** button. If you hold down the **Shft** key when you press this button, all of the rows from the selected row to the bottom will be deleted).

All shortcut keys for editing the time series table are summarized below:

Shortcut Key	Action
Ctrl+A	Selects all rows
Arrow keys	Move active cell up, down, left or right
Ctrl+Left arrow	Move active cell to first column
Ctrl+Right arrow	Move active cell to last column

Ctrl+Up arrow	Move active cell to first row
Ctrl+Down arrow	Move active cell to last row
Ctrl+	Insert N new rows below active cell
Shift+	Delete all rows from active cell (or first selected row) to bottom
Ctrl+Tab or Ctrl+	Insert new row *below* active cell
Shift+Ctrl+Tab	Insert new row *above* active cell
Ctrl+Backspace or Ctrl+	Delete row containing active cell or all currently selected rows

Note: When you press **OK** to close the dialog, GoldSim deletes all blank rows (rows in which the time value and data value are not defined).

Note: You can select one of the columns by clicking on the columns header. You can select both columns by clicking on the first column header and dragging to the second. You can select the entire table (including headers and row numbers) by clicking in the upper right-hand corner of the table.

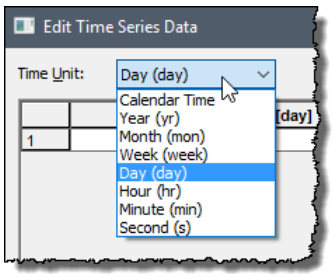
The fields in the table only accept numbers (they do not accept links). Moreover, you should not append units to the numbers.

The time entries can be entered either as numbers or as dates. If your Simulation Settings are set to Elapsed Time when you insert the element, they default to being entered as numbers; if your Simulation Settings are set to Date-Time when you insert the element, they default to being entered as dates. However, you can override the default setting by changing the selection in the **Time Unit** field.

Read more: Entering Time Series Data as Dates or Elapsed Times (page 203).

If time entries are entered as numbers, the assumed units for the time column are defined in the **Time unit** field. (This field defaults to the Time Display Units specified in the **Time** tab of Simulation Settings dialog.)

You can enter time in seconds, minutes, hours, days, weeks, months or years:



Note: Because month and year do not represent a constant period of time (the length of these units changes depending on the month or the year), GoldSim assumes that each of these units is defined by their average value. In particular, one year is assumed to consist of 365.25 days, and one month is assumed to consist of 30.4375 days (365.25/12).

If you select "Calendar Time" from the **Specify time unit** field, time entries are entered as dates. The date format that is expected is determined by the Windows settings for your machine. A typical setting might be MM/DD/YYYY HH:MM:SS. (To change these settings, go to Control Panel and edit the Regional Options.)

The assumed units for the data are the **Display Units** specified on the main Time Series dialog. The assumed units are displayed in the column headers.

Note: The values of Time must increase monotonically as you move downward in the table. If they do not, GoldSim will automatically sort the rows into the correct order.

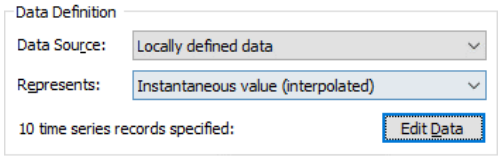
Two important rules must be followed when defining time series data:

- Unless your input data represent Discrete Changes, the *first* data point must be at or prior to the beginning of the simulation. That is, if you have specified time entries as elapsed times, the first data point must be 0. If you have specified time entries as dates, the first date must be at or prior to the start time for the simulation.
- Unless you are using the Time Shifting feature, if the data is specified to represent either "Instantaneous value" or "Change over the next time interval", the *last* data point must be at or beyond the end of the simulation. That is, if you have specified time entries as elapsed times, the last data point must be greater than the simulation duration. If you have specified time entries as dates, the last date must be at or after the end time for the simulation.

Read more: Time Shifting Time Series Data (page 219).

If either one of these requirements is not met, GoldSim will issue a fatal error when you try to run the model.

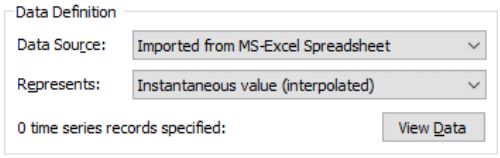
After you have defined the data and closed the dialog, the number of defined data points is indicated in the main Time Series dialog.



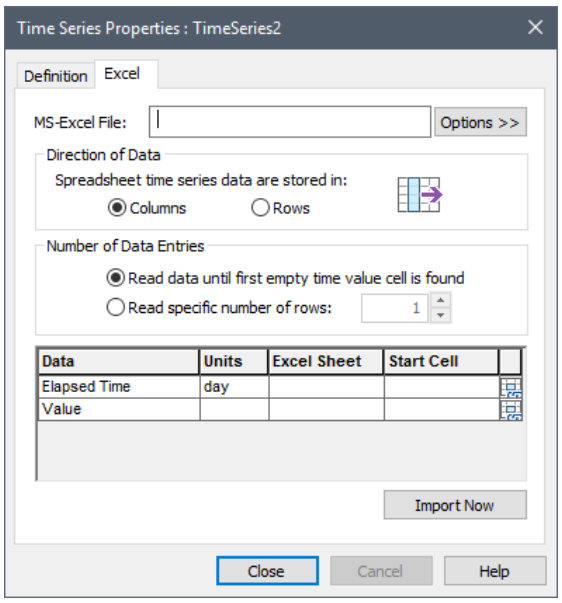
Importing Data into a Time Series from a Spreadsheet

You can link a Time Series element directly to a spreadsheet. This allows you to automatically import data from a spreadsheet at the beginning of each simulation.

You link a Time Series element to a spreadsheet by selecting “Imported from MS-Excel Spreadsheet” from the **Data Source** field in the Data Definition portion of the dialog:



When you do so, a new tab (**Excel**) is added to the dialog that allows you to define the properties of the spreadsheet link:



You must first enter the name of a Microsoft Excel spreadsheet file by pressing the **Options** >> button. This will provide options for either selecting an existing file, or creating (and then selecting) a new file.

Note: If you select a file in the same directory as (or a subdirectory below) your GoldSim .gsm file, GoldSim will subsequently display just a local path. If you select a file in a directory above your .gsm file, it will display the full path.

Once you have selected a file, you can subsequently use the **Options** >> button to select a different file. You can also use the **Options**>> button to open the selected file in Excel.

Note: GoldSim supports both .xlsx and .xls Excel files. However, if you have an older version of Excel (prior to Office 2007), you will need to install Microsoft's Office Compatibility Pack in order to read .xlsx files. Excel 2007 and later support an extended worksheet size (1,048,576 rows by 16,384 columns) than earlier versions (65,536 rows by 256 columns). If you wish to import data from an extended worksheet range into GoldSim, you must use Excel 2007 or newer, and the file format must be .xlsx. Note that GoldSim does not officially support versions of Excel prior to Excel 2003.

Warning: You should never try to open a spreadsheet that is linked to GoldSim while a simulation is running. In addition, prior to running a GoldSim model that is linked to a spreadsheet, all referenced spreadsheets should be closed. If you try to interact with a spreadsheet that is being used by GoldSim during a simulation, all interaction with the spreadsheet is blocked by GoldSim. However, under some circumstances this may not be possible and could lead to errors. Hence, as a general rule, you should not use Excel while a Goldsim model that references Excel is running.

Warning: Within Excel, a date is stored internally as the number of days (which can be fractional) since December 31, 1899 00:00:00. When GoldSim imports a date from Excel, it converts this Julian value to a date. Unfortunately, Excel mistakenly adds an extra day into its calendar that did not actually exist (February 29, 1900). As a result, the *effective* Julian date reference for all times after March 1, 1900 in Excel is actually December 30, 1899 00:00:00. Within GoldSim, the Run Property Time represents the elapsed time since the reference date December 30, 1899 00:00:00. Hence, for all dates after March 1, 1900, Excel and GoldSim have the same effective Julian date reference. However, for dates prior to March 1, 1900, GoldSim and Excel will differ by one day.

After selecting the spreadsheet file, you must specify the direction of the data in the spreadsheet. That is, the data can be organized into **Columns** or **Rows**. **Columns** implies that the data exists in the spreadsheet vertically: there is one column containing all of the time entries with a different time entry for each row, and another column containing all the value entries with a different value entry for each row. **Rows** implies that the data exists in the spreadsheet horizontally: there is one row containing all of the time entries with a different time entry for each column, and another row containing all the value entries with a different value entry for each column.

The time and value data do not need to be contiguous rows or columns in the spreadsheet. They must, however, either both exist as rows, or both exist as columns.

You must also specify when GoldSim should stop importing the data. There are two options:

Read data until first empty time value cell is found. Data is read until an empty or non-numeric time value cell is encountered.

Read specific number of rows or columns. A specific number of time value entries are read.

Edit Location button

You then specify the location of the data. You do this by specifying the **Excel Sheet** and the **Start Cell** (e.g., A2) for both the series of Elapsed Times and for the series of Values. You can do this directly by typing this information into the **Starting Cell** field. Alternatively, you can press the Edit Location button (located at the end of each row in the dialog), which opens the spreadsheet and provides a dialog allowing you to directly select the desired cell.

Note: GoldSim allows you to define a time series of vector (or matrix) data and import it from the spreadsheet. If you define your element as a vector (or matrix), rather than specifying an **Excel Sheet** and a **Start Cell** for a single data value at each time point, you specify these for multiple data values (one for each item of the vector or matrix).

Read more: Specifying Time Series Data as Vectors or Matrices (page 205).

Note: The time column must increase monotonically in the spreadsheet. If it does not, GoldSim will stop the import just prior to the first time data point that is not monotonically increasing.

The row or column of time entries that you import from the spreadsheet can exist either as numbers or as dates in the spreadsheet. If they are formatted as dates in the spreadsheet, they will always be imported as dates into the Time Series element. If they are formatted as numbers in the spreadsheet, they will always be imported as elapsed time values into the Time Series element. Once they are imported into the Time Series element, GoldSim provides a mechanism by which you can convert dates to elapsed times, and vice-versa.

Read more: Entering Time Series Data as Dates or Elapsed Times (page 203).

You must also specify the units in which the time and value entries are represented in the spreadsheet. Obviously, the time entries must have dimensions of time. The units for the value entries must have the same dimension as the **Display Units** specified in the Time Series dialog (and defaults to those units).

Read more: Setting the Basic Time Options (page 471).

GoldSim automatically imports data from the spreadsheet at the start of a simulation if either 1) any of the properties on the **Excel** tab have been modified; or 2) the Excel file itself has been changed since the last import. You can also import data manually at any time prior to running a simulation (e.g., so you can view it) by pressing the **Import Data** button in the Excel tab.

Note: If GoldSim cannot find the spreadsheet when you try to run the model but you have already imported the data previously, it will use the data that was imported previously and will log a warning message to the Run Log.

Warning: You should never try to open a spreadsheet that is linked to GoldSim while a simulation is running. In addition, prior to running a GoldSim model that is linked to a spreadsheet, all referenced spreadsheets should be closed.

If you want to ensure that you do not import data from a spreadsheet that has been inadvertently edited since you last imported the data, you can choose to "Lock onto" a spreadsheet file (by checking "Lock onto selected file" from the **Options>>** button). If you are locked onto a file, GoldSim will not allow the simulation to run if the file has been modified in any way (the file is set to read

only when it is locked onto). In order to run a simulation with a changed file, you must first remove the lock (by clearing "Lock onto selected file" from the **Options>>** button).

The example file (ImportTimeSeries.gsm) in the TimeSeries subfolder of the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) includes an example of how a Time Series can be imported from a spreadsheet.

Note: When you link a Time Series to a spreadsheet, the **Edit Data…** button changes to **View Data….** If you press this button to access the dialog displaying the time series data, you will note that they are no longer editable. Once you are linked to a spreadsheet in this way, you can not edit the data manually unless you change **Data Source** back to "Locally defined data". When you do so, GoldSim keeps the imported data and makes it editable.

Note: Spreadsheets *cannot* be used to import multiple time series. That is, if a Time Series is linked to a spreadsheet, it can only import a single series. Importing multiple time series from a spreadsheet into a Time Series element is not supported.

Read more: Defining Multiple Time Series in a Single Time Series Element (page 223).

Pasting Data into a Time Series

You can paste directly from a spreadsheet, Word table or from a comma delimited text file into the table of time series data. To paste data from the Windows clipboard into a table, simply click once in the cell representing the upper left-hand corner of the region of the table into which you wish to paste the data, and press **Ctrl+V**.

When you paste data into a time series table, GoldSim will overwrite any data existing in the target region, and if necessary, will automatically expand the size of the table (i.e., add rows) to accommodate all of the data being pasted.

Entering Time Series Data as Dates or Elapsed Times

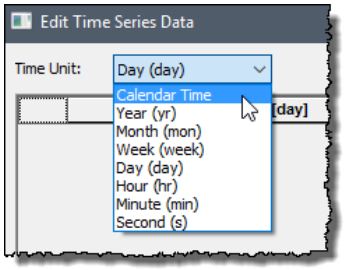
You can carry out dynamic simulations in one of two ways in GoldSim (this is controlled via the Simulation Settings dialog):

- **Elapsed Time**: In an Elapsed Time simulation (the default), you specify a Duration and the number of timesteps (and optionally, a Start date-time). The simulation is tracked in terms of elapsed time from the point the simulation began.
- **Date-time**: In a Date-time simulation, you enter a Start date-time and an End date-time, along with the number of timesteps, and the simulation is tracked in terms of the date-time.

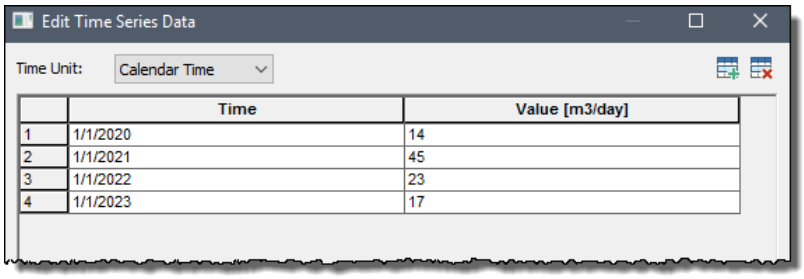
Read more: Setting the Basic Time Options (page 471).

Whether you are carrying out a Date-time simulation or an Elapsed Time simulation, you can choose whether your time series data is defined in terms of elapsed time or date-time. If your Simulation Settings are set to Elapsed Time when you insert the element, they default to being entered as numbers (with the default **Time Unit** being the Time Display Units specified in the **Time** tab of the Simulation Settings dialog); if your Simulation Settings are set to Date-Time when you insert the element, they default to being entered as dates.

However, you can override the default setting by changing the selection in the **Time Unit** field:



If you select "Calendar Time" from this list, the column expects a date-time to be entered:



Warning: If you are importing your time series from a spreadsheet, and the time series is formatted as dates in the spreadsheet, it will always be imported as dates into the Time Series element (even if **Specified time unit** is not set to "Calendar Time").

Read more: Importing Data into a Time Series from a Spreadsheet (page 199).

The date format that is expected is determined by the Windows settings for your machine. To change these settings, go to Control Panel and edit the Regional Options. In the example above, the date-time is specified as MM/DD/YYYY HH:MM:SS. You can use 12 hour formatting (and must then specify AM or PM) or use 24 hour formatting. Note that if you omit the hours, minutes, and seconds, GoldSim assumes 00:00:00 AM (the start of the day).

Note: Time Series elements accept dates between 1 January 100 and 31 December 9999.

Warning: Dates are entered in expressions in a different way than they are entered into a Time Series element. In particular, in an expression, dates must be surrounded by quotation marks. This requirement, however, does not apply when entering dates into Time Series elements.

Read more: Referencing Dates in Expressions (page 135).

After entering (or importing) time series in one format or the other, you can modify the format changing the selection for **Specify time unit**. If the data are

in Date-time, they will be converted to elapsed time relative to the specified Start-time in the Simulation Settings dialog. If the data are in elapsed time, they will be converted to Date-time by adding the elapsed time to the specified Start-time in the Simulation Settings dialog.

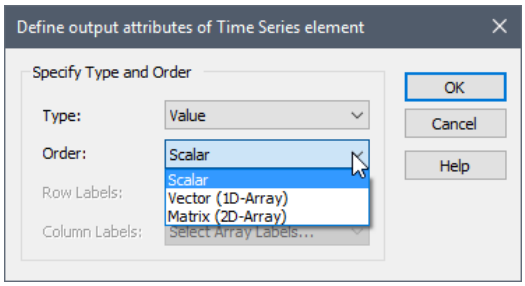
Note: Even when running an Elapsed Time simulation, the Start-time is available for editing in the Simulation Settings dialog.

Specifying Time Series Data as Vectors or Matrices

GoldSim allows you to define a time series of vector or matrix data. If you define your element as a vector or matrix, rather than inputting a single data value for each time point, you specify a set of data values (one for each item of the vector or matrix) at each time point.

Read more: Using Vectors and Matrices (page 848).

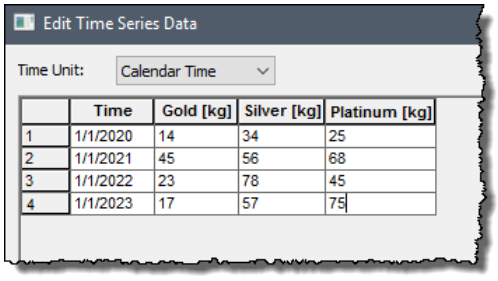
To define your element as a vector, press the **Type…** button on the dialog. The following dialog will appear:



From the **Order** drop-list select "Vector (1-D Array)". You will then need to specify a set of **Row Labels**.

Read more: Understanding Array Labels (page 849).

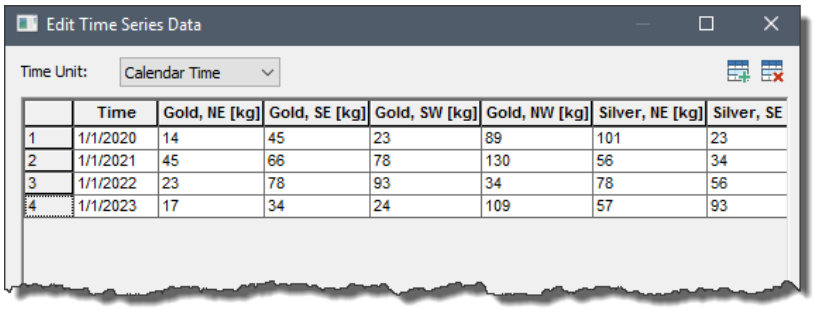
If you specify the time series as a vector, the dialog for defining the data records for your time series (accessed via the **Edit Data…** button) will look similar to this:



There is one data column for each item of the vector. In this example, the vector has three items (Gold, Silver, Platinum). Note that each data column is labeled with the vector's array labels.

To define your element as a matrix, select "Matrix (2-D Array)" as the Order when defining the Type. You will then need to specify a set of **Row Labels** and a set of **Column Labels**.

If you specify the time series as a matrix, the dialog for defining the data records for your time series (accessed via the **Edit Data…** button) will look similar to this:



	Time	Gold, NE [kg]	Gold, SE [kg]	Gold, SW [kg]	Gold, NW [kg]	Silver, NE [kg]	Silver, SE
1	1/1/2020	14	45	23	89	101	23
2	1/1/2021	45	66	78	130	56	34
3	1/1/2022	23	78	93	34	78	56
4	1/1/2023	17	34	24	109	57	93

In this case, a scroll bar at the bottom of the dialog allows you to scroll to see all of the columns.

There is one data column for each item of the matrix. In this example, the matrix has three rows (Gold, Silver, Platinum) and 4 columns (NE, SE, SW, NW). Hence, there are 12 items (12 data columns). Note that each data column is labeled with the matrix's array labels (row, column).

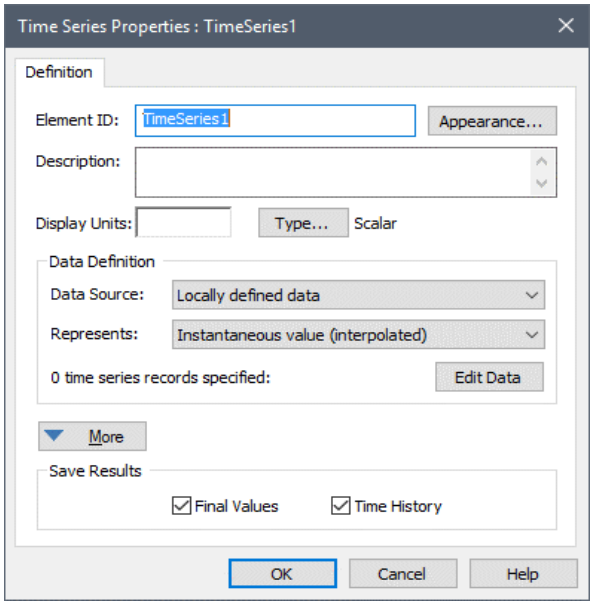
The example file (ArrayTimeSeries.gsm) in the TimeSeries subfolder of the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) includes an example of how a Time Series can be defined as a vector or a matrix.

Specifying Time Series Outputs

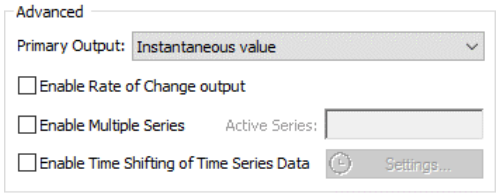
After you have defined the time series data (the input), it is necessary to define what outputs are to be produced by the element. That is, you must specify how GoldSim should manipulate the time series input data to produce one or more time series outputs that can subsequently be used in your model.

By default, GoldSim produces a single output, which (if the output is a value, as opposed to a discrete change) corresponds to the instantaneous value of the output at each point in time (i.e., at each model timestep), computed by simply interpolating between the specified data points. In many cases, this will meet your needs, and there is no reason to modify this.

However, in some cases, you may want to take advantage of some advanced features of the Time Series element when specifying Time Series outputs. To access these features, you must press the **More** button on the Time Series dialog:

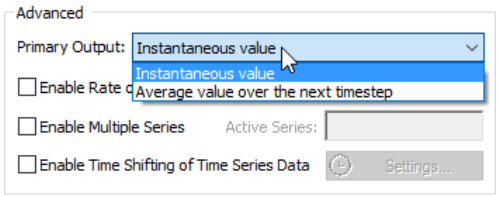


Pressing this button provides access to the following section of the dialog:



The first two options in this section pertain to options for specifying Time Series outputs.

Because the time series data can be specified at arbitrary time points (that are unrelated to the timesteps used in the GoldSim model), GoldSim allows you to specify exactly how the time series will be mapped to timesteps in GoldSim. GoldSim provides two options for the Primary Output:



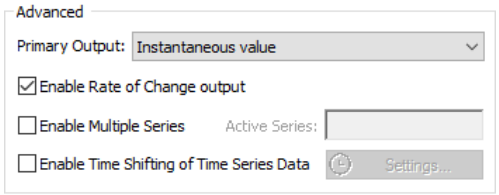
If **Instantaneous value** is selected (the default), GoldSim computes the instantaneous value of the output at each point in time (i.e., at each timestep).

If **Average value over the next timestep** is selected, GoldSim averages the output over the projected timestep length. This option should be selected when your time series represents flows or fluxes, as by doing so, you ensure that the flow or flux is properly conserved.

Note: If your input data represents Discrete Changes (i.e., the data Type has been defined as a Discrete Change Signal, rather than a Value), the only option available for the Primary Output is "Discrete Change". In this case, the element will generate Discrete Change Signals with an Add instruction at the specified time points (and independent of the scheduled timesteps).

Read more: Example: Time Series Inputs Represent Discrete Changes (page 216); Defining the Data Type and Units for a Time Series (page 194).

In addition to the primary output, you can also choose to produce a secondary output that represents the Rate of Change of the variable. This is done by checking the **Enable Rate of Change output** option:



If this box is checked, the element computes a secondary output (called Rate_of_Change). It represents the rate of change of the variable over the next projected timestep. The display units for this output are the display units for the

Time Series divided by the Time Display Unit defined in the Simulation Settings dialog.

The Rate_of_Change output is valuable when the data you have collected represents changes in the cumulative value of a variable (e.g., cumulative sales, cumulative rainfall) over specified intervals, and you are interested in computing average rates between the measurement points (e.g., sales rates, rainfall rates). In these cases, you enter changes in the cumulative value of a variable between the measurement points (e.g., every week or every month, or at irregular intervals), and specify that the data represents a "Change over the next time interval". You then specify that you want to "Enable the Rate of Change output". The Rate_of_Change output then represents the average rate (e.g., rainfall or sales rate) for each interval (e.g., month).

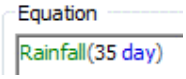
Note: Because GoldSim computes the **Average Value over the next timestep** primary output and the Rate_of_Change secondary output by assuming a timestep length, and under some circumstances the timestep length could subsequently be shortened (due to an event), the values that are computed could contain a slight error. In such a case, GoldSim tracks any error that is incurred, and corrects for it at the next timestep (in order to ensure conservation of the variable).

Note: If the input represents an Instantaneous value, and the last data point corresponds exactly with the end of the simulation, the Rate_of_Change output drops to zero at the last timestep (since GoldSim cannot compute a "forward looking" rate of change at that point).

Note: The Rate_of_Change output is not available if your input data represent Discrete Changes.

Referencing a Time Series Using a Function

In some situations, you might want to reference a value from a Time Series element at some point in the future or past (as opposed to at the current time in the simulation). To support this, Time Series elements can be referenced in the way that you would reference a built-in function (like sin or min). That is, once you define a Time Series, you can reference it in input expressions for other elements as if it were a function:



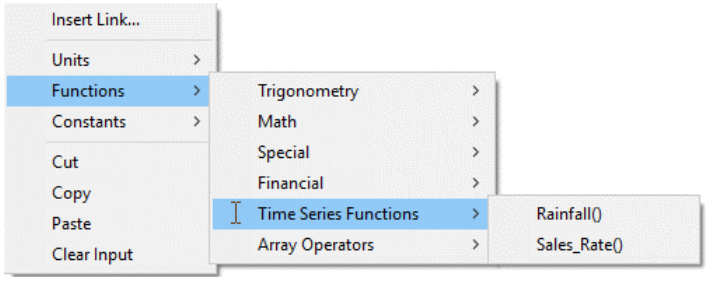
This expression instructs GoldSim to use the Time Series defined by the element named Rainfall and compute its value at time = 35 days. When specifying a date, you must enclose it in quotation marks. The format for referencing a date is determined by the Regional and Language time/date settings specified by the operating system.

Read more: Referencing Dates in Expressions (page 135).

Of course, once you have defined the table, you can reference it at multiple locations (i.e., in the input fields for various elements) using different input

arguments (different time values) in the same manner as you would use the built-in functions provided by GoldSim multiple times.

Note that when you create a Time Series, GoldSim automatically lists it as a function in the Function menu that is accessible from the context menu within an input field:



The dimensions of the Time Series function are determined by the Display Units specified when the Time Series element was defined. Note that if the Time Series itself is defined as an array, the output of the function is an equivalent array.

Time Series functions have two arguments (with the second one being optional). In most cases, you will call the function with only the first argument. The first argument is the time value. If you omit the second argument, the first argument is interpreted in the same manner in which the Time Series was defined. Hence, if the Time Series was defined based on Calendar Time, the first argument is assumed to be a date. If the Time Series was defined based on Elapsed time, the first argument is assumed to be an elapsed time.

By using the second argument, you can specifically override the default setting for how the first argument in interpreted. In particular, if

Second Argument = 1: The first argument is interpreted as a date.

Second Argument = 2: The first argument is interpreted as an elapsed time from the beginning of the simulation.

Warning: To utilize this function properly, it is important to understand how dates and elapsed times are represented in GoldSim. In particular, note that dates are represented internally in GoldSim as times. In particular, a date is stored as the amount of time since 30 December 1899. As a result, if you specify a first argument of 90 days, but indicate that this is a date (e.g., by specifying the second argument as 1), it will be interpreted as the calendar date 30 March 1900. Similarly, if you specify a first argument of "16 October 2011" and indicate that this is an elapsed time (e.g., by specifying the second argument as 2), it will be interpreted as the elapsed time of 40832 days (the number of days since 30 December 1899).

Read more: Referencing Dates in Expressions (page 135).

Note that if the first argument represents a time that precedes the earliest entry in the Time Series, the function returns the value associated with the first entry. Similarly, if the first argument represents a time that is later than the last entry in the Time Series, the function returns the value associated with the last entry.

Note: If your Time Series is defined as an array, you can use GoldSim's array functions to reference a single item from the array. For example, to reference the value at 4 days for the 3rd item of a Time Series vector named X, you would use the following expression: getitem(X(4 day), 3).

Read more: Array Functions (page 868).

Time Series Examples

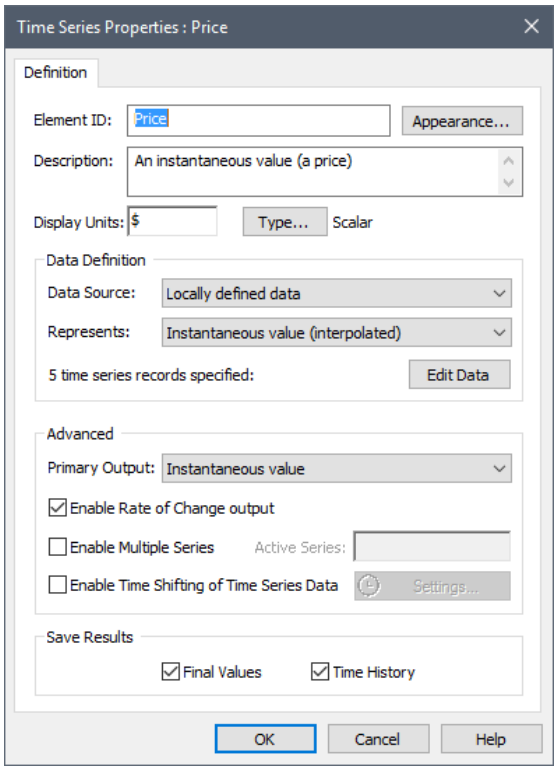
In order to gain a better appreciation for how to use Time Series elements, the manner in which the outputs are computed for each of the four kinds of input data is described in the sections below, along with an example for each kind of input. The specific examples mentioned here can be viewed in the file named BasicTimeSeries.gsm, which can be found in the TimeSeries subfolder of the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Example: Time Series Inputs Represent Instantaneous Values

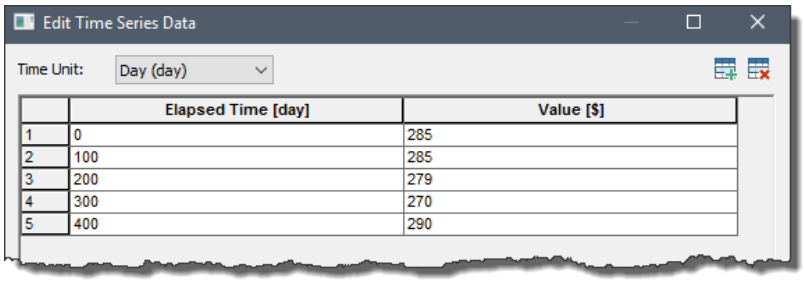
This example illustrates the use of a Time Series where the input data represent the instantaneous value of a variable at specified times. This is useful for simulating such things as the price of a commodity (e.g., gold), the price of an asset (e.g., a stock), or the height of a projectile.

The example can be viewed in the file named BasicTimeSeries.gsm, which can be found in the TimeSeries subfolder of the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

In this example, the input data represent the instantaneous price of a commodity (e.g., gold) at specified points in time:



The actual data set looks like this:

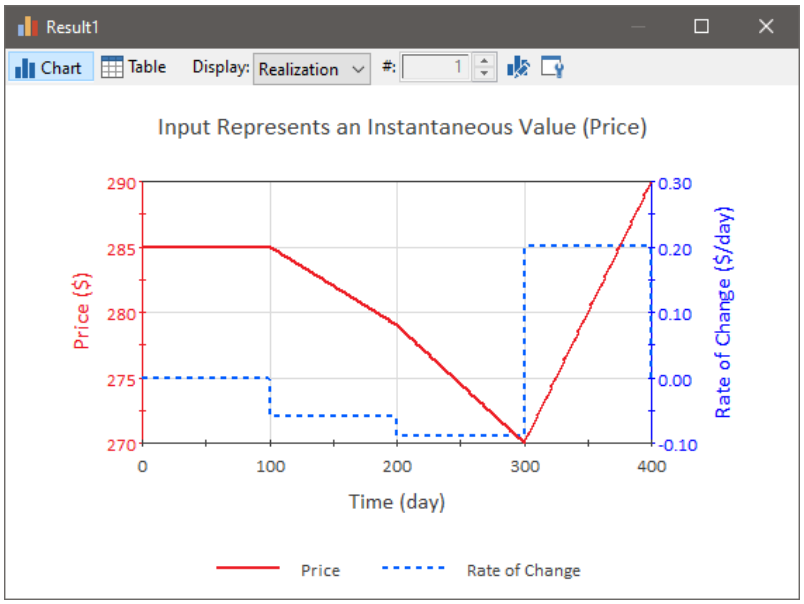


	Elapsed Time [day]	Value [$]
1	0	285
2	100	285
3	200	279
4	300	270
5	400	290

The Primary Output is computed by linearly interpolating between the specified points at every update (i.e., timestep).

For example, at Time = 250 days, the Value output would be $274.50 (halfway between 279 and 270). The Rate_of_Change output is computed by differentiating the specified values. Hence, between 200 and 300 days, the Rate is -$9/100 days = -0.09 $/day.

The Primary Output and Rate_of_Change outputs for this particular example are shown below:



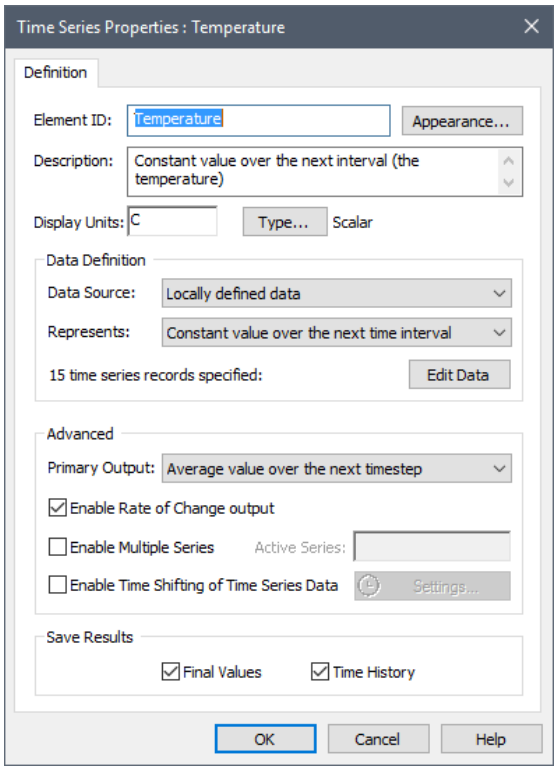
Note: If the data are specified to represent an "Instantaneous value", the *last* data point must be at or beyond the end of the simulation. That is, if you have specified time entries as elapsed times, the last data point must be greater than the simulation duration. If you have specified time entries as dates, the last date must be equal to or after the end time for the simulation.

Example: Time Series Inputs Represent Constant Values Over Specified Intervals

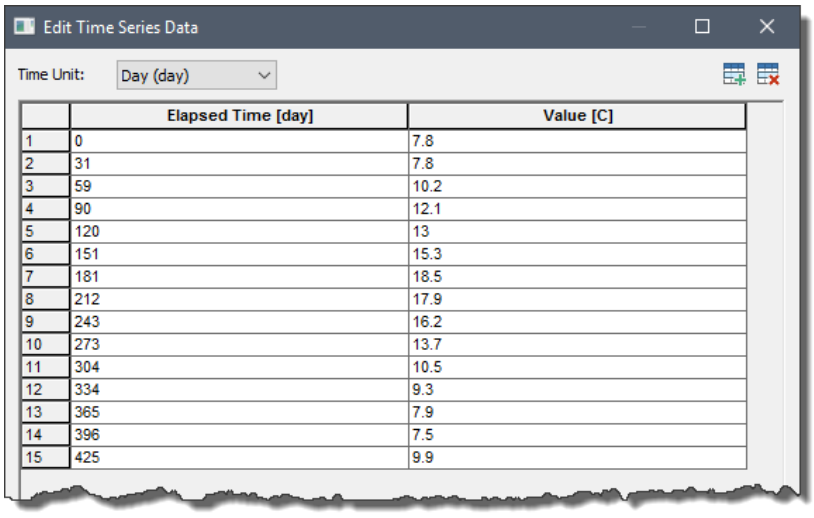
This example illustrates the use of a Time Series where the input data represent constant values over specified intervals. That is, the data "stair-steps" from interval to interval. In some instances, this may reflect the fact that the variable actually is held constant over each interval. In other cases, it may be an artifact of how the data was recorded (e.g., it may have only been recorded in terms of an average value over the interval).

The example can be viewed in the file named BasicTimeSeries.gsm, which can be found in the TimeSeries subfolder of the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

In this example, the input data represent the average temperature over specified time periods:



The actual data set looks like this:

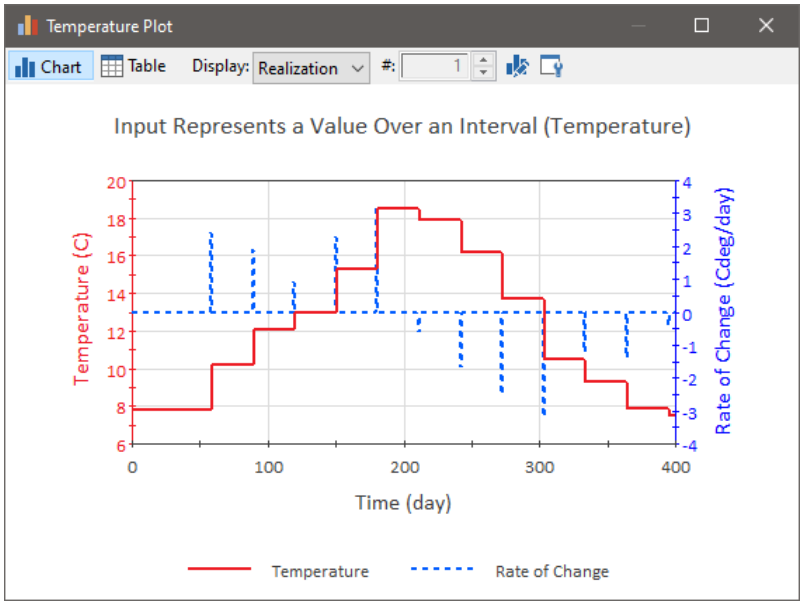


	Elapsed Time [day]	Value [C]
1	0	7.8
2	31	7.8
3	59	10.2
4	90	12.1
5	120	13
6	151	15.3
7	181	18.5
8	212	17.9
9	243	16.2
10	273	13.7
11	304	10.5
12	334	9.3
13	365	7.9
14	396	7.5
15	425	9.9

The Primary Output is computed by assuming that the specified values stay constant over the time intervals between data points. That is, GoldSim does not interpolate between the data points. Hence, in this example, between 59 and 90 days, the temperature is assumed to be constant at 10.2 C.

Note: There are two options for representing time series that represent constant values over specified intervals. You can specify that the data is constant over the *next* interval (as specified above), or you can specify that the data is constant over the *previous* interval. In the latter case, the data set shown above would imply that between 59 and 90 days, the temperature is assumed to be constant at 12.1 C. (In order for the two representations to provide the same results, you would need to shift the data column by one row.)

The Primary Output and the Rate_of_Change outputs for this particular example are shown below:



In this example, the Rate_of_Change output is also computed, although for this type of input data (constant values over intervals), this would typically not be done. The Rate_of_Change is computed by differentiating the Values. Because the value is assumed to remain constant between data points, and then jumps discontinuously, the Rate is zero between data points, and then "spikes" when the Value changes. Theoretically, the derivative at this point is infinite (the curve is a vertical line). GoldSim computes the derivative as the difference between values divided by the timestep length. As such, the Rate_of_Change is somewhat arbitrary. Note, however, that due to the way the Rate_of_Change is computed, if you were to integrate this, it would correctly reproduce the Primary Output.

Note: If the data is specified to represent a "Constant value over the next interval", the *first* data point must be at or before the beginning of the simulation. That is, if you have specified time entries as elapsed times, the first data point must be less than or equal to zero. If you have specified time entries as dates, the first date must be at or before the start time for the simulation. Similarly, if the data is specified to represent a "Constant value over the previous interval", the *last* data point must be at or beyond the end of the simulation. That is, if you have specified time entries as elapsed times, the last data point must be greater than the simulation duration. If you have specified time entries as dates, the last date must be at or after the end time for the simulation.

Example: Time Series Inputs Represent Changes Over Specified Intervals

This example illustrates the use of a Time Series where the input data represent changes over specified intervals. This option is usually used to output cumulative values (e.g., cumulative rainfall, cumulative sales) and/or rates (e.g., sales rates, rainfall rates) that are specified by defining incremental changes in a variable (e.g., monthly sales, monthly rainfall) over specified intervals.

The example can be viewed in the file named BasicTimeSeries.gsm, which can be found in the TimeSeries subfolder of the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

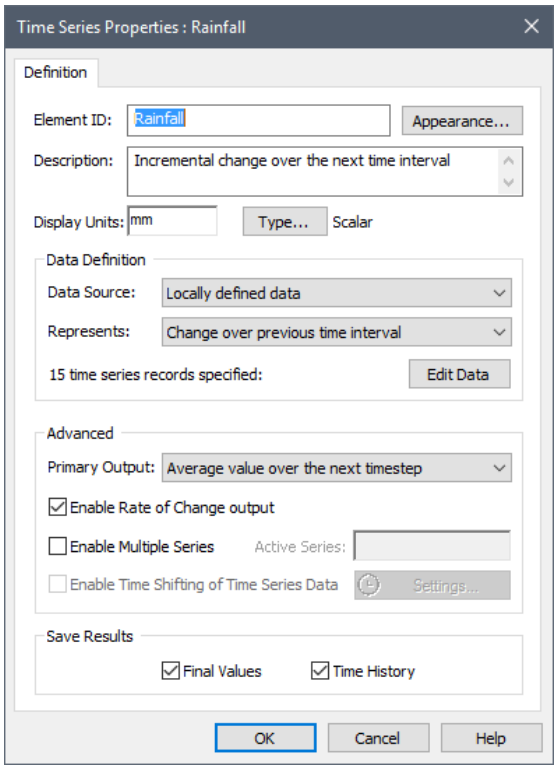
It is important to understand that when this option is selected, the Primary Output of the Time Series is not the specified time series itself. Rather, it is the *cumulative value* of the variable at each point in the simulation (assuming that the specified changes occur uniformly over each interval). This option therefore typically takes advantage of the Rate_of_Change output.

The Rate_of_Change output for a Time Series that is defined as a series of changes over specified intervals represents the rate of change of the cumulative value. For example, if the data was entered as monthly sales increments, the Rate_of_Change would represent the sales rate.

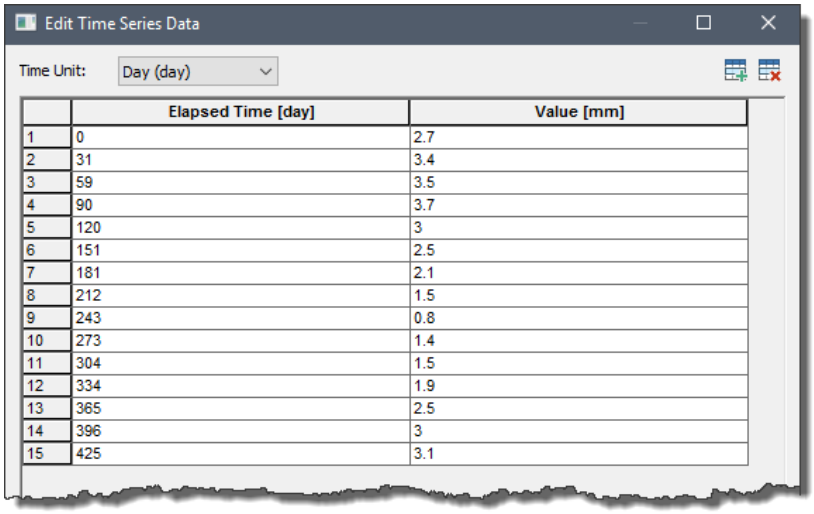
The rate is computed by dividing the incremental change in the variable over the interval by the interval length. GoldSim assumes that the variable (e.g., cumulative rainfall or sales) changes uniformly over the time period, which means that the rate of change is constant over the interval (i.e., it "stair-steps").

Note: This option is particularly useful for time series that are collected at variable time points (e.g., once per month, since the number of days in a month is not constant). GoldSim is able to readily turn such data into rates.

In this example, the input data represent the total rainfall over specified time periods:



The actual data set looks like this:

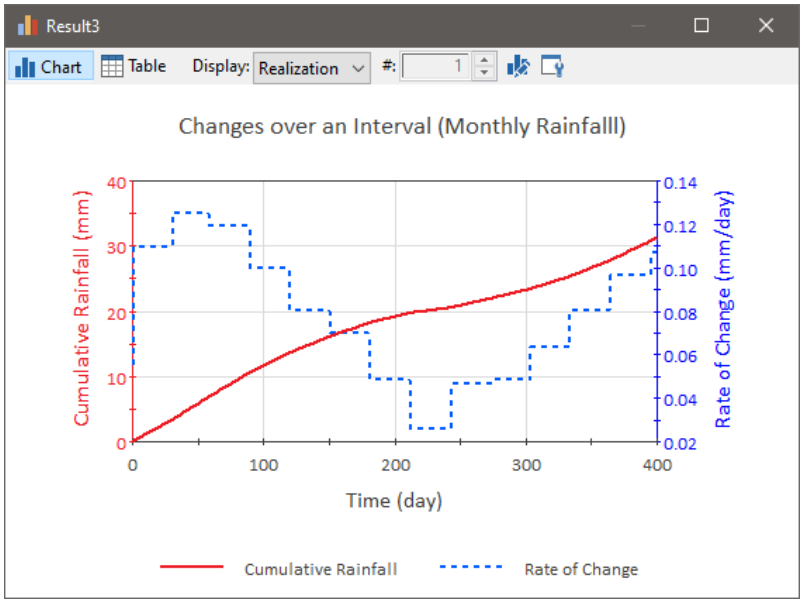


	Elapsed Time [day]	Value [mm]
1	0	2.7
2	31	3.4
3	59	3.5
4	90	3.7
5	120	3
6	151	2.5
7	181	2.1
8	212	1.5
9	243	0.8
10	273	1.4
11	304	1.5
12	334	1.9
13	365	2.5
14	396	3
15	425	3.1

In this example, between 59 and 90 days, the value is assumed to have changed by 3.5 mm.

Note: There are two options for representing time series that represent changes over specified intervals. You can specify that the data changes over the *next* interval (as specified above), or you can specify that the data changes over the *previous* interval. In the latter case, the data set shown above would imply that between 59 and 90 days, the value changed by 3.7 mm. (In order for the two representations to provide the same results, you would need to shift the data column by one row.)

The Primary Output and the Rate_of_Change outputs for this particular example are shown below:



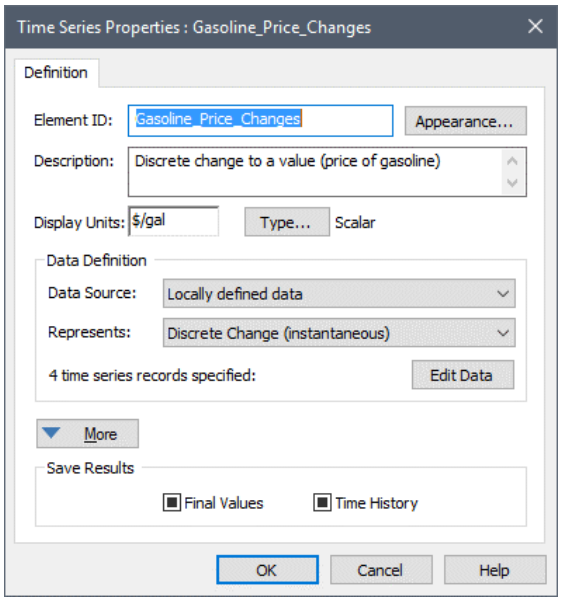
The Primary Output is computed by integrating the changes, assuming that the changes occur uniformly over each interval. Note that this implies that the rate of change is constant over the interval (i.e., it "stair-steps"). This is the appropriate way to represent variables that are measured on a monthly basis (e.g., sales, rainfall) and need to be converted into rates for use in your model (e.g., sales rate, rainfall rate).

Note: If the data is specified to represent a "Change over an interval" (either next or previous), then the *first* data point must be at or before the beginning of the simulation, and the *last* data point must be at or beyond the end of the simulation. That is, if you have specified time entries as elapsed times, the first data point must be less than or equal to zero, and the last data point must be greater than or equal to the simulation duration. If you have specified time entries as dates, the first date must be at or before the start time for the simulation, and the last date must be at or after the end time for the simulation.

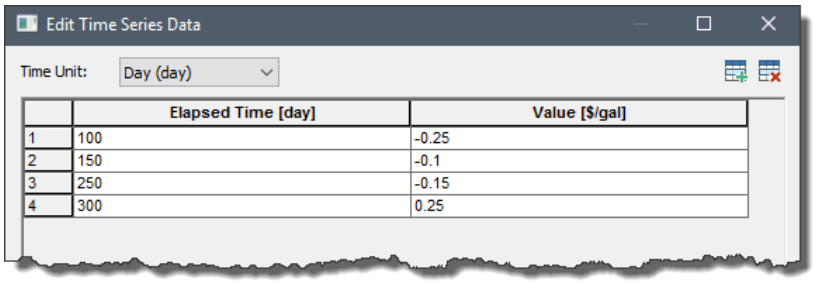
Example: Time Series Inputs Represent Discrete Changes

This example illustrates the use of a Time Series where the input data represent discrete changes at specified times. It can be viewed in the file named BasicTimeSeries.gsm, which can be found in the TimeSeries subfolder of the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

In this example, the input data represent discrete changes to a price (in this case, gasoline):



The actual data set looks like this:

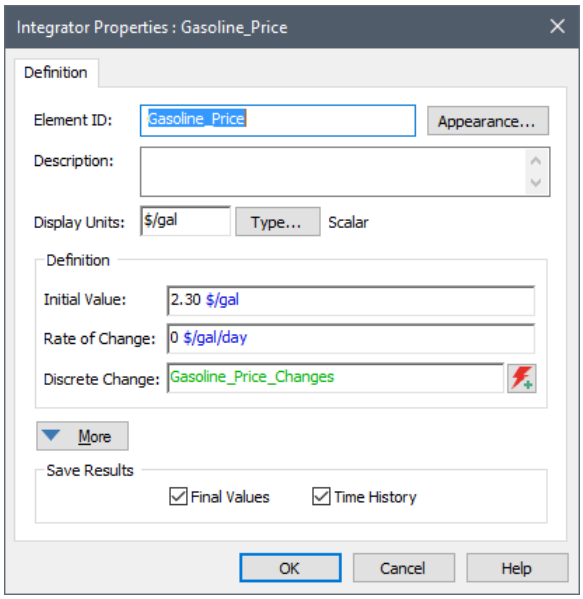


	Elapsed Time [day]	Value [$/gal]
1	100	-0.25
2	150	-0.1
3	250	-0.15
4	300	0.25

When the input data represent discrete changes to a variable at specified times, the Primary Output is a ***discrete change signal*** (with an Add Instruction). Only certain elements in GoldSim can accept discrete change signals as inputs.

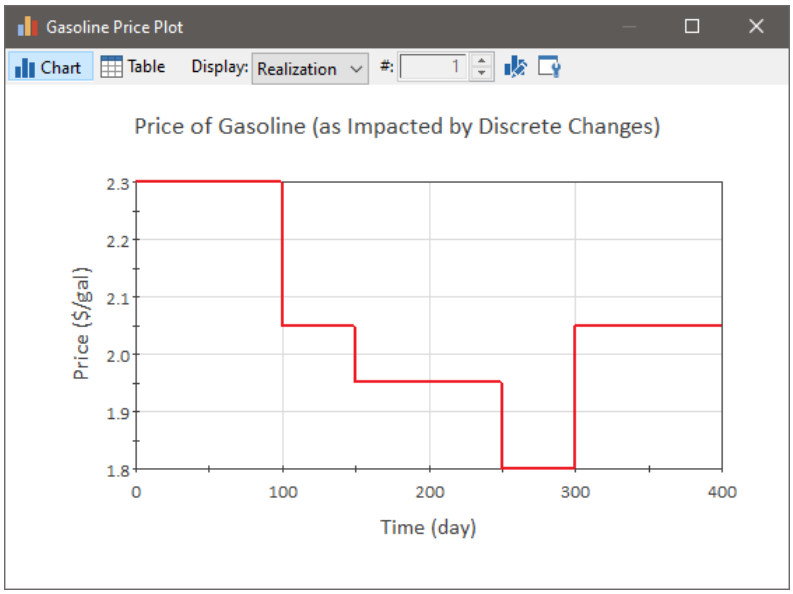
Read more: Propagating Discrete Signals Between Elements (page 367); Generating Discrete Changes Using Time Series Elements (page 430).

Discrete change signals are instantaneous quantities that cannot be directly plotted. They are used to instantaneously change the value of a quantity (represented by an Integrator, a Reservoir or a Pool element). In this example, an Integrator is used to represent the current gasoline price. It is modified by the output of the Time Series:



Read more: Integrator Elements (page 233).

The output of the Integrator looks like this:



Note: Unlike other kinds of Time Series, when the input data represent discrete changes, it is not necessary for the first data point to start prior to or at the start of the simulation.

Advanced Time Series Options

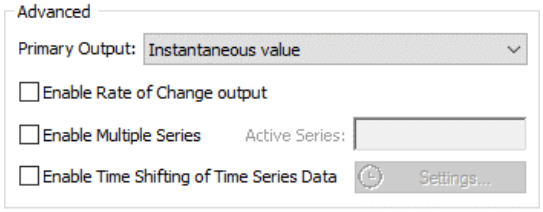
GoldSim provides five advanced options for defining and using Time Series elements:

- You can enter historic time series data and then instruct GoldSim to adjust the time/date column (time shift) in a specified way for each simulation (e.g., in order to start at a random point in the data series, or to shift the series forward so that historic dates are appropriately mapped onto the simulated dates).

- You can specify multiple sets of time series data within a single Time Series element, and then specify which series is to be used for any particular simulation. For example, this allows different time series data to be used for each separate realization in a Monte Carlo simulation.
- You can read the output of any other element in GoldSim, and "record" the results, and then "play them back" in a subsequent run of the model. Among other applications, this can be used to copy results from one model and use them as inputs for another.
- You can link to a "time series definition" that was output by another Time Series element within an embedded SubModel or from an external function (a DLL). The primary application of this advanced option is to transfer time history data between SubModels.

These features are discussed in detail in the sections below.

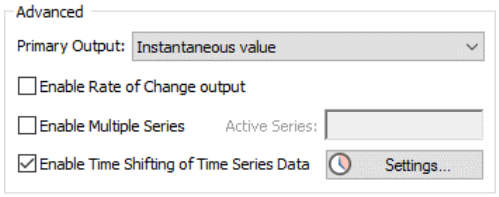
Many of these advanced features are accessed by pressing the **More** button on the Time Series dialog, which provides access to the "Advanced" section of the dialog:



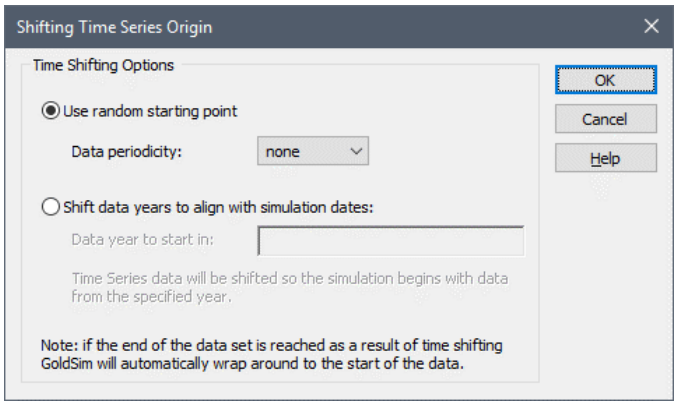
Time Shifting Time Series Data

In many cases, you will want to use historic data to populate a Time Series. Having done so, you then want to apply that historic data to your simulation (which likely looks forward in time). In order to do this, therefore, you need to time shift the data so that the historic data is applied in an appropriate and consistent manner.

To support this, GoldSim provides an option to time shift a data series in an appropriate manner. This feature is provided in the "Advanced" section of the Time Series dialog, accessed via the **More** button:



If you check **Enable Time Shifting of Time Series Data**, the **Settings…** button becomes available, providing access to this dialog (in fact, when you first check the Time Shifting box, this dialog opens automatically):



Note: Time shifting is not available if the input represents a "Change over the next time interval", a "Change over the previous time interval" or a "Discrete Change".

GoldSim provides two different ways that Time Series can be shifted.

The first option is to **Use random starting point**. This option randomly samples a starting point in the data set for each realization. This is useful, for example, if you have 50 years of rainfall data, you want to carry out a 1 year simulation, and you want GoldSim to randomly sample a different historic year for each realization.

The manner in which GoldSim randomly samples the starting point in a data set is controlled by two things:

- The **Data periodicity**, which is either "none", "annual", or "diurnal"; and
- Whether or not the time series data is specified in terms of Dates (Calendar Time) or Elapsed Time.

Read more: Entering Time Series Data as Dates or Elapsed Times (page 203).

The behavior is summarized below:

- If the **Data periodicity** is "none", for each realization GoldSim randomly picks a point from within the total span of the time series data, and assumes that this time point corresponds to an elapsed time of zero. Note that this means that if data is entered as Calendar Time, the date-time is not respected; GoldSim randomly selects a point in time (and corresponding data value) from the time series data set, and "shifts" this point in time so that in the simulation it becomes an elapsed time of zero (i.e., the Simulation Start Date).
- If the **Data periodicity** is "annual", GoldSim ensures that the random starting point for each realization is sampled such that all starting points are a multiple of 1 (average) year apart. In particular, random starting points for successive realizations are always multiples of 365.25 days apart (rounded to the nearest day). Hence,
  - If data is entered as elapsed time, the random starting point is either 0d, 365d, 731d, 1096d, etc.).
  - If data is entered as dates (Calendar Time), the random starting points for successive realizations would be generated by first

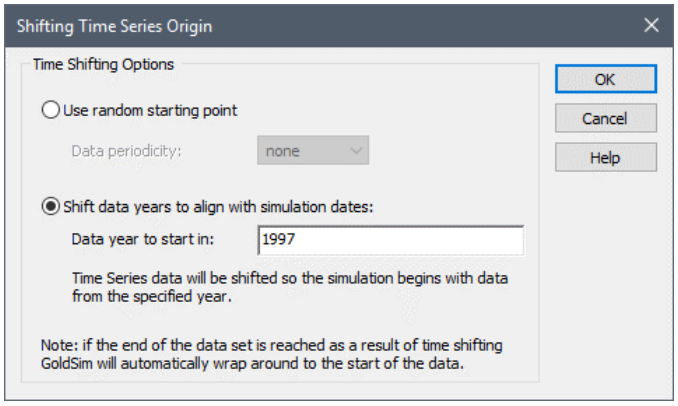
finding a data point in the data set that respected the month, day and time of the Simulation Start time, and then randomly shifting from that point by a multiple of 365.25 days (rounded to the nearest day). (Note that this implies that the shifted calendar day could be off by one day from the actual date).

Note: When specifying time shifting using annual periodicity, your time series should contain at least 366 days of data.

- If the **Data periodicity** is "diurnal", GoldSim ensures that the random starting point for each realization is sampled such that all starting points are a multiple of 1 day apart. In particular,
  - If data is entered as elapsed time, random starting points for successive realizations are always multiples of 1 day apart. That is, the random starting point is either 0d, 1d, 2d, 3d, etc.).
  - If data is entered as dates (Calendar Time), random starting points for successive realizations respect the hour, minute and second of the Simulation Start time.

Note: The random sampling also takes into account the amount of data. For example, if you had 1000 days of data and selected "annual" Data periodicity, the probability of picking the first two years for the starting point would be (365/1000), while the probability of picking the last year would be only (270/1000). In this example, in order to have equal probability of picking any year as a starting point, you would require three full years of data.

The second option for time shifting Time Series is to **Shift data years to align with simulation dates**. This option is only available if the Time Series data is specified using Calendar Time.



This option shifts the time series data forward (or backward) by a multiple of a year such that the simulation begins by using data from the specified **Data year to start in**. For example, if the actual data set started on 31 July1989 and ended on 31 December 2011, the Simulation Start Date was 1 January 2013, and the **Data year to start in** was entered as 1990, GoldSim would treat the data set such that the data point corresponding to 1 January 1990 would be used for 1 January 2013 (and, assuming daily data was entered, the data point for 2 January 1990 would be used for 2 January 2013, etc.).

This is useful, for example, if you wish to apply historic data to a forward-looking simulation, assuming no uncertainty or randomness. That is, this option assumes that with regard to the Time Series, the future will be exactly the same as the past (as represented by the historic data).

Note: If you wanted to account for uncertainty and randomness while still directly using historic data, you could do so by entering multiple years of data, and then using the **Use random starting point** option with "annual periodicity".

In order to better understand how this works, the table below summarizes how the data would be shifted under various conditions. For this table, it is assumed that the actual time series data range is from 31 July 1989 to 31 December 2011, and the Simulation Start Date is 1 January 2013:

Specified "Data year to start in"	Data point used to represent 1 January 2013	Comment
1990	1 January 1990	
1995	1 January 1995	
1989	Fatal error	There is no data point for 1 January 1989 (since the data set starts on 1 July 1989).
2012	Fatal error	There is no data point for 1 January 2012 (since the data set ends on 31 December 2011).

Several points should be noted regarding the use of this option:

- The **Data year to start in** must be specified such that the data set contains data (directly or via interpolation) in the specified year for the month and day defined by the Simulation Start Date. Otherwise, as shown in the table above, GoldSim will display a fatal error.
- The value entered for **Data year to start in** is always rounded to the nearest integer.
- **Data year to start in** can be specified as a function. One way this can be used is to specify a different year for every realization. For example, if **Data year to start in** was defined as "1990 + Realization - 1", data would be used starting from 1990 for the first realization, 1991 for the second realization, and so on.
- When you use this option, you are implicitly stating that the data has annual periodicity. This has implications for how GoldSim wraps data (as pointed out in the second bullet below).

When you choose to **Enable Time Shifting of Time Series Data**, GoldSim automatically wraps around to the start of the data set if the end of the data set is reached during a simulation. The manner in which this is done depends on the periodicity of the data:

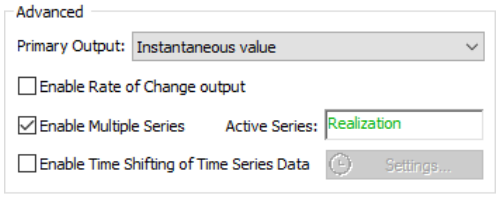
- If using a random starting point with no periodicity, when the end of the data set is reached, the data set is effectively replicated and shifted foward by a period of time equal to the span of the data set. For example, if the last data point was at 1000 days, and the simulation extended beyond 1000 days, the data set would be shifted forward by 1000 days, so that the initial starting value (e.g., elapsed time = 0) would correspond to 1000 days.
- If using a random starting point with annual periodicity *or* if aligning data years with simulation dates, when the end of the data set is reached, the data set is effectively replicated and shifted foward by N years, where N is the number of whole years in the data set. For example, if there were 3.5 years of data in the data set, the last data point was on December 31, and the simulation extended beyond 3.5 years, the data set would be shifted forward by 3 years, so that the first occurrence of January 1 in the data set would follow the last point in the data set.
- If using a random starting point with diurnal periodicity, when the end of the data set is reached, the data set is effectively replicated and shifted forward by N days, where N is the number of whole days in the data set. For example, if there were 21.5 days of data in the data set, the last data point was on day 21.5 days, and the simulation extended beyond 21.5 days, the data set would be shifted forward by 21 days, so that the data point at 0.5 days would follow the last point in the data set.

The example file (TimeShifting.gsm) in the TimeSeries subfolder of the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) includes examples on the use of time shifting Time Series elements.

Defining Multiple Time Series in a Single Time Series Element

One of the advanced features of Time Series elements is the ability to specify multiple sets of time series data within a single Time Series element, and then specify which series is to be used for any particular simulation. This provides a way, for example, for different time series data to be used for each separate realization in a Monte Carlo simulation.

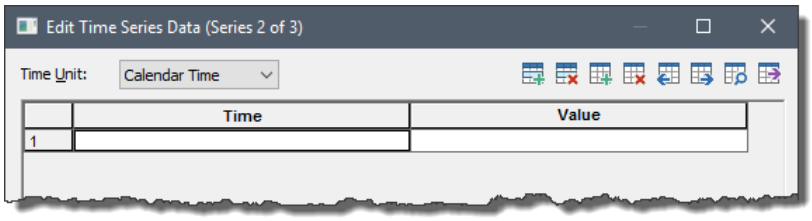
This feature is provided in the "Advanced" section of the Time Series dialog, accessed via the **More** button:



If you check **Enable Multiple Series**, there are two changes to the dialogs:

1. The **Active Series** field becomes available, and defaults to "Realization" (this will be discussed further below); and
2. The time series editing dialog accessed via the **Edit Data** button is modified to support specifying multiple series.

This expanded editing dialog (with two additional series added in this case) looks like this:



In addition to the two original buttons (add and remove rows), there are six new buttons at the top of the dialog:

Button	Action
	Add new row to current series
	Remove selected row from current series
	Add new series
	Remove current series
	Go to previous series (hold Ctrl key to go to first series)
	Go to next series (hold Ctrl key to go to last series)
	Go to series at a specified index (dialog will prompt for series number)
	Change the current series number to a specified number (dialog will prompt for series number). If the specified series is higher than the current series, the specified series (and all series before it) are shifted down. If the specified series is lower than the current series, the specified series (and all series after it) are shifted up. (Instead of entering a number, you can also hold the Ctrl key and press the button to shift the data series to the next index; or also hold the Ctrl and Shft keys and press the button to shift the data series to the previous index.)

These buttons allow you to create, remove, edit and navigate the various time series data sets.

As you are moving between time series, the current series is indicated in the Title bar (e.g., “Series 2 of 3”).

The **Description** field can be valuable when creating multiple series, as it provides a mechanism for you to document what that particular series represents (e.g., “Scenario 3”).

The **Time Unit** that is specified in the dialog is always applied to all the series. That is, if you change it for one series, it is changed for all series.

Note: When you have multiple series, they do not have to have the same time points, or even the same duration or data span (although they often will). Of course, as is the case for any Time Series element, if the time series data does not contain appropriate starting and end points, it may trigger an error message at run time.

Once you have specified multiple time series, for any given simulation, you must specify which series to use via the **Active Series** field. This field must be a scalar dimensionless value that corresponds to one of the defined time series. Note that the time series are numbered sequentially, starting with 1. So, for example, if you had defined 10 series, then **Active Series** would need to be a number between 1 and 10, inclusive.

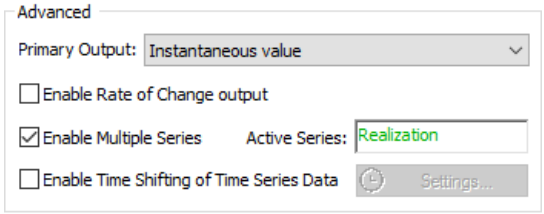
GoldSim will round off real numbers that are entered in the field (e.g., 2.3 would be interpreted as 2). However, if the rounded number does not correspond to one of the defined series numbers, GoldSim issues a fatal error.

The two most common ways that multiple time series are likely to be used are to 1) represent alternative input scenarios; and 2) to represent multiple realizations.

For example, if you had six different scenarios for a model (each with a different input time series), you could represent this by defining six series in a Time Series element, and setting the Active Series to "Scenario", which would be an element in the model that took on values of 1 through 6 (i.e., a Scenario Data element).

Read more: Scenario Data: Defining Inputs for Different Scenarios (page 527).

To use multiple time series to represent different realizations, you could define a different series for each Monte Carlo realization, and then set **Active Series** to "Realization". In fact, this is the default setting when you activate multiple realizations:



Why would you want to use different time series for each realization?

There are two primary reasons why you might want to enter a large number of time series, each representing a different realization:

1. To represent uncertainty in time series inputs. For example, you could generate (using another program) 100 different random time series records. Every realization would then use a different time series.

Note: Currently, spreadsheets *cannot* be used to automatically import multiple time series. That is, if a Time Series is linked to a spreadsheet, it can only import a single series. Importing multiple time series from a spreadsheet into a Time Series element is not supported. As a result, if you needed to import a large number of separate time series records into a Time Series element, you would need to manually copy and paste the series into each element.

Read more: Importing Data into a Time Series from a Spreadsheet (page 199).

2. To use the probabilistic results of one model as the input for a completely different model. For example, the first model might represent one part of the system whose only impact on the rest of the system (represented by a second model) was the time history output of

a single element in the first model. If there was no feedback from second model back to the first, the two models could be run separately in series. Importing the multiple time history realizations of the connecting element into a Time Series element in the second model provides the linkage between the two models.

To support this second application, GoldSim provides a mechanism to import time history realizations into a Time Series as multiple series. In particular, you can read the output of any other element in a GoldSim model, and "record" the results, and then "play them back" in a subsequent run of the model.

Read more: Using a Time Series Element to Record and Play Back a History (page 226).

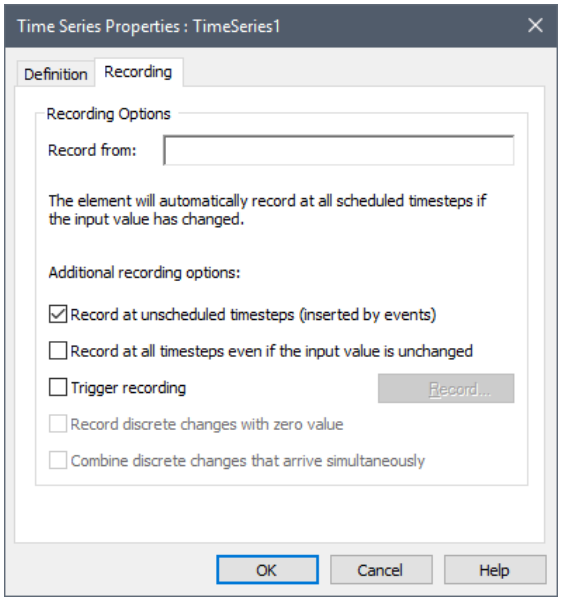
This feature is described in detail in the section below.

The example file (MultipleSeries.gsm) in the TimeSeries subfolder of the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) includes examples of Time Series elements with multiple series.

Using a Time Series Element to Record and Play Back a History

Time Series elements provide an advanced option in which you can read the output of another element in GoldSim, and "record" the results.

To access this capability, the **Data Source** should be set to "Recording output history". When you select this option, a new tab appears (**Recording**) from which you specify the link from the other element, as well as several additional options regarding how the output is recorded:



The **Record from** field represents the output that you wish to record. It must have the same dimensions and Type as specified on the main page (Definition tab) of the Time Series dialog.

The manner in which GoldSim records Time Series is controlled by how you have defined what the Time Series **Represents**, and whether or not the **Trigger recording** option is selected:

Time Series Represents	Trigger recording	Default Recording Logic Used by GoldSim
Instantaneous value	On	Records the value at start and end of simulation, and whenever triggered.
Instantaneous value	Off	Records the value at start and end of simulation, and at all scheduled timesteps if value has changed.
Constant value over the next (or previous) time interval	Not applicable (always On)	Records the *average* value over the intervals at the start and end of simulation, and when triggered.
Change over the next time (or previous) interval	Not applicable (always On)	Records the *change* in the value over the intervals at the start and end of simulation, and when triggered.
Discrete change	Not applicable (always Off)	Records every discrete change.

Read more: Specifying What the Input to a Time Series Represents (page 195).

When **Trigger recording** is checked (either manually or by default based on what the Time Series represents), events that trigger a recording are specified by pressing the **Record…** button:

This provides access to a standard Triggering dialog.

Read more: Understanding Event Triggering (page 369).

When recording Time Series, you should follow these general guidelines to ensure that the data is recorded in such a way that it fully captures the actual behavior of the output:

- If the output that is being recorded represents a quantity (e.g., the output of a Reservoir), the Time Series **Represents** should be set to "Instantaneous value".
- For most other outputs (and particularly for outputs that represent flows of material), the Time Series **Represents** should be set to "Constant value over the next (or previous) interval".

Note that the recording logic listed in the preceding table represents the minimum set of data points that GoldSim records. When the Time Series represents Instantaneous data, you can instruct GoldSim to record additional data by selecting one or more of the options below.

Record at unscheduled timesteps (inserted by events). When recording, the Time Series adds a time point at each scheduled timestep in the simulation. Some elements (that generate events) can also insert "unscheduled" timesteps (in between the scheduled timesteps). If this box is checked (the default), the Time Series records (adds a timepoint) at these unscheduled events also.

Read more: Understanding Timestepping in GoldSim (page 473).

Record at all timesteps even if the input value is unchanged. By default, when recording for some types of outputs (see above), the Time Series does not necessarily record every time point. If this box is checked, the Time Series records (adds a timepoint) at all timesteps.

The final two options only apply if the input data to the Time Series represent discrete changes. In this case, the **Record from** link specified must be a Discrete Change Signal. Note that multiple discrete change signals can be entered into this field by separating them with a semicolon.

Record discrete changes with zero value. This determines whether or not discrete changes with a zero value are recorded as time points. This box is defaulted on.

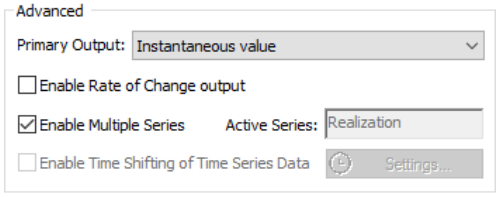
Combine discrete changes that arrive simultaneously. If two or more discrete changes that are being recorded by this Time Series occur at the same time, this checkbox determines whether the discrete changes are combined (the default), or if both are to be recorded separately.

While you are recording a Time Series, the element passes through as its output the instantaneous value of the input being recorded.

Note: Even if **Enable Rate of Change output** is checked, the Rate of Change output is not calculated while recording the history (it is output as zero).

Note: Even if the **Primary Output** is set to "Average value over the next timestep", the output of a Time Series that is currently recording is always the instantaneous value.

Recording time series can also be used to record multiple series. To do so, you must check **Enable Multiple Series** on the Time Series dialog:



Note that when enabling multiple series when recording, the **Active Series** field defaults to "Realization" and cannot be changed.

Read more: Defining Multiple Time Series in a Single Time Series Element (page 223).

There are three primary applications for a "recording" Time Series:

- By recording the output of an element and then changing the **Data Source** field back to "Locally defined data", you can "play back" the history in a subsequent run of the model.
- You can record the times of "unscheduled" updates.
- You can pass the output of a Time Series that is "recording" to another Time Series element. The primary application of this is to transfer time histories between SubModels.

These applications are discussed briefly below.

Recording and Playing Back a History

This can be useful, for example, if you want to copy the result of one model into another model. In order to use a Time Series in this way, you would need to do the following:

1. Insert one or more Time Series elements (one for each output you are interested in), set their **Data Source** to "Recording output history", and specify the output that you wish to record on the Recording tab.
2. Run the model. After you run the model, copy and paste the Time Series element into a different model, and set **Data Source** to "Locally defined data".
3. The Time Series elements you have pasted will contain the results from the other model and can now be used as input for te current model.

Recording the Time of Unscheduled Events

Because GoldSim only saves results at scheduled timesteps, the impact of "unscheduled" timesteps that are inserted by events can sometimes be difficult to see directly.

Read more: Understanding Timestepping in GoldSim (page 473).

A recording Time Series element, however, provides a way to actually see when these "unscheduled" timesteps occur. To use the Time Series in this way, you would need to do the following:

1. Insert a Time Series element into your model, set the **Represents** field to "Instantaneous value", set the **Data Source** to "Recording output history", and specify an output. If you are only interested in the time of the "unscheduled" timesteps themselves, the output that you specify is not important (e.g., you could simply choose Etime).
2. Make sure that **Record at unscheduled timesteps (inserted by events)** is checked on.
3. After the simulation is over, by pressing the **View Data** button, you will be able to view a table of times for all of the scheduled and unscheduled timesteps.

Note: Although recording Time Series can be used in this manner, under most circumstances, there is a much easier way to achieve the same thing. GoldSim provides an option (under a specified set of conditions) to view the values of selected outputs at unscheduled updates in the Advanced Time settings.

Read more: Including Unscheduled Updates in Time History Results (page 496).

Transferring a Time History Out of a SubModel

In some situations, you may want to run a SubModel in GoldSim, and then pass the entire time history of one or more outputs to a location outside of the SubModel (e.g., to another SubModel).

Read more: Using SubModels to Embed Models Within Models (page 1047).

To take advantage of this feature, you must use the Time History Definition output of the element. This is a complex output that contains the complete definition for the element and can be passed from the element (through a SubModel interface) to another Time Series element.

Read more: Browser View of a Time Series Element (page 232); Referencing a Time Series Definition Output (page 230).

To use the Time Series in this way, you would need to do the following:

1. Insert one or more Time Series elements into your SubModel, set their **Data Source** to "Recording output history", and specify the outputs that you wish to transfer outside of the SubModel.
2. Add the Time Series Definition Output of each Time Series that you wish to transfer to the output interface of the SubModel.

   Read more: Creating the Output Interface to a SubModel (page 1059).
3. For each Time Series that you wish to transfer from the SubModel, you must define a corresponding "play back" Time Series element outside of the SubModel. For these Time Series, set their **Data Source** to "Linked to external Time Series Definition", and on the **Linked** tab, enter the Time Series Definition output from the SubModel interface.
4. The output of these Time Series elements will directly reflect the time histories generated by the Time Series elements inside the SubModel.

Note: Although recording Time Series can be used in this manner to transfer a time series out of a SubModel, under most circumstances, there is a more straightforward way to achieve the same thing. GoldSim provides an option to directly add an output inside a SubModel as a Time Series Definition to the SubModel interface. This allows you to skip step #1 above. The primary motivation to use a recording Time Series rather than adding the output directly to the SubModel interface would be if it was necessary to capture high resolution results (i.e., unscheduled updates) from inside the SubModel.

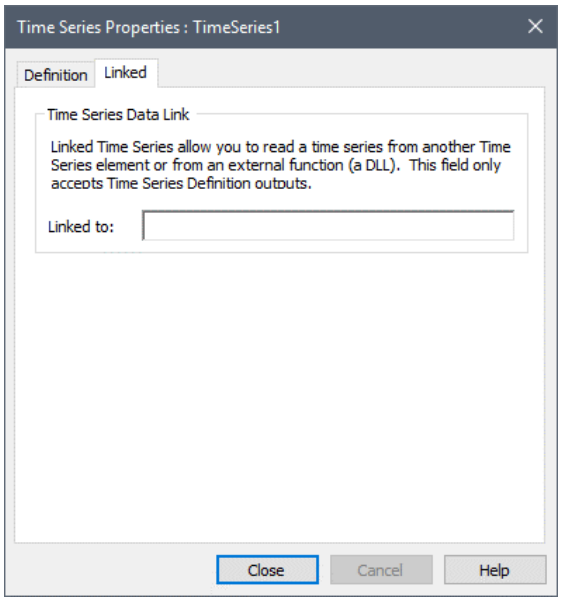
Read more: Including Unscheduled Updates in Time History Results (page 496).

The example file RecordingLinkingTimeSeries.gsm in the TimeSeries subfolder of the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) includes examples of recording Time Series elements.

Referencing a Time Series Definition Output

Time series elements provide an advanced option in which you can read a "Time Series Definition" output from another Time Series element or from an external function (a DLL).

To access this capability, the **Data Source** should be set to "Linked to external Time Series Definition**"**. When you select this option, a new tab appears (**Linked**) from which you specify the link from the other element:



The **Linked to** field only accepts Time Series Definition outputs.

Read more: Browser View of a Time Series Element (page 232).

This is a complex output that can only be produced by another Time Series element, by an external function, or by a SubModel.

Note: This field will not accept a Time Series Definition output directly from another Time Series. It will only accept Time Series Definition outputs from the output interface of a SubModel, or Time Series Definition outputs produced directly by an external function (a DLL).

Read more: Using SubModels to Embed Models Within Models (page 1047).

The primary application of this Time Series feature is to transfer time history data between SubModels. In this case, it is used in conjunction with a Time History Definition output on the output interface of a SubModel.

Read more: Creating the Output Interface to a SubModel (page 1059).

Occasionally, rather than reading the time history directly into a Time Series outside of the SubModel, you may wish to first process that data in some way. This is facilitated by allowing external functions (DLLs) to read and write Time Series Definitions.

Read more: External (DLL) Elements (page 1004).

Note: If using an External element to output a Time Series Definition, the DLL can only be called at etime = 0. That is, because a Time Series must be defined at the beginning of the simulation, if you try to redefine the time series in the middle of the simulation, GoldSim will issue a Fatal Error.

To use the Time Series in this way, you would need to do the following:

1. Insert one or more Time Series elements into your SubModel, set their **Data Source** to "Recording output history", and specify the outputs that you wish to transfer outside of the SubModel.
2. Add the Time Series Definition Output of each Time Series that you wish to transfer to the output interface of the SubModel.

   Read more: Creating the Output Interface to a SubModel (page 1059).
3. For each Time Series that you wish to transfer from the SubModel, you must define a corresponding Time Series element outside of the SubModel. For these Time Series, set their **Data Source** to "Linked to external Time Series Definition", and on the **Linked** tab, enter the Time Series Definition output from the SubModel interface.

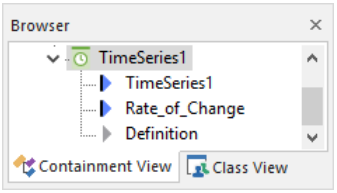
Note: If you wanted to process the data in some way, after exporting it from the SubModel, you could read the Time Series Definition into a DLL that subsequently passed an updated Time Series Definition to another Time Series element.

4. The output of these Time Series elements will reflect the time histories generated by the Time Series elements inside the SubModel.

The example file RecordingLinkingTimeSeries.gsm in the TimeSeries subfolder of the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) includes an examples of a Time Series element reading in a Time Series definition input from a SubModel.

Browser View of a Time Series Element

The browser view of a Time Series element shows at least two, and in some cases, three outputs (the number of outputs produced by the element being user-determined):



Note: Element outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

Read more: Using the Browser (page 106).

The first output is the Primary Output for the Time Series. If the user has selected to **Enable Rate of Change output**, a Rate_of_Change output is also available.

The Time Series Definition output is also always present, and is a complex output that can be used to transfer time series data between SubModels (or External elements).

Read more: Referencing a Time Series Definition Output (page 230).

Because the entries to the table defining the data records must be numbers, they are not shown in the browser (since they cannot be linked to). Hence, within the browser, a Time Series element has no inputs.

Using Stock Elements

Stock Elements are perhaps the most important elements in GoldSim. Stock elements are important because they have the property that they accumulate past events and provide systems with inertia and memory, and hence are responsible for internally generating the dynamic behavior of a system. Without such elements, your models could respond to outside (exogenous) drivers, but could not generate any dynamics of their own. While there are other elements that behave in this way that are not Stocks (i.e., Delay elements), most (if not all) real-world dynamic systems will involve at least one Stock.

Stock elements have the special property that their outputs are influenced by what has happened in the past. That is, their outputs are determined by the *previous* values of their inputs.

GoldSim provides three types of Stock elements, listed below in terms of increasing complexity:

- Integrators are intended to integrate information. For example, integrating a time series of the velocity of a projectile using an Integrator would yield the height of the projectile.
- Reservoirs are intended to integrate/accumulate material flows and represent things such as reservoirs of water, financial account balances, and inventories.
- Pools are more powerful versions of Reservoirs (i.e., they are also intended to integrate/accumulate material flows). They have additional features to more easily accommodate multiple inflows and outflows.

Integrator Elements

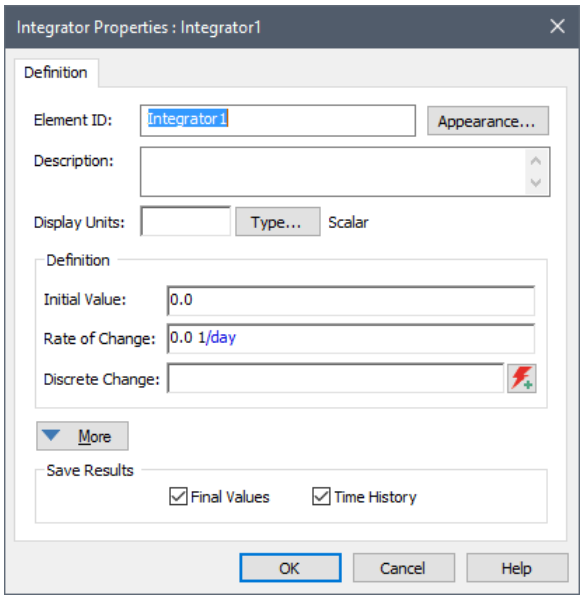
Integrator elements are elements that integrate rates. You use them to integrate and track information, such the distance traveled by a car, interest rates, commodity prices, temperature, rainfall totals, consumer confidence, or the condition (reliability, strength) of a machine or a material. You can also use an Integrator element to calculate moving averages of the input signal (the Rate of Change).

Their default symbol is an integration sign because, mathematically, they represent integrals. An Integrator requires an **Initial Value** and a **Rate of Change**, and computes a single output (its Value) as follows:

$$\text{Value} = \text{Initial Value} + \int (\text{Rate of Change})\,dt$$

The Rate of Change, of course, can be a function of time.

The properties dialog for an Integrator looks like this:



An example model which illustrates the use of Integrator elements (Integrator.gsm) can be found in the General Examples/Stocks folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

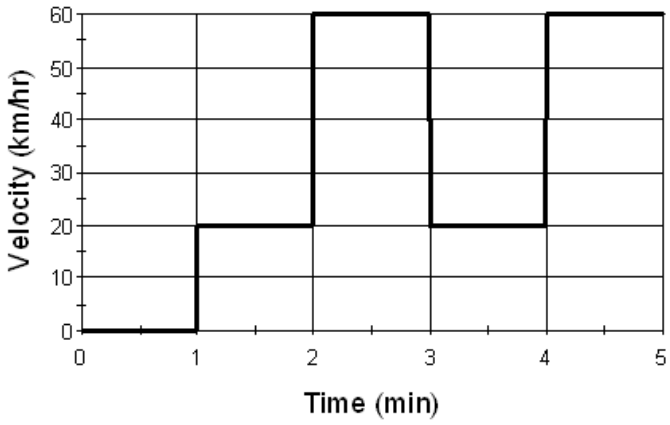
How an Integrator Element Computes its Output

Numerically, GoldSim approximates the integral represented by an Integrator as a sum:

$$\text{Value}(t_n) = \text{Initial Value} + \sum_{i=1}^{n} \text{Rate of Change}(t_i - \Delta t_i)\Delta t_i$$

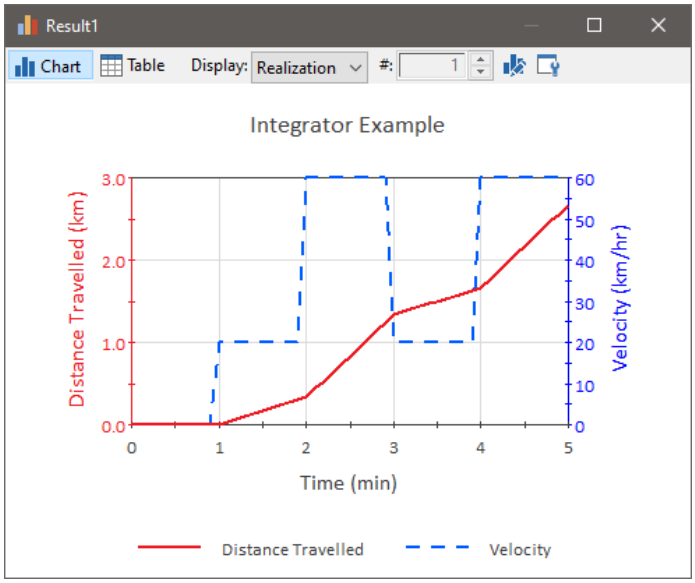
where Δt_i is the timestep length just prior to time t_i (typically this will be constant in the simulation), and Value(t_n) is the value at the end of timestep n. Note that the Value at a given time is a function of the Rate of Change at previous timesteps (but is not a function of the Rate of Change at the current time).

In order to better understand how GoldSim carries out this numerical integration, it is worthwhile to consider the following example. Consider a car that drives on a road for five minutes. We input the time history of the velocity of the car as follows:



Hence, it is stopped for the first minute, travels at 20 km/hr for the second minute, 60 km/hr for the third minute, 20 km/hr for the fourth minute, and 60 km/hr for the fifth minute.

If we put this time history into an Integrator element, and run the simulation for 5 minutes with a constant 1 minute timestep, we get the following for the cumulative distance traveled (assuming an Initial Value of 0):



(This example model, named Integrator.gsm, can be found in the General Examples folder in your GoldSim directory, accessed by selecting **File | Open Example...** from the main menu.)

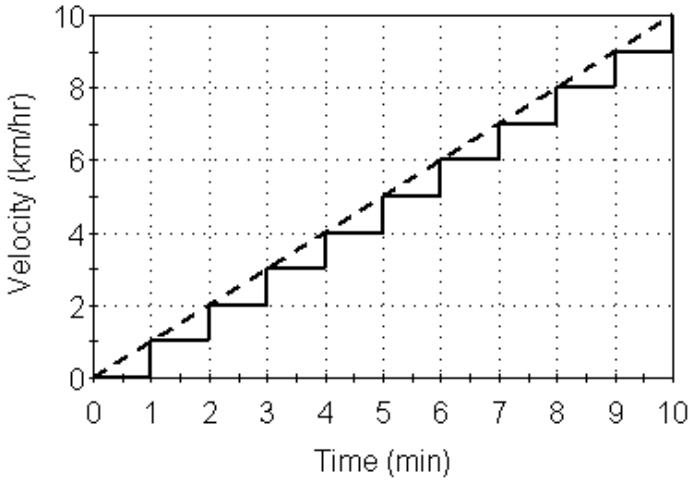
The manner in which GoldSim computed these results is summarized in the following table:

i timestep	t_i (min)	Velocity During Next Step Velocity(t_i)	Distance Traveled During Previous Step Velocity(t_i-Δt) * Δt	Cumulative Distance Traveled at time = t_i
-	0	0 km/hr	-	
1	1	20 km/hr	0 km/hr * 1 min = 0 km	0
2	2	60 km/hr	20 km/hr * 1 min = 0.333 km	0.333 km
3	3	20 km/hr	60 km/hr * 1 min = 1 km	1.333 km
4	4	60 km/hr	20 km/hr * 1 min = 0.333 km	1.666 km
5	5	-	60 km/hr * 1 min = 1 km	2.666 km

Note that the Value (cumulative distance traveled) at time t_i is independent of the Rate of Change (velocity) at time t_i. It is only a function of the Rates (velocities) at previous timesteps.

This particular numerical integration method is referred to as ***Euler integration***, and is discussed further in Appendix F. For the present purposes, it is sufficient to note that Euler integration assumes that the Rate of Change is constant over a timestep. Hence, if you specify that the Rate of Change to an Integrator varies

linearly from 0 km/hr to 10 km/hr over 10 minutes, and simulate the system with a 1 minute timestep, GoldSim will approximate the velocity curve internally as a stair-step function:



The dashed line represents the specified Rate of Change. The solid line illustrates how the Integrator element would interpret the Rate of Change, assuming a 1 minute timestep.

Note: By default, the Rate of Change at time t is treated as the constant rate of change over the *next* timestep (i.e., from t to t + Δt). GoldSim provides an advanced option to allow you to modify this behavior such that the Rate of Change at time t is treated as the constant rate of change over the *previous* timestep (i.e., from t to t - Δt).

Note: Euler integration is the simplest and most common method for numerical integration. However, if the timestep is large, this method can lead to significant errors. This is particularly important for certain kinds of systems in which the error is cumulative (e.g., sustained oscillators such as a pendulum). In these cases, these errors can be reduced by using Containers with Internal Clocks, which allow you to locally use a much smaller timestep.

Read more: Modifying How Integrators Treat the Rate of Change (page 237); Specifying Containers with Internal Clocks (page 493).

Specifying the Inputs to an Integrator

The **Display Units** determine the dimensions of the Integrator's output. This output can only be specified as a value (it cannot be a condition), and can be specified as a scalar, a vector or a matrix. You can specify whether the Integrator is a scalar, vector or matrix by pressing the **Type…** button. By default, the output of a new Integrator element is a scalar, dimensionless value.

Read more: Using Vectors and Matrices (page 848).

The **Initial Value** input to the Integrator must have the same attributes (order and dimensions) as the output.

Note: The **Initial Value** must be a number or a link from a static variable (e.g., a constant Data element or some other output that does not change with time).

The **Rate of Change** input (which can be positive or negative) must have the same order, but the dimensions must represent a rate of change of the output (e.g., if the output has units of length, the Rate of Change must have units of length per time).

Note: The specified **Rate of Change** represents the constant rate over the next timestep. Hence, if a Rate of Change was defined as "if(time > 10 day, 2 m/day, 1 m/day)", and you were using a 1 day timestep, the rate would not actually change to 2 m/day until time = 11 days. That is, since at time = 10 days, the if statement indicates that the rate is equal to 1 m/day, GoldSim would assume that the rate was equal to 1 m/day between 10 days and 11 days. If you wanted the rate to change at 10 days, you would write the if statement as "if(time >= 10 day, 2 m/day, 1 m/day)".

Note: If the output of an Integrator is specified as being an array (a vector or a matrix), the inputs (**Initial Value** and **Rate of Change**) must, by definition, themselves be arrays. Since you often may wish to enter a zero array (a vector or matrix of zeros) for the **Initial Value** or the **Rate of Change**, GoldSim allows you to leave one or both of these input fields blank, in which case it interprets the field as a zero array.

Specifying Discrete Changes to an Integrator

Integrators can also accept discrete (as opposed to continuous) changes. That is, Integrators actually compute their Current Value by accounting for discrete changes as follows:

$$\text{Value}(t_n) = \text{Initial Value} + \sum_{i=1}^{n} \text{Rate of Change}(t_i - \Delta t_i)\Delta t_i + \sum \text{Discrete Changes}$$

Discrete changes are specified by linking a ***discrete change signal*** input into the Discrete Change field.

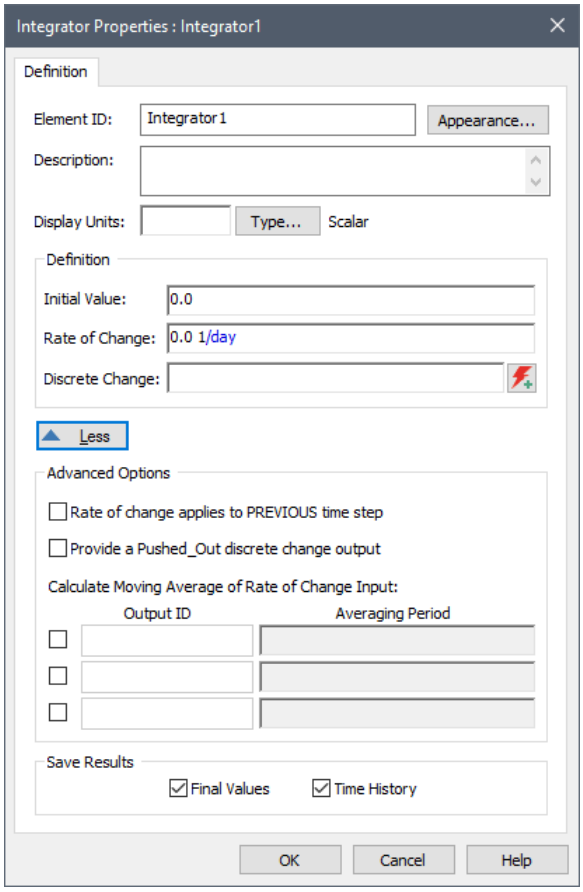
Read more: Basic Concepts of Discrete Event Modeling (page 366); Modeling Discrete Changes to an Integrator (page 399).

Modifying How Integrators Treat the Rate of Change

By default, the **Rate of Change** at time t is treated as the constant rate of change over the *next* timestep (i.e., from t to t + Δt). In some very special cases, however, you may actually want GoldSim to treat the **Rate of Change** in a different manner. In particular, you may want to modify this behavior such that the **Rate of Change** at time t is treated as the constant rate of change over the *previous* timestep (i.e., from t to t - Δt).

The most common reason for doing this is when you want to use an Integrator to integrate a mass flux coming from a pathway element in the GoldSim Contaminant Transport Module. Pathway elements output mass flux rates that represent rates over the *previous* timestep. Therefore, in order to correctly integrate such a flux, an Integrator element would need to treat the **Rate of Change** as if it represented the rate of change over the previous timestep.

GoldSim provides an option to allow Integrators to treat the **Rate of Change** in this way. By default, the option is deactivated. To activate it, you must press the **More** button to expand the dialog:



By default, the checkbox labeled **Rate of change applies to the PREVIOUS time step** is cleared. If you check this checkbox, the Integrator element will treat the **Rate of Change** as if it represented the rate of change over the *previous* timestep.

Using an Integrator to Compute Moving Averages

In some cases you may want to represent a moving average in your model. For example, at any given time, you might want to know what the average value was over the previous 30 days.

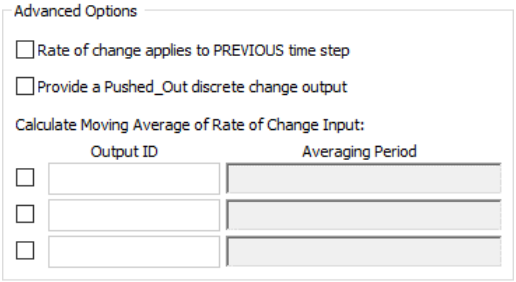
You can use an Integrator to compute a moving average of the **Rate of Change** input.

A moving average is a uniformly-weighted average of the **Rate of Change** over a specified averaging time (ATime). It is calculated as the change in the value of the Integrator over the averaging time divided by the averaging time:

$$\text{Moving Average} = \frac{\int_{t=ETime-ATime}^{t=Etime} (\text{Rate of Change})\, dt}{ATime}$$

Note: To account for elapsed times that are less than the averaging time, the actual averaging time used is the minimum of the elapsed time and the specified averaging time. The value of the moving average at elapsed time = 0 is equal to the initial value of the **Rate of Change**.

GoldSim provides an option to compute up to three different moving averages. To activate it, you must press the **More** button to expand the dialog:



By checking a box, you can specify the name of the moving average output and define the **Averaging Period**. If you specify multiple moving average outputs, they must have unique names. The **Output IDs** follow the same naming conventions as element names. The **Averaging Period** must have units of time, and must be a number or a link from a static variable (e.g., a constant Data element or some other output that does not change with time).

Discrete changes (applied in the Discrete Change field) will affect the moving average outputs. In particular, any discrete changes that are applied to the Integrator will affect the moving average as if they were distributed uniformly over the preceding timestep (i.e., from the previous update of the element to the update where the discrete change was applied.

Note: The moving average outputs have the same dimensions as the **Rate of Change** *input* (not the dimensions defined by the Display Units for the Integrator itself). For example, if the variable you are interested in computing a moving average for has dimensions of volume/time, then the Integrator would need to have dimensions of volume. Similarly, if the variable you are interested in computing a moving average for has dimensions of mass, then the Integrator would need to have dimensions of mass-time.

Note: The Display Units for the moving average outputs are the Display Units for the element divided by the Time Display Units (specified in the Simulation Settings dialog). If this results in unusual Display Units, you can simply route the output into an Expression with adjusted Display Units.

Read more: Simulation Settings (page 470).

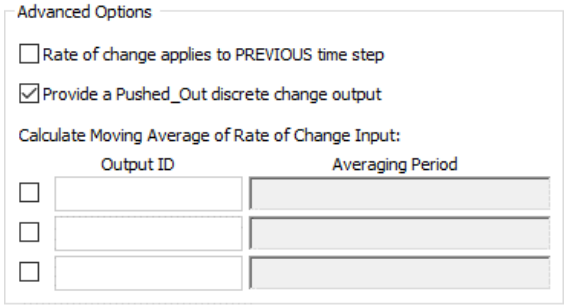
Using an Integrator to Model an Aging Chain

In some situations, it is necessary to keep track of the age structure of a stock of material or objects. For example, you may want to track the number of people in each of a number of age groups, the number of people in a company at

different experience levels (e.g., new hire, experienced, expert), or the number of trucks of different age groups on the road.

To model such a situation, you cannot use a single Stock (e.g., an Integrator). Rather, you must disaggregate the total stock into multiple categories (referred to as cohorts). Each cohort "graduates" to the next cohort over time (and can only move in one direction). However, each cohort may grow and shrink for other reasons (e.g., if you were modeling a population of people, a particular category could grow due to immigration, and shrink due to emmigration and death). Note that these rates of growing and shrinking are likely a function of the specific cohort (e.g., death rates).

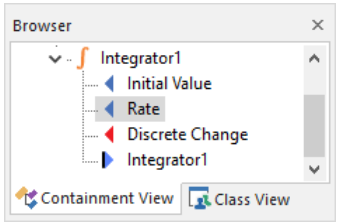
GoldSim provides several methods for modeling aging chains. One of these involves using an Integrator and processing a specialized discrete change signal (called a Push). The advanced option to Provide a Pushed_Out discrete change output is used for this method:



Read more: Modeling Aging Chains Using Integrators with Discrete Pushes (page 880).

Browser View of an Integrator Element

By, default, the browser view of an Integrator element shows three inputs and a single output:



Several Advanced Options can add inputs and outputs. If the moving average options is used, the browser would display additional inputs and outputs (one for each moving average specified). If the option to provide a "Pushed_Out" output is selected, the browser would display an additional Discrete Change output.

Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

Reservoir Elements

Reservoir elements are elements that accumulate flows. You use them to accumulate and track material, such as the quantity of water in a lake, the amount of soil in a stockpile, the number of people in a city, and the number of widgets in a warehouse.

Their default symbol is a container of water since this is an excellent analogy for the behavior of the element. Like a container of water, a Reservoir element has a current value (e.g., the volume of water in the container), inflows, withdrawals and overflows.

A Reservoir is fundamentally similar to an Integrator (since both are Stocks), but is different in three important ways:

- Reservoirs are designed to integrate (accumulate) material; Integrators are designed to integrate information.
- Reservoirs explicitly differentiate between positive rates and discrete changes (additions) and negative rates and discrete changes (withdrawals).
- Reservoirs allow you to specify upper and lower bounds. Due to these bounds, a Reservoir has more than one output.

Note: If you are modeling a system that has multiple distinct withdrawals (particularly if the Reservoir can reach its Lower Bound), you likely will want to use a more powerful version of the Reservoir, referred to as a Pool.

Read more: Pool Elements (page 258).

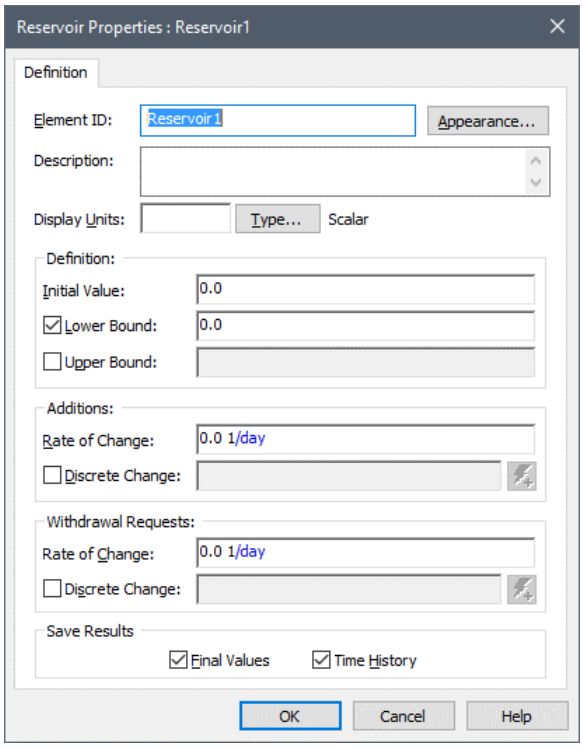
Like an Integrator, a Reservoir requires an **Initial Value** and a **Rate of Change**. The **Rate of Change**, however, is specified in terms of two separate inputs, one representing the Rate of Addition and one representing the Rate of Withdrawal.

In the absence of Upper and Lower Bounds, the primary output of the Reservoir (its Value) is computed as follows:

$$\text{Value} = \text{Initial Value} + \int (\text{Rate of Addition} - \text{Rate of Withdrawal})\, dt$$

The Rates of Addition and Withdrawal can, of course, be functions of time.

The Properties dialog for a Reservoir element looks like this:



By default, when you create a new Reservoir element, a **Lower Bound** of 0 is assumed. You can subsequently remove the **Lower Bound**, or modify it.

An example model which illustrates the use of Reservoir elements (Reservoir.gsm) can be found in the General Examples/Stocks folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

How a Reservoir Element Computes its Primary Output

Numerically, GoldSim approximates the integral represented by a Reservoir as a sum:

$$\text{Value}(t_n) = \text{Initial Value} + \sum_{i=1}^{n} \text{Rate of Change}(t_i - \Delta t_i)\Delta t_i$$

where

$$\text{Rate of Change}(t_i - \Delta t_i) = \text{Rate of Addition}(t_i - \Delta t_i) - \text{Rate of Withdrawal}(t_i - \Delta t_i)$$

In these equations, Δt_i is the timestep length just prior to time t_i (typically this will be constant in the simulation), and Value(t_n) is the value at end of timestep n. Note that the Value at time t_i is a function of the Rates of Addition and Withdrawal at previous timesteps (but is not a function of these Rates at time t_i).

Note that if you specify **Upper** or **Lower Bounds** for a Reservoir, the equation shown above is constrained by the specified bounds (i.e., the Value cannot exceed the **Upper Bound** and can not be less than the **Lower Bound**).

Read more: Defining Upper and Lower Bounds for a Reservoir (page 246).

Reservoirs and Integrator elements use the same numerical integration method, referred to as Euler Integration. A simple example illustrating this integration method is provided in the section discussing how an Integrator element computes its output.

Read more: How an Integrator Element Computes its Output (page 234).

The key assumption involved in this integration method is that at any point in time, the **Rates of Change** (Additions and Withdrawals) represent the rates over the next timestep, and those rates are assumed to be constant over the timestep. Euler Integration is discussed in additional detail in Appendix F.

Note: Euler integration is the simplest and most common method for numerical integration. However, if the timestep is large, this method can lead to significant errors. This is particularly important for certain kinds of systems in which the error is cumulative (e.g., sustained oscillators such as a pendulum). In these cases, these errors can be reduced by using Containers with Internal Clocks, which allow you to locally use a much smaller timestep.

Read more: Specifying Containers with Internal Clocks (page 493).

Specifying the Dimensions, Initial Value and Rates of Change for a Reservoir

The primary output of a Reservoir is its Value. The **Display Units** determine the dimensions of this output. The primary output of a Reservoir is always a value (it cannot be a condition), but can be specified as a scalar, a vector or a matrix. You can specify the order by pressing the **Type…** button. By default, the primary output of a new Reservoir element is a scalar, dimensionless value.

Read more: Using Vectors and Matrices (page 848).

Note: GoldSim encourages (but does not require) you to specify **Display Units** for a Reservoir whose dimensions are consistent with materials. In particular, it expects the units to have dimensions of mass, volume, energy, amount, currency, or to be dimensionless. When you first specify your **Display Units**, GoldSim will warn you if your units do not have one of these dimensions. GoldSim will not, however, prevent you from using other units.

The **Initial Value** input to the Reservoir must have the same attributes (order and dimensions) as the primary output.

Note: The **Initial Value** must be a number or a link from a static variable (e.g., a constant Data element or a Stochastic).

There are two **Rate of Change** inputs: one representing **Additions** and one representing **Withdrawal Requests**. These inputs must have the same order (i.e., scalar, vector, matrix) as defined for the element. Moreover, the dimensions must represent a rate of change of the primary output (e.g., if the primary output has units of mass, the **Rate of Change** inputs must have units of mass per time).

The **Rate of Change** inputs must be entered as non-negative values. Negative values for these inputs during a simulation will result in a fatal error.

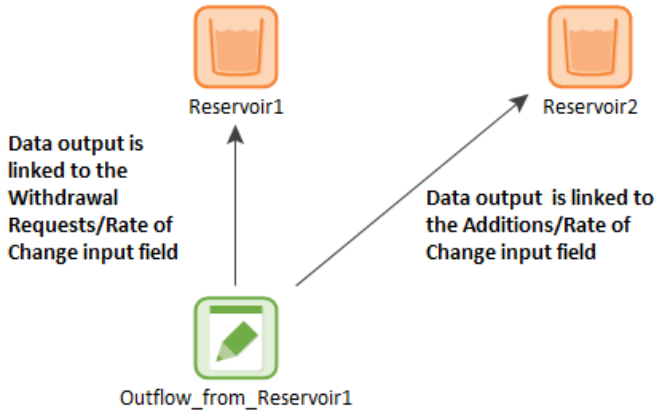
Note: The specified **Rate of Change** inputs represent constant rates over the *next* timestep. Hence, if an **Rate of Change** was defined as "if(time > 10 day, 2 m^3/day, 1 m^3/day)", and you were using a 1 day timestep, the rate would not actually change to 2 m^3/day until time = 11 days. That is, since at time = 10 days, the if statement indicates that the rate is equal to 1 m^3/day, GoldSim would assume that the rate was equal to 1 m^3/day between 10 days and 11 days. If you wanted the rate to change at 10 days, you would write the if statement as "if(time >= 10 day, 2 m^3/day, 1 m^3/day)".

Note: If the output of a Reservoir is specified as being an array (a vector or a matrix), the **Initial Value** and **Rate of Change** inputs must, by definition, themselves be arrays. Since you often may wish to enter a zero array (a vector or matrix of zeros) for one or more of these inputs, GoldSim allows you to leave any of these input fields blank, in which case it interprets the field as a zero array.

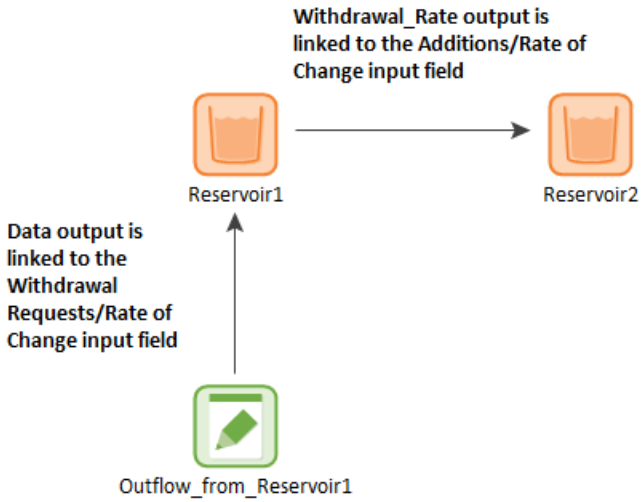
Using the Withdrawal Rate Output of a Reservoir

By default, a Reservoir element has two outputs: the Value (which has the same name as the element) and a Withdrawal_Rate. In the absence of a **Lower Bound**, the Withdrawal_Rate output is exactly equal to the **Withdrawal Requests/Rate of Change** input.

To illustrate the use of the Withdrawal_Rate output, consider an example in which Reservoir1 flows into Reservoir2 (i.e., the Withdrawal_Rate output from Reservoir1 is the **Additions/Rate of Change** input for Reservoir2). One way to build this model is as follows:



By using the Withdrawal_Rate output, however, this model can become more transparent:



As can be seen, by linking the Withdrawal_Rate output from Reservoir1 to the **Additions/Rate of Change** input of Reservoir2, it becomes visually much clearer that Reservoir1 flows into Reservoir2.

Although the visual advantage of using the Withdrawal_Rate output is important, there is a much more important reason to use this output. In the first example above, the Data element serves as both an input to Reservoir1 (as the **Withdrawal Requests/Rate of Change**) and an input to Reservoir2 (as the **Additions/Rate of Change**). Note, however, that as will be discussed in detail in the next section, if a **Lower Bound** is specified for the Reservoir, the Withdrawal_Rate output is not necessarily identical to the **Withdrawal Requests/Rate of Change** input. In particular, if Reservoir1 hits its **Lower Bound**, the Data element no longer necessarily represents the actual amount being added to Reservoir2. The actual amount being added might be restricted and hence might be less than Data element Outflow_from_1. This is because the Data element represents the *requested* rate of withdrawal, but this is not necessarily the *actual* rate of withdrawal that is possible (there might not be enough material available). As a result, such a structure could cause you to artificially create material in this model!

Read more: How a Reservoir Computes the Withdrawal Rate (page 251).

Note: Because ignoring the Withdrawal_Rate output when a Reservoir reaches its **Lower Bound** (and the withdrawal is restricted) could result in a significant error in your model, GoldSim generates a warning message whenever a Reservoir reaches its **Lower Bound** such that the requested withdrawal cannot be delivered AND the Withdrawal_Rate output is not referenced by another element.

Note: If you are modeling a system that has multiple distinct withdrawals (particularly if the Reservoir can reach its **Lower Bound**), you likely will want to use a slightly more powerful version of the Reservoir, referred to as a Pool.

Read more: Pool Elements (page 258).

Defining Upper and Lower Bounds for a Reservoir

One of the most powerful features of a Reservoir is that you can specify a Lower and/or Upper Bound. If the **Lower Bound** and **Upper Bound** boxes are cleared for a Reservoir, the Value is not constrained and is unbounded (as is the case for an Integrator).

Checking one or both of these boxes, however, provides additional functionality and has important impacts on the outputs for the element. In particular:

- If the **Lower Bound** is checked, GoldSim enforces that limitation on the Value. As a result, the Withdrawal_Rate output is not necessarily equal to the **Withdrawal Requests/Rate of Change** input. In this case, the Withdrawal_Rate output represents the actual rate of withdrawal from the Reservoir, which may be less than the specified **Withdrawal Requests/Rate of Change** (which represents the demand or requested rate of withdrawal).

  For example, if the Reservoir is at the **Lower Bound**, and the **Additions/Rate of Change** is zero, the Withdrawal_Rate output must be equal to zero, regardless of the **Withdrawal Requests/Rate of Change** (there is no material available to be withdrawn). Similarly, if the Reservoir is at the **Lower Bound**, and the **Additions/Rate of Change** is equal to 10, the Withdrawal_Rate output can be no greater than 10, regardless of the **Withdrawal Requests/Rate of Change** (if there is no storage, you cannot withdrawal more than is being supplied).

  By default, when you create a new Reservoir element, the **Lower Bound** is checked (and a value of 0 is assumed).

Note: If the **Lower Bound** is constant, the Value in the Reservoir will never fall below the **Lower Bound**. However, if the **Lower Bound** is changing with time, under some circumstances, it is possible for the Value of the Reservoir to fall below the **Lower Bound**. The primary purpose of the **Lower Bound** is to accurately compute the Withdrawal_Rate. If the **Lower Bound** exceeds the amount in the Reservoir (because the **Lower Bound** has changed during a timestep), the Reservoir will not permit any withdrawals until it returns to the **Lower Bound** (via additions).

Note: If you are modeling a system that has multiple distinct withdrawals (particularly if the Reservoir can reach its **Lower Bound**), you likely will want to use a slightly more powerful version of the Reservoir, referred to as a Pool.

Read more: Pool Elements (page 258).

- If the **Upper Bound** is checked, GoldSim enforces that limitation on the Value. GoldSim also adds two new (secondary) outputs: Overflow_Rate (a value) and Is_Full (a condition). If the Value is below the **Upper Bound**, the Overflow_Rate output is equal to zero and the Is_Full output is False. If the Value is at the **Upper Bound**, the Overflow_Rate output is equal to the difference between the specified Addition Rate and the specified Withdrawal Rate and the Is_Full output is True.

Read more: Using the Is_Full Output of a Reservoir (page 256).

Note: If the **Upper Bound** is constant, the Value in the Reservoir will never exceed the **Upper Bound**. However, if the **Upper Bound** is changing with time, under some circumstances, it is possible for the Value of the Reservoir to exceed the **Upper Bound**. If the **Upper Bound** is exceeded (because it has changed during a timestep), GoldSim will overflow the excess uniformly over the next timestep.

Most real-world Reservoirs have such bounds. For example, many Reservoirs would have a logical lower bound of zero (e.g., a pond cannot contain a negative quantity of water, a parking lot cannot contain a negative number of cars). Many Reservoirs also have a logical upper bound (e.g., tanks and parking lots have maximum capacities). Some Reservoirs may have a lower bound, but no upper bound (e.g., a bank perhaps could not be negative, or at least there will be some limit on the amount that can be overdrawn, but would probably have no practical upper bound).

Note: If your specified **Upper Bound** is reached during a simulation, and the Overflow_Rate output is not referenced by any other element (e.g., as an inflow to another Reservoir), GoldSim will display a warning, as this could indicate that you have neglected to track flows leaving the Reservoir.

Note: GoldSim generates a warning message whenever a Reservoir reaches its **Lower Bound** such that the requested withdrawal cannot be delivered AND the Withdrawal_Rate output is not referenced by another element.

The Reservoir element is particularly powerful because it enforces the bounds while properly conserving the material being tracked. That is, if a Reservoir's **Additions/Rate of Change** causes it to reach its **Upper Bound**, GoldSim produces an Overflow_Rate (which can be routed to a downstream Reservoir). Similarly, if you specify a **Withdrawal Requests/Rate of Change** that exceeds what can actually be delivered, GoldSim accurately reports the actual Withdrawal_Rate.

Furthermore, as is discussed below, the **Upper** and **Lower Bounds** can be specified as functions of time. This allows you to simulate systems such as a pond which is filling up with silt and sand (and hence decreasing its capacity), and a warehouse whose capacity is being expanded (via construction) throughout a simulation.

The **Lower Bound** and the **Upper Bound** inputs to the Reservoir must have the same attributes (order and dimensions) as the Reservoir's primary output. In addition, the following limitations imposed on the inputs should be specifically noted:

- The **Upper Bound** must be greater than or equal to the **Lower Bound**.
- The **Initial Value** must be greater than or equal to the **Lower Bound** and less than or equal to the **Upper Bound**.

Note: If the output of a Reservoir is specified as being an array (a vector or a matrix), the **Upper** and **Lower Bounds** must, by definition, themselves be arrays. Because these fields are optional (you must check the box to activate them), if the box is selected, you cannot leave the field blank (like you can do for the **Rate of Change** inputs). For example, if you wish to specify a vector of zeroes (e.g., for the lower bound), you must do so by entering "vector(0)".

How a Reservoir Computes the Overflow Rate

The Overflow_Rate output of a Reservoir has meaning (and is computed) only if you have specified an **Upper Bound**. GoldSim computes the Overflow_Rate such that the flowing material (e.g., water, widgets, people, rocks) is conserved. To understand how it does so, recall the key assumption regarding the Euler integration method: *The specified Rates of Change (Additions and Withdrawal Requests) represent constant rates over the next timestep*.

Hence, at the beginning of a timestep, GoldSim can project what the Value will be at the end of timestep, compare it to the **Upper Bound**, and easily compute an Overflow_Rate for that timestep. To illustrate this, consider the following simple example. Assume we are modeling a pond with an **Upper Bound** of 3000 m^3, and that at time = 10 days, the pond contains 2700 m^3 of water. Let's further assume that our model has a 2 day timestep. Assume that for times greater than 10 days, the **Additions/Rate of Change** and the **Withdrawal Requests/Rate of Change** are constant and equal to 500 m^3/day and 100 m^3/day, respectively, so that the pond will fill up and start to overflow at 10.75 days.

In order to compute overflow rates accurately, by default GoldSim inserts an "unscheduled update" when the Reservoir reaches an **Upper Bound**. Unscheduled updates are timesteps that are automatically inserted by GoldSim during the simulation in order to more accurately simulate the system.

Read more: Understanding Timestepping in GoldSim (page 473).

In particular, the Overflow_Rate for the example described above is treated as follows. At 10 days, GoldSim would report an (instantaneous) Overflow_Rate of zero. A new timestep (an "unscheduled update") would then be inserted at 10.75 days when the pond would start to overflow. The Overflow_Rate at this time would actually be internally calculated as 400 m^3/day. However, because by default GoldSim only reports values at scheduled timesteps (e.g., 10 days, 12 days), the Overflow_Rate will not be displayed as 400 m^3/day until 12 days.

Hence, it is important to understand that the Overflow_Rate represents the *instantaneous* overflow rate at the reported time. You cannot assume that this rate is constant over the next scheduled timestep. That is, it would be incorrect to assume that the overflow rate was zero between 10 and 12 days. In fact, at 10 days, the overflow rate was indeed 0 m^3/day, but it changed to 400 m^3/day at 10.75 days (between the scheduled updates). Because 10.75 days is an unscheduled timestep, you would not see this in a time history plot. However, if the Overflow_Rate was integrated (using an Integrator or another Reservoir that represented the total amount of water that has overflowed), the following results would be obtained:

Time (days)	Reported Overflow Rate (m^3/day)	Total Water Overflowed (m^3)
8	0	0
10	0	0
12	400	500
14	400	1300

Note that the amount of water is properly conserved. At 12 days, the pond has been overflowing for 1.25 days (at a rate of 400 m^3/day), so that a total volume of 500 m3 has overflowed. At 14 days, the pond as been overflowing for 3.25 days, so a total volume of 1300 m^3 has overflowed.

Note: In some cases, it may be of interest to see the values (such as the Overflow_Rate) that were computed at unscheduled updates. To facilitate this, GoldSim provides an option to do so (under a specified set of conditions) in the Advanced Time settings.

Read more: Including Unscheduled Updates in Time History Results (page 496).

Note: Most spreadsheet models implicitly compute *average* values (e.g., flows) over a step (or the change from one step to the next). You can compute average values such as these (e.g., in order to compare GoldSim with a spreadsheet model) by using Goldsim's Reporting Periods feature.

Read more: Defining Reporting Periods (page 479).

Note: As noted above, by default, GoldSim inserts an unscheduled update when the Reservoir reaches an **Upper Bound**. However, if desired, you can disable unscheduled updates (although it is generally not recommended). If you do so, the reported Overflow_Rate is the average rate over the next scheduled timestep and can be assumed to be constant. (This option is accessed via the **Advanced…** button in the **Time** tab of the Simulation Setting dialog).

Read more: Controlling Unscheduled Updates (page 489).

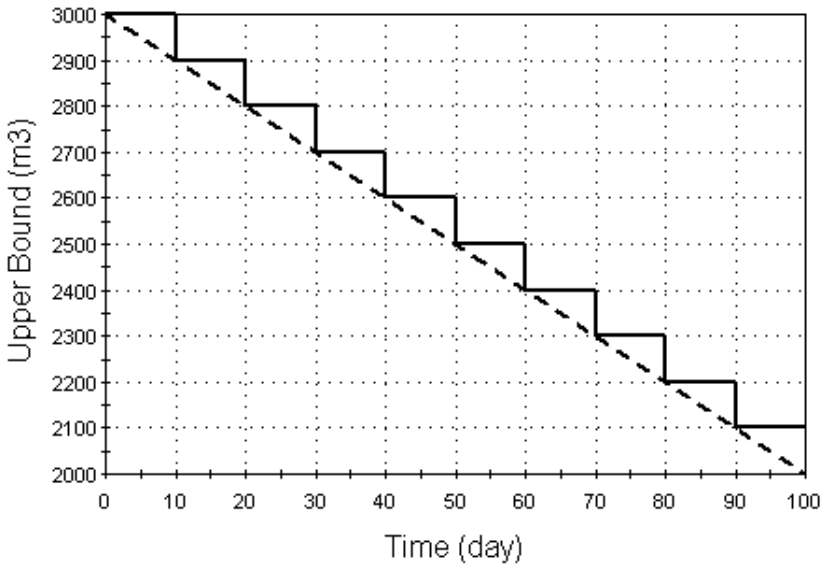
Note: You can record when Reservoirs hit or depart from their **Upper** and **Lower Bounds** in the model's Run Log. This logging can be activated via the **General** tab of the Options dialog (accessed via **Model|Options** from the main menu).

Read more: The General Tab of the Options Dialog (page 466).

The calculation of an Overflow_Rate is further complicated because the **Upper Bound** can be specified to change with time (i.e., you could specify this input as being time-variable). If you do so, GoldSim makes the following assumption:

like the **Rates of Change**, the **Upper Bound** is assumed to remain constant over a timestep.

For example, if you specify that the **Upper Bound** varies linearly from 3000 m^3 to 2000 m^3 over 100 days, and simulate the system with a 10 day timestep, GoldSim will approximate the **Upper Bound** curve internally as a stair-step function:



The dashed line represents the Specified Upper Bound
The solid line represents the Upper Bound as simulated by GoldSim, assuming a 10 day timestep

Hence, within a given timestep, GoldSim follows the same logic outlined in the previous example to compute the Overflow_Rate for that timestep.

Note that an Overflow_Rate can be generated even if there is no net inflow of material into the Reservoir. This can happen if the **Upper Bound** decreases below the Value. To illustrate this, consider the following simple example. Assume we are modeling a pond with an **Upper Bound** of 3000 m^3. Further assume that at the beginning of a timestep, the pond contains 2700 m^3 of water. There are no further additions or withdrawals from the pond. However, assume that over the next timestep, the **Upper Bound** decreases from 3000 m^3 to 2500 m^3 (e.g., it fills up with silt).

How would GoldSim handle this? During the timestep the **Upper Bound** would be assumed to remain at 3000 m^3. At the beginning of the following timestep, however, it would instantaneously decrease to 2500 m^3. This would result in 2700 – 2500 = 200 m^3 of water that would instantaneously have to overflow. GoldSim actually spreads this out over the following timestep, such that with a 2 day timestep, the Overflow_Rate over the following timestep would be 200/2 = 100 m^3/day.

Note: If the **Upper Bound** is constant, the Value in the Reservoir will never exceed the **Upper Bound**. However, if the **Upper Bound** is changing with time, under some circumstances, it is possible for the Value of the Reservoir to exceed the **Upper Bound**. If the **Upper Bound** is exceeded (because it has changed during a timestep), GoldSim will overflow the excess uniformly over the next timestep.

Note: Although GoldSim conserves mass in these situations, this does not imply that the result is perfectly accurate. In fact, the accuracy of the result is a function of the timestep, since GoldSim is approximating continuously varying functions (i.e., rates and bounds) using stair-step functions. This approximation is discussed further in Appendix F.

How a Reservoir Computes the Withdrawal Rate

In the absence of a **Lower Bound**, the Withdrawal_Rate output is equal to the **Withdrawal Requests/Rate of Change** input. However, if a **Lower Bound** is specified, the Withdrawal_Rate output represents the actual rate of withdrawal from the Reservoir, which may be less than the specified **Withdrawal Requests/Rate of Change** (which can be thought of as the demand or requested rate of withdrawal).

Note: The Withdrawal_Rate is completely independent of and does not include the Overflow_Rate. The Withdrawal_Rate only considers of withdrawals specified in the **Withdrawal Requests/Rate of Change** input field.

GoldSim compares the **Withdrawal Requests/Rate of Change** to the amount of material available, and only outputs what can actually be withdrawn from the Reservoir over the timestep. Hence, if the Value is above the **Lower Bound** throughout the timestep, the Withdrawal_Rate output is exactly equal to the specified **Withdrawal Requests/Rate of Change**. If the Value is at the **Lower Bound** throughout the timestep, the Withdrawal_Rate output is equal to the specified **Additions/Rate of Change**.

If the Reservoir reaches (or leaves) the **Lower Bound** during the timestep, GoldSim uses logic similar to that for computing overflow rates in order to correctly compute the actual withdrawal rate. In order to compute withdrawal rates accurately, by default GoldSim inserts an "unscheduled update" when the Reservoir reaches a **Lower Bound**. Unscheduled updates are timesteps that are automatically inserted by GoldSim during the simulation in order to more accurately simulate the system.

Read more: Understanding Timestepping in GoldSim (page 473).

To illustrate how GoldSim treats withdrawal rates, consider the following simple example. Assume we are modeling a pond with a **Lower Bound** of zero. Further assume that at time = 10 day, the pond contains 200 m^3 of water. GoldSim computes the constant **Additions/Rate of Change** and the **Withdrawal Requests/Rate of Change** for times greater than 10 days to be 100 m^3/day and 300 m^3/day, respectively. Therefore, the pond will run out of water at 11 days. Let's further assume that our model has a 2 day timestep (so that this occurs in the middle of the scheduled timesteps).

The Withdrawal_Rate is computed as follows. At 10 days, GoldSim will report a Withdrawal_Rate of 300 m^3/day. A new timestep (an "unscheduled update") is then inserted at 11 days when the pond becomes empty. The Withdrawal_Rate at this time will actually be internally calculated as 100 m^3/day (since the pond is empty, the Withdrawal_Rate can be no greater than the **Additions/Rate of Change**). However, because by default GoldSim only reports values at scheduled timesteps (e.g., 10 days, 12 days), the Withdrawal_Rate will not be displayed as 100 m^3/day until 12 days.

Hence, it is important to understand that the Withdrawal_Rate represents the *instantaneous* withdrawal rate at the reported time. You cannot assume that this rate is constant over the next scheduled timestep. That is, it would be incorrect to assume that the Withdrawal_Rate was 300 m^3/day between 10 and 12 days. In fact, at 10 days, the Withdrawal_Rate was indeed 300 m^3/day, but it changed to 100 m^3/day at 11 days (between the scheduled updates). Because 11 days is an unscheduled timestep, you would not see this in a time history plot. However, if the Withdrawal_Rate was integrated (using an Integrator or another Reservoir that represented the total amount of water that has been withdrawn), the following results would be obtained:

Time (days)	Reported Withdrawal Rate (m^3/day)	Total Water Withdrawn (m^3)
10	300	0
12	100	400
14	100	600

Note that the amount of water is properly conserved. At 12 days, the pond has been empty for 1 day (and hence the Withdrawal_Rate during that period has been equal to the inflow rate of 100 m^3/day), so that a total volume of 300 m^3/day * 1 day + 100 m^3/day * 1 day = 400 m^3 has been withdrawn. At 14 days, the pond as been empty for 3 days, so that a total volume of 300 m^3/day * 1 day + 100 m^3/day * 3 day = 600 m^3 has been withdrawn.

Note: In some cases, it may be of interest to see the values (such as the Withdrawal_Rate) that were computed at unscheduled updates. To facilitate this, GoldSim provides an option to do so (under a specified set of conditions) in the Advanced Time settings.

Read more: Including Unscheduled Updates in Time History Results (page 496).

Note: Most spreadsheet models implicitly compute *average* values (e.g., flows) over a step (or the change from one step to the next). You can compute average values such as these (e.g., in order to compare GoldSim with a spreadsheet model) by using Goldsim's Reporting Periods feature.

Read more: Defining Reporting Periods (page 479).

Note: As noted above, by default, GoldSim inserts an unscheduled update when the Reservoir reaches a **Lower Bound**. However, if desired, you can disable unscheduled updates (although it is generally not recommended). If you do so, the reported Withdrawal_Rate is the average rate over the next scheduled timestep and can be assumed to be constant. . (This option is accessed via the **Advanced…** button in the **Time** tab of the Simulation Setting dialog).

Read more: Controlling Unscheduled Updates (page 489).

Note: You can record when Reservoirs hit or depart from their **Upper** and **Lower Bounds** in the model's Run Log. This logging can be activated via the **General** tab of the Options dialog (accessed via **Model|Options** from the main menu).

Read more: The General Tab of the Options Dialog (page 466).

Note: In many material flow models, you will likely have multiple withdrawals from a Reservoir, with each withdrawal being directed to a different place. For example, if you were simulating a pond, you could imagine having three different withdrawals from the pond: 1) pumping out of the pond (e.g., to another pond); 2) leakage out the bottom pond (into the underlying ground); and 3) evaporation (into the atmosphere). In such a case, the Withdrawal_Rate output would represent the total withdrawal. In such a case, you should use the Pool element, which is an expanded version of the Reservoir specifically designed to handle multiple withdrawals.

Read more: Pool Elements (page 258).

The calculation of a Withdrawal_Rate can be further complicated because the **Lower Bound** can be specified to change with time (i.e., you could specify this input as being time-variable).

Note: If the **Lower Bound** is constant, the Value in the Reservoir will never fall below the **Lower Bound**. However, if the **Lower Bound** is changing with time, under some circumstances, it is possible for the Value of the Reservoir to fall below the **Lower Bound**. The primary purpose of the **Lower Bound** is to accurately compute the Withdrawal_Rate. If the **Lower Bound** exceeds the amount in the Reservoir (because the **Lower Bound** has changed during a timestep), the Reservoir will not permit any withdrawals until it returns to the **Lower Bound** (via additions).

As is the case with **Upper Bounds**, GoldSim carries out such calculations by assuming that bounds remain constant over a timestep. A simple example illustrating this is provided in the section discussing how GoldSim computes the Overflow_Rate with a changing **Upper Bound**.

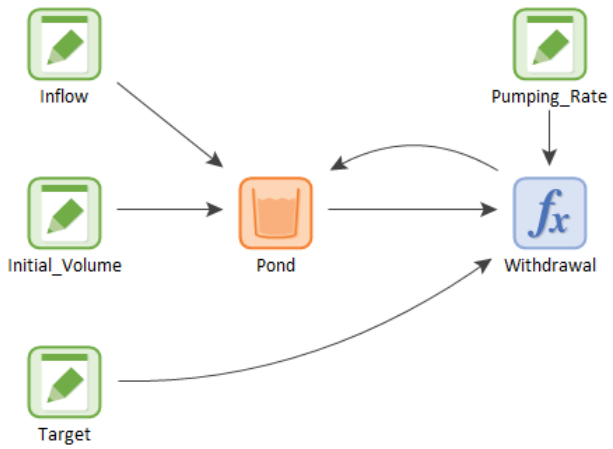
Read more: How a Reservoir Computes the Overflow Rate (page 248).

Note: Although GoldSim conserves mass when computing the actual withdrawal rate, it does not imply that the result is perfectly accurate. In fact, the accuracy of the result is a function of the timestep, since GoldSim is approximating continuously varying functions (i.e., rates and bounds) using stair-step functions. This approximation is discussed further in Appendix F.

Avoiding Oscillatory Behavior When Using Reservoirs

Some types of systems can exhibit oscillatory behavior, showing repetitive variation about a central value or between two or more different states. In some cases, this behavior is real. A pendulum is the classic example of such a system. It is also possible, however, to create logic that results in *unrealistic* oscillatory behavior. Most commonly, poor logic defining the Addition Rate and the Withdrawal Rate for a Reservoir can cause it to oscillate in an unrealistic manner.

To illustrate this, let's consider the example pictured below:



In this simple model, water flows into a pond at a constant rate (100 m^3/day), and we wish to actively control the volume of water in the pond (maintaining a target volume of 300 m^3) by turning a pump (that removes water from the pond) on and off in a specified manner. The pump, when on, pumps at a rate of 200 m^3/day.

The Withdrawal from the pond is defined as follows:

Equation

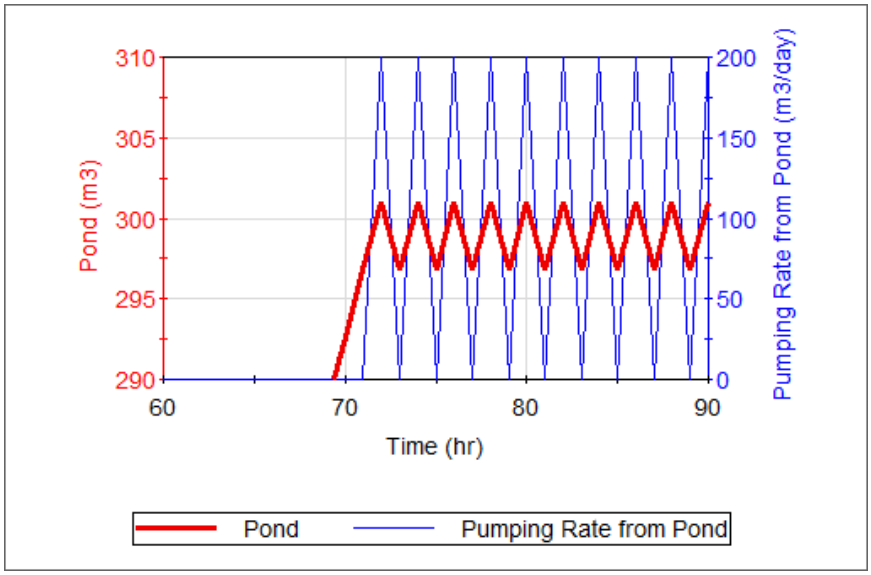
```
if(Pond>=Target, Pumping_Rate, 0 m3/day)
```

That is, when the pond volume is greater than or equal to the target volume, the pump is turned on. When it is below the target volume, it is turned off. Note that the Pumping_Rate is larger than the Inflow, so when the pump is turned on, the volume in the pond is reduced. This creates a ***feedback loop***between the pond volume and the withdrawal – it is an active feedback control system that is analogous to those common in many engineered systems.

Read more: Evaluating Feedback Loops (page 361).

But will this logic work? At first glance, it seems to make sense, but if you were run the model and look at the results, you would quickly realize that a real

system would be unlikely to be controlled by logic like this. The result looks like this:



As you can see, the pond fills up, and then oscillates right around 300 m3. As soon as it reaches the target, the pump turns on, the volume is reduced and the pump turns off, and so on. The timestep for this model is 1 hr, and the model oscillates back and forth every hour. In fact, if we reduced the timestep to 1 minute, as long as the pumping rate is high enough (and it is), it would oscillate every minute! Clearly, the system would never be designed to operate like this in the real world (e.g., the pump would not last very long if it was turned on and off every minute).

In this example, the goal is to control the Reservoir around a particular "target" level. Although this is a common objective (e.g., a thermostat), it is also quite common for feedback control systems like this to be used to control the behavior of a system as it approaches its bounds (and these are the situations most likely to result in oscillatory behavior). In this case, you can imagine the need to actively adjust flows as the volume approaches the bounds. Using similar logic as above, you might choose to turn off the pump when the pond empties and turn it on as soon as it exceeds zero:

Equation

```
if(Pond>0 m3, Pumping_Rate, 0 m3/day)
```

Unfortunately, such logic will often cause the model to oscillate even more rapidly than in the previous example. This is because GoldSim inserts unscheduled updates whenever a bound is reached. Logic such as this could result in the Reservoir continuously oscillating at the bound (with a timestep being inserted each time the bound is reached). This can result in timesteps being inserted practically continuously (e.g., every second or less)!

Read more: Understanding Timestepping in GoldSim (page 473).

So what is the proper way to model these kinds of systems? The key is to build logic that is realistic (i.e., logic that could actually be practically implemented in the real world). For example, if you really did want to manage a Reservoir to a target, what you would likely do is use what is referred to as a "deadband" or a target range within which the system is controlled. This is actually how a thermostat typically works (e.g., "turn the heat on when the temperature is 68

degrees and turn it off when it reaches 70 degrees"). You could implement this in GoldSim using a Status element.

Read more: Simulating a Deadband Using a Status Element (page 415).

When trying to control the behavior of a system as it approaches its bounds (as pointed out above, often the situations most likely to result in oscillatory behavior), it becomes particularly important to model the system realistically. In particular, additions/withdrawals should either 1) be changed abruptly *before* the bound is reached (e.g., a pump turns off when the water level drops to a certain level but before the pond is actually empty); or 2) gradually ramped down such that when the Reservoir reaches its bound, the additions/withdrawals have gradually changed to the appropriate value (e.g., gradually ramp the withdrawal rate down as the volume decreases until it reaches zero when the volume reaches the lower bound). If using the first approach, you would also likely implement a deadband, so that, for example, the pump turns off when the water level drops to a certain level (but before the pond is actually empty), and turns back on at some higher level.

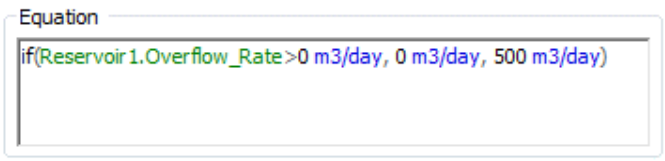
Using the Is_Full Output of a Reservoir

The Is_Full output is only available if you specify an **Upper Bound** for a Reservoir. It is a condition (False if the Reservoir is below the **Upper Bound**, and True if it is at the **Upper Bound**.

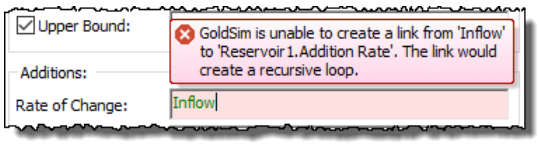
This output is useful because it is a special type of output called a ***state variable*** (the primary output of a Reservoir is also a state variable). This has the important implication that inputs to the Reservoir (e.g., the **Additions/Rate of Change**) can reference this output without causing a recursive error.

Read more: Evaluating Feedback Loops (page 361).

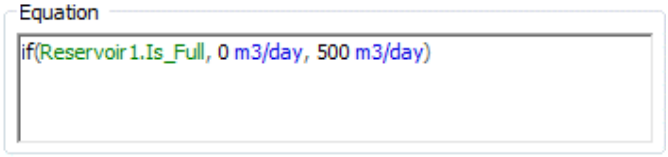
As an example, suppose that you wanted to add water to a Reservoir only if it was not overflowing; once it started to overflow, you wanted the flow rate to go to zero. To accomplish this, you could define an Expression for the inflow rate as follows:



Unfortunately, because the Overflow_Rate is not a state variable, if you then tried to link this Expression into the **Additions/Rate of Change** input for the Reservoir, you would get this error:



However, you can solve this problem by using the Is_Full output:



If the Expression was defined as above, then you could link to this Expression into the **Additions/Rate of Change** field without causing a recursive error.

Note: Although the Is_Full output allows you to create such feedback loops, you need to take care when using such logic to avoid creating unrealistic oscillatory behavior.

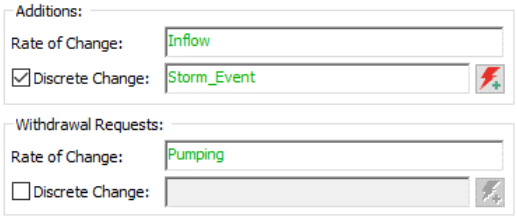
Read more: Avoiding Oscillatory Behavior When Using Reservoirs (page 254).

Specifying Discrete Additions and Withdrawals to a Reservoir

In addition to continuous Rates of Addition and Withdrawal Requests, Reservoirs can also accept discrete changes. That is, the Reservoirs actually compute their Value by accounting for discrete changes as follows:

$$\text{Value}(t_n) = \text{Initial Value} + \sum_{i=1}^{n} \text{Rate of Change}(t_i - \Delta t_i)\Delta t_i + \sum \text{Discrete Additions} - \sum \text{Discrete Withdrawals}$$

Discrete Additions and Withdrawals are specified by checking the **Discrete Change** box (in the **Additions** and/or **Withdrawal Requests** sections) and by specifying a link to a ***discrete change signal*** with an Add instruction:



Note that if you check a **Discrete Change** checkbox, GoldSim will add new outputs to the element (for **Additions**, Discrete_Overflow if there is an Upper Bound defined, and for **Withdrawal Requests**, Discrete_Withdrawals).

Read more: Basic Concepts of Discrete Event Modeling (page 366); Modeling Discrete Changes to a Reservoir (page 401).

Instantaneously Replacing the Current Value of a Reservoir

In some cases, you may want to instantaneously replace the current value of a Reservoir with a specified value.

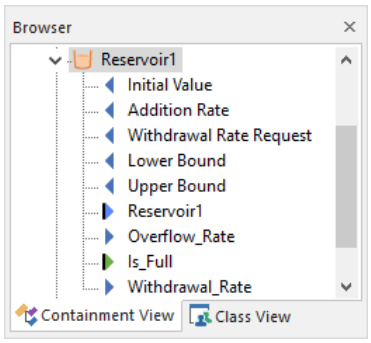
This can be accomplished by checking the **Additions** field and specifying a link to a ***discrete change signal*** with a Replace instruction

Read more: Basic Concepts of Discrete Event Modeling (page 366); Modeling Discrete Changes to a Reservoir (page 401).

Note: If you have specified an **Upper** or **Lower Bound**, and choose to Replace the current value of a Reservoir, the replacement value must be within the bounds (or GoldSim will display a fatal error message).

Browser View of a Reservoir Element

The browser view of a Reservoir element shows up to seven inputs and up to six outputs (depending on which boxes are checked in the dialog). If the **Upper** and **Lower Bound** boxes are checked, the browser view looks like this:



Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

Pool Elements

Pool elements are elements that, like Reservoirs, accumulate flows. And like Reservoirs, you can use them to accumulate and track material, such as the quantity of water in a lake, the amount of soil in a stockpile, the number of people in a city, and the number of widgets in a warehouse.

Their default symbol is very similar to that of a Reservoir - a container of water - since this is an excellent analogy for the behavior of the element. Like a container of water, a Pool element has a current value (e.g., the volume of water in the container), inflows, withdrawals and overflows.

Read more: Reservoir Elements (page 240).

A Pool is an expanded (and more powerful) version of the Reservoir element. It can do everything that a Reservoir can do (e.g., it can have Upper and Lower Bounds), but is different (and hence more powerful) in three important ways:

- Pools allow you to specify **Inflows** as separate and individual inputs. (Reservoirs provide only a single input for inflows).
- Pools allow you to specify **Requested Outflows** as separate and individual inputs. (Reservoirs provide only a single input for a "withdrawal request"). In turn, in addition to providing a "total outflow" output, Pools provide separate and individual outputs for each requested outflow. (Reservoirs provide only a single "withdrawal rate" output). This allows you to easily route different outflows to different locations.
- Because Pools allow you to specify multiple **Requested Outflows**, and it is possible (if the Pool reaches its Lower Bound) that the Pool may not be able to provide the total for all requests, you also specify Priorities for each requested outflow, and the total outflow is then allocated accordingly among the requests if the Pool is unable to provide all of the requests.

Note: Due to the differences pointed out above, if you are modeling a system that has multiple distinct outflows, you should use a Pool rather than a Reservoir.

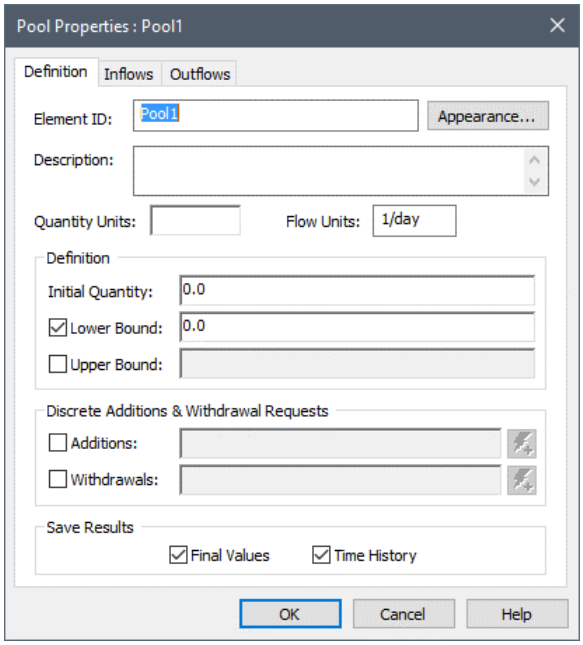
The fundamental inputs to a Pool are an **Initial Quantity**, **Inflows** and **Outflows**.

In the absence of Upper and Lower Bounds, the primary output of the Pool (its Quantity) is computed as follows:

$$\text{Quantity} = \text{Initial Quantity} + \int (\text{Inflows} - \text{Outflows})\, dt$$

The Inflows and Outflows can, of course, be functions of time.

The Properties dialog for a Pool element looks like this:



The Pool dialog has three tabs: a **Definition** tab (where the **Units**, **Initial Quantity**, **Lower Bound**, **Upper Bound** and discrete **Additions** and **Withdrawals** are specified), an **Inflows** tab (where inflows to the Pool are specified), and an **Outflows** tab (where requested outflows from the Pool are specified).

All Pools have the following outputs:

- The quantity in the Pool (the primary output, having the same name as the element);
- The Total_Inflow to the Pool (simply the sum of all the Inflow inputs);
- The Total_Request from the Pool (simply the sum of all the Requested Outflow inputs);
- The Total_Outflow from the Pool (which is always less than or equal to the Total_Request); and
- Each individual Outflow from the Pool (whose names are user-defined).

Optional outputs include:

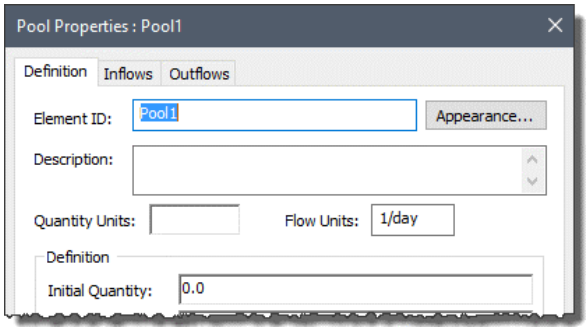
- The Overflow from the Pool (only available if an Upper Bound is defined);
- Is_Full, a condition indicating whether or not the Pool is at its Upper Bound (only available if an Upper Bound is defined);

- Discrete_Overflow, a discrete change signal (only available if an Upper Bound is defined and a Discrete Addition is specified); and
- Discrete_Withdrawals, a discrete change signal (only available if a Discrete Withdrawal is specified).

An example model which illustrates the basic use of Pool elements (Pool.gsm), as well as a model illustrating more advanced features (PoolAdvanced.gsm) can be found in the General Examples/Stocks folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Specifying the Dimensions and Initial Quantity for a Pool

Within the Properties dialog, two sets of **Units** must be specified for a Pool (the **Quantity Units** and the **Flow Units**):



The primary output of a Pool is its Current Value (its Quantity). The **Quantity Units** determine the dimensions of this output. This output is always a value (it cannot be a condition). Moreover, it can only be a scalar (and hence, all of the inputs for the element must be scalars).

Note: If you need to model a vector or matrix quantity, you must use a Reservoir element

The **Flow Units** determine the display units for the Outflow outputs of the element. The dimensions of this output must be the same as those of the Quantity divided by Time. For example, if the **Quantity Units** have dimensions of Volume, the **Flow Units** must have dimensions of Volume/Time.

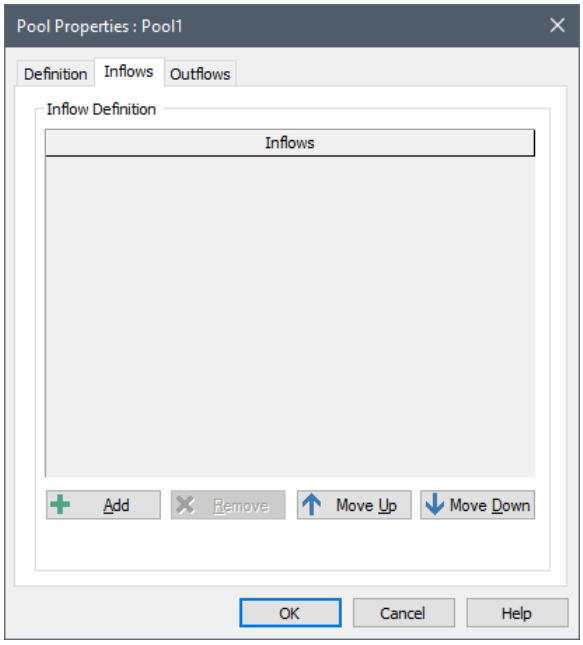
Note: GoldSim encourages (but does not require) you to specify **Quantity Units** for a Pool whose dimensions are consistent with materials. In particular, it expects the units to have dimensions of mass, volume, energy, amount, currency, or to be dimensionless. When you first specify your **Quantity Units**, GoldSim will warn you if your units do not have one of these dimensions. GoldSim will not, however, prevent you from using other units.

The **Initial Quantity** input to the Pool must have the same dimensions at the **Quantity Units**.

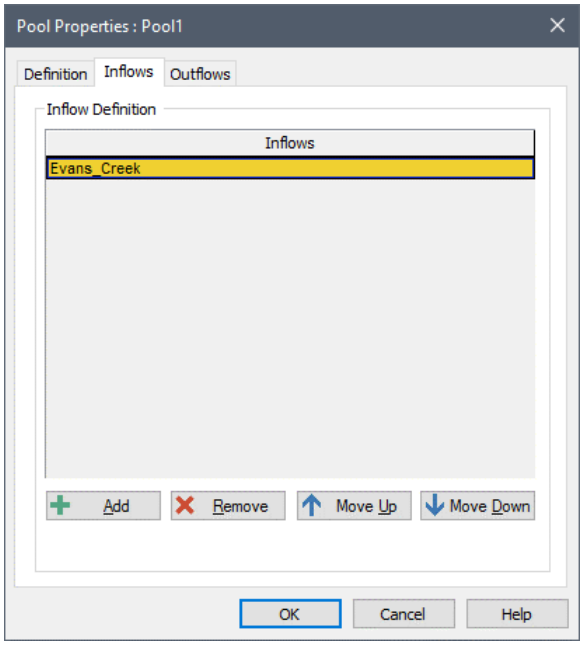
Note: The **Initial Quantity** must be a number or a link from a static variable (e.g., a constant Data element or a Stochastic).

Specifying the Inflow Rates for a Pool

The inflows to a Pool are specified using the **Inflows** tab:



You can add **Inflows** by pressing the **Add** button. A browser tree showing all of the elements in the model will be displayed. Note that this tree is organized by *containment* in the same manner as the main browser. To insert a link from this dialog, you select a specific output (or an element having a primary output), and then press **OK**. If you press **Cancel**, GoldSim will insert a new blank (zero) item. In either case, the dialog will close and the item will be added to the list Inflows:



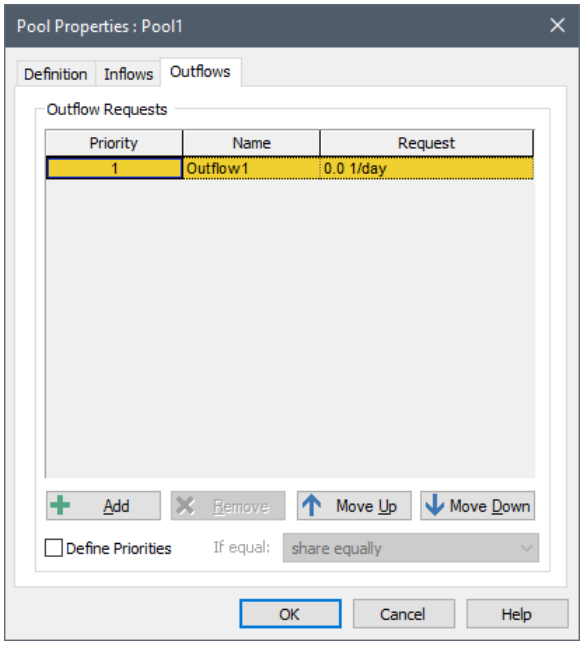
Inflows can be deleted using the **Remove** button moved up and down in the list using the two buttons to the right of the **Remove** button.

Inflows can be specified as constants or expressions and/or links, and may change with time. All **Inflows** must be non-negative values. Negative values for these inputs during a simulation will result in a fatal error.

Note: The specified **Inflows** represent constant rates over the *next* timestep. Hence, if an Inflow was defined as "if(time > 10 day, 2 m^3/day, 1 m^3/day)", and you were using a 1 day timestep, the rate would not actually change to 2 m^3/day until time = 11 days. That is, since at time = 10 days, the if statement indicates that the rate is equal to 1 m^3/day, GoldSim would assume that the rate was equal to 1 m^3/day between 10 days and 11 days. If you wanted the rate to change at 10 days, you would write the if statement as "if(time >= 10 day, 2 m^3/day, 1 m^3/day)".

Specifying the Outflow Requests for a Pool

The outflow requests from a Pool are specified using the **Outflows** tab:



By default, a Pool element initially has one **Outflow Request** (named Outflow1). You can add additional **Outflow Requests** by pressing the **Add** button. Outflows can be deleted using the **Remove** button, and moved up and down in the list using the two buttons to the right of the **Remove** button.

Note: You cannot delete an **Outflow Request** if it is the only one (there must always be one). Of course, it can be set to zero (which is the default).

The names of the Outflows can be changed by editing the items in the **Name** column.

For each **Outflow Request** in the list, you specify the actual **Request**. The **Request** has the same dimensions as the **Flow Units**.

Read more: Specifying the Dimensions and Initial Quantity for a Pool (page 260).

Requests can be specified as constants or expressions and/or links, and may change with time.

Note: The specified **Requests** represent constant rates over the *next* timestep. Hence, if a Request was defined as "if(time > 10 day, 2 m^3/day, 1 m^3/day)", and you were using a 1 day timestep, the Request would not actually change to 2 m^3/day until time = 11 days. That is, since at time = 10 days, the if statement indicates that the Request is equal to 1 m^3/day, GoldSim would assume that the Request was equal to 1 m^3/day between 10 days and 11 days. If you wanted the Request to change at 10 days, you would write the if statement as "if(time >= 10 day, 2 m^3/day, 1 m^3/day)".

GoldSim sums the **Outflow Requests** to compute the Total_Request output. If the Pool stays above the **Lower Bound** (or there is no specified **Lower Bound**), then the Total_Outflow output is equal to the Total_Request. If the Pool reaches the **Lower Bound**, however, GoldSim compares the Total_Request to the amount of material available, and the Total_Outflow is computed such that it represents what can actually be withdrawn from the Pool at that time (which, depending on the **Inflows**, may be less than the Total_Request).

Read more: How a Pool Computes the Total Outflow (page 269).

Note that if the Total_Outflow is limited (such that it is less than the Total_Request), and there are multiple **Outflow Requests**, it becomes necessary to allocate the Total_Outflow among the requests. This is done based on the specified **Priority** for each Outflow Request.

Read more: How a Pool Computes the Individual Outflows (page 271).

How a Pool Element Computes its Primary Output (the Quantity)

Numerically, GoldSim approximates the integral represented by a Pool as a sum:

$$\text{Quantity}(t_n) = \text{Initial Quantity} + \sum_{i=1}^{n} \left[\text{Inflows}(t_i - \Delta t_i) - \text{Outflows}(t_i - \Delta t_i)\right]\Delta t_i$$

In these equations, Δt_i is the timestep length just prior to time t_i (typically this will be constant in the simulation), and Quantity(t_n) is the value at end of timestep n. Note that the Quantity at time t_i is a function of the Inflows and Outflows at previous timesteps (but is not a function of these flows at time t_i).

Note that if you specify **Upper** or **Lower Bounds** for a Pool, the equation shown above is constrained by the specified bounds (i.e., the Quantity cannot exceed the **Upper Bound** and can not be less than the **Lower Bound**).

Read more: Defining Upper and Lower Bounds for a Pool (page 264).

Pools, Reservoirs and Integrators use the same numerical integration method, referred to as Euler Integration. A simple example illustrating this integration method is provided in the section discussing how an Integrator element computes its output.

Read more: How an Integrator Element Computes its Output (page 234).

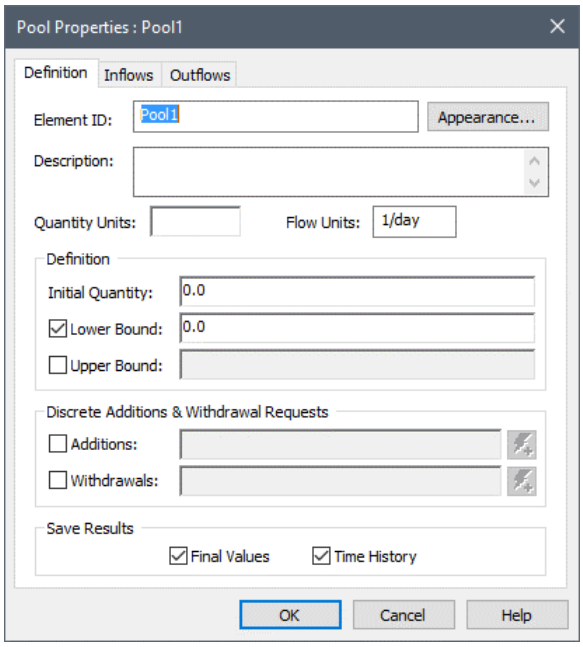
The key assumption involved in this integration method is that at any point in time, the rates (**Inflows** and **Outflow Requests**) represent the rates over the next timestep, and those rates are assumed to be constant over the timestep. Euler Integration is discussed in additional detail in Appendix F.

Note: Euler integration is the simplest and most common method for numerical integration. However, if the timestep is large, this method can lead to significant errors. This is particularly important for certain kinds of systems in which the error is cumulative (e.g., sustained oscillators such as a pendulum). In these cases, these errors can be reduced by using Containers with Internal Clocks, which allow you to locally use a much smaller timestep.

Read more: Specifying Containers with Internal Clocks (page 493).

Defining Upper and Lower Bounds for a Pool

One of the powerful features of a Pool is that you can specify a **Lower** and/or **Upper Bound**. If the **Lower Bound** and **Upper Bound** boxes are cleared for a Pool, the Quantity is not constrained and is unbounded. These Bounds are defined on the default (**Definition**) tab of the Pool element:



By default, when you create a new Pool element, a **Lower Bound** of 0 is assumed. You can subsequently remove the **Lower Bound**, or modify it.

Checking one or both of these boxes, however, provides additional functionality and has important impacts on the outputs for the element. In particular:

- If the **Lower Bound** is checked, GoldSim enforces that limitation on the Quantity. As a result, the Total_Outflow output is not necessarily equal to the Total_Request output (which simply sums the **Outflow Requests**). In this case, the Total_Outflow output represents the actual outflow from the Pool, which may be less than the specified sum of the **Outflow Requests** (which represents the demand or requested outflow).

  For example, if the Pool is at the **Lower Bound**, and there are no **Inflows**, the Total_Outflow output must be equal to zero, regardless of the Total_Request (there is no material available to outflow). Similarly, if the Pool is at the **Lower Bound**, and the **Inflows** total to 10, the Total_Outflow output can be no greater than 10, regardless of

the Total_Request (if there is no storage, you cannot outflow more than is being supplied via inflow).

Note: If the **Lower Bound** is constant, the Quantity in the Pool will never fall below the **Lower Bound**. However, if the **Lower Bound** is changing with time, under some circumstances, it is possible for the Quantity in the Pool to fall below the **Lower Bound**. The primary purpose of the **Lower Bound** is to accurately compute the Total_Outflow. If the **Lower Bound** exceeds the amount in the Pool (because the **Lower Bound** has changed during a timestep), the Pool will not permit any outflows until it returns to the **Lower Bound** (via inflows).

- If the **Upper Bound** is checked, GoldSim enforces that limitation on the Quantity. GoldSim also adds two new (secondary) outputs: Overflow (a value) and Is_Full (a condition). If the Quantity is below the **Upper Bound**, the Overflow output is equal to zero and the Is_Full output is False. If the Quantity is at the **Upper Bound**, the Overflow output is equal to the difference between the sum of the specified **Inflows** and the sum of the specified **Requested Outflows** and the Is_Full output is True.

  Read more: Using the Is_Full Output of a Pool (page 278).

Note: If the **Upper Bound** is constant, the Quantity in the Pool will never exceed the **Upper Bound**. However, if the **Upper Bound** is changing with time, under some circumstances, it is possible for the Quantity in the Pool to exceed the **Upper Bound**. If the **Upper Bound** is exceeded (because it has changed during a timestep), GoldSim will overflow the excess uniformly over the next timestep.

Note: If your specified **Upper Bound** is reached during a simulation, and the Overflow output is not referenced by any other element (e.g., as an inflow to another Pool), GoldSim will display a warning, as this could indicate that you have neglected to track flows leaving the Pool.

The Pool element is particularly powerful because it enforces the bounds while properly conserving the material being tracked. That is, if a Pool's **Inflows** cause it to reach its **Upper Bound**, GoldSim produces an Overflow (which can be routed, for example, to a downstream Pool). Similarly, if the sum of the **Outflow Requests** exceeds what can actually be delivered, GoldSim accurately reports the actual Total_Outflow.

Furthermore, the **Upper** and **Lower Bounds** can be specified as functions of time. This allows you to simulate systems such as a pond which is filling up with silt and sand (and hence decreasing its capacity), and a warehouse whose capacity is being expanded (via construction) throughout a simulation.

An example model which illustrates a changing Upper Bound in a Pool element (PoolAdvanced.gsm) can be found in the General Examples/Stocks folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

The **Lower Bound** and the **Upper Bound** inputs to the Pool must have the same dimensions as the Pool's **Quantity Units**. In addition, the following limitations imposed on the inputs should be specifically noted:

- The **Upper Bound** must be greater than or equal to the **Lower Bound**.
- The **Initial Quantity** must be greater than or equal to the **Lower Bound** and less than or equal to the **Upper Bound**.

How a Pool Computes the Overflow

The Overflow output of a Pool has meaning (and is computed) only if you have specified an **Upper Bound**. GoldSim computes the Overflow such that the flowing material (e.g., water, widgets, people, rocks) is conserved. To understand how it does so, recall the key assumption regarding the Euler integration method: *The specified Rates (**Inflows** and **Outflow Requests**) represent constant rates over the next timestep*.

Hence, at the beginning of a timestep, GoldSim can project what the Quantity will be at the end of timestep, compare it to the **Upper Bound**, and easily compute an Overflow for that timestep. To illustrate this, consider the following simple example. Assume we are modeling a pond with an **Upper Bound** of 3000 m^3, and that at time = 10 days, the pond contains 2700 m^3 of water. Let's further assume that our model has a 2 day timestep. Assume that for times greater than 10 days, the **Inflows** and the **Outflow Requests** are constant and equal to 500 m^3/day and 100 m^3/day, respectively, so that the pond will fill up and start to overflow at 10.75 days.

In order to compute overflow rates accurately, by default GoldSim inserts an "unscheduled update" when the Pool reaches an **Upper Bound**. Unscheduled updates are timesteps that are automatically inserted by GoldSim during the simulation in order to more accurately simulate the system.

Read more: Understanding Timestepping in GoldSim (page 473).

In particular, the Overflow for the example described above is treated as follows. At 10 days, GoldSim would report an (instantaneous) Overflow of zero. A new timestep (an "unscheduled update") would then be inserted at 10.75 days when the pond would start to overflow. The Overflow at this time would actually be internally calculated as 400 m^3/day. However, because by default GoldSim only reports values at scheduled timesteps (e.g., 10 days, 12 days), the Overflow will not be displayed as 400 m^3/day until 12 days.

Hence, it is important to understand that the Overflow represents the *instantaneous* overflow rate at the reported time. You cannot assume that this rate is constant over the next scheduled timestep. That is, it would be incorrect to assume that the Overflow was zero between 10 and 12 days. In fact, at 10 days, the Overflow was indeed 0 m^3/day, but it changed to 400 m^3/day at 10.75 days (between the scheduled updates). Because 10.75 days is an unscheduled timestep, you would not see this in a time history plot. However, if the Overflow was integrated (e.g., using an Integrator or a Reservoir that represented the total amount of water that has overflowed), the following results would be obtained:

Time (days)	Reported Overflow Rate (m^3/day)	Total Water Overflowed (m^3)
8	0	0
10	0	0
12	400	500
14	400	1300

Note that the amount of water is properly conserved. At 12 days, the pond has been overflowing for 1.25 days (at a rate of 400 m^3/day), so that a total volume of 500 m3 has overflowed. At 14 days, the pond as been overflowing for 3.25 days, so a total volume of 1300 m^3 has overflowed.

Note: In some cases, it may be of interest to see the output values (such as the Overflow) that were computed at unscheduled updates. To facilitate this, GoldSim provides an option to do so (under a specified set of conditions) in the Advanced Time settings.

Read more: Including Unscheduled Updates in Time History Results (page 496).

Note: Most spreadsheet models implicitly compute *average* values (e.g., flows) over a step (or the change from one step to the next). You can compute average values such as these (e.g., in order to compare GoldSim with a spreadsheet model) by using Goldsim's Reporting Periods feature.

Read more: Defining Reporting Periods (page 479).

Note: As noted above, by default, GoldSim inserts an unscheduled update when the Pool reaches an **Upper Bound**. However, if desired, you can disable unscheduled updates (although it is generally not recommended). If you do so, the reported Overflow is the average rate over the next scheduled timestep and can be assumed to be constant. (This option is accessed via the **Advanced…** button in the **Time** tab of the Simulation Setting dialog).

Read more: Controlling Unscheduled Updates (page 489).

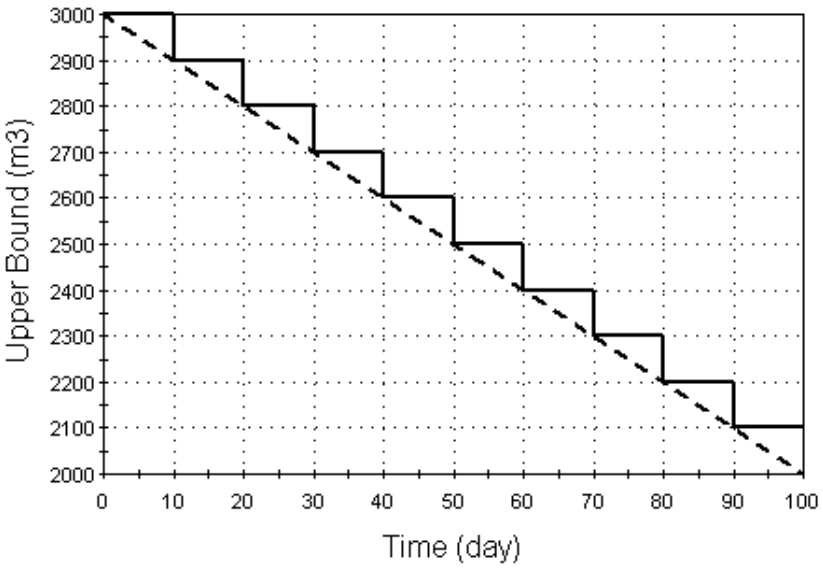
Note: You can record when Pools hit or depart from their **Upper** and **Lower Bounds** in the model's Run Log. This logging can be activated via the **General** tab of the Options dialog (accessed via **Model|Options** from the main menu).

Read more: The General Tab of the Options Dialog (page 466).

The calculation of the Overflow is further complicated because the **Upper Bound** can be specified to change with time (i.e., you could specify this input as being time-variable). If you do so, GoldSim makes the following assumption:

like the **Inflows and Outflow Requests**, the **Upper Bound** is assumed to remain constant over a timestep.

For example, if you specify that the **Upper Bound** varies linearly from 3000 m^3 to 2000 m^3 over 100 days, and simulate the system with a 10 day timestep, GoldSim will approximate the **Upper Bound** curve internally as a stair-step function:



The dashed line represents the Specified Upper Bound
The solid line represents the Upper Bound as simulated by GoldSim, assuming a 10 day timestep

Hence, within a given timestep, GoldSim follows the same logic outlined in the previous example to compute the Overflow for that timestep.

Note that an Overflow can be generated even if there is no net inflow of material into the Pool. This can happen if the **Upper Bound** decreases below the value of the Quantity. To illustrate this, consider the following simple example. Assume we are modeling a pond with an **Upper Bound** of 3000 m^3. Further assume that at the beginning of a timestep, the pond contains 2700 m^3 of water. There are no further inflows or outflows from the pond. However, assume that over the next timestep, the **Upper Bound** decreases from 3000 m^3 to 2500 m^3 (e.g., it fills up with silt).

How would GoldSim handle this? During the timestep the **Upper Bound** would be assumed to remain at 3000 m^3. At the beginning of the following timestep, however, it would instantaneously decrease to 2500 m^3. This would result in 2700 – 2500 = 200 m^3 of water that would instantaneously have to overflow. GoldSim actually spreads this out over the following timestep, such that with a 2 day timestep, the Overflow over the following timestep would be 200/2 = 100 m^3/day.

Note: If the **Upper Bound** is constant, the Quantity in the Pool will never exceed the **Upper Bound**. However, if the **Upper Bound** is changing with time, under some circumstances, it is possible for the Quantity of the Pool to exceed the **Upper Bound**. If the **Upper Bound** is exceeded (because it has changed during a timestep), GoldSim will overflow the excess uniformly over the next timestep.

Note: Although GoldSim conserves mass in these situations, this does not imply that the result is perfectly accurate. In fact, the accuracy of the result is a function of the timestep, since GoldSim is approximating continuously varying functions (i.e., rates and bounds) using stair-step functions. This approximation is discussed further in Appendix F.

How a Pool Computes the Total Outflow

In the absence of a **Lower Bound**, the Total_Outflow output is equal to the Total_Request output (which simply sums the **Outflow Requests**). However, if a **Lower Bound** is specified, the Total_Outflow output represents the actual rate of outflow from the Pool, which may be less than the specified sum of the **Outflow Requests** (which can be thought of as the demand or requested rate of withdrawal).

Note: The Total_Outflow is completely independent of and does not include the Overflow. The Total_Outflow only only considers outflows resulting from the **Outflow Requests** on the **Outflow** tab.

GoldSim compares the sum of the **Outflow Requests** to the amount of material available, and only outflows what can actually be withdrawn from the Pool over the timestep. Hence, if the Quantity is above the **Lower Bound** throughout the timestep, the Total_Outflow output is exactly equal to the sum of the specified **Outflow Requests**. If the Quantity is at the **Lower Bound** throughout the timestep, the Total_Outflow output is equal to the sum of the specified **Inflows**.

If the Pool reaches (or leaves) the **Lower Bound** during the timestep, GoldSim uses logic similar to that for computing overflow rates in order to correctly compute the actual Total_Outflow. In order to compute the Total_Outflow accurately, by default GoldSim inserts an "unscheduled update" when the Pool reaches a **Lower Bound**. Unscheduled updates are timesteps that are automatically inserted by GoldSim during the simulation in order to more accurately simulate the system.

Read more: Understanding Timestepping in GoldSim (page 473).

To illustrate how GoldSim treats outflow rates, consider the following simple example. Assume we are modeling a pond with a **Lower Bound** of zero. Further assume that at time = 10 day, the pond contains 200 m^3 of water. GoldSim computes the constant **Inflows** and the **Outflow Requests** for times greater than 10 days to be 100 m^3/day and 300 m^3/day, respectively. Therefore, the pond will run out of water at 11 days. Let's further assume that our model has a 2 day timestep (so that this occurs in the middle of the scheduled timesteps).

The Total_Outflow is computed as follows. At 10 days, GoldSim will report a Total_Outflow of 300 m^3/day. A new timestep (an "unscheduled update") is then inserted at 11 days when the pond becomes empty. The Total_Outflow at this time will actually be internally calculated as 100 m^3/day (since the pond is

empty, the Total_Outflow can be no greater than the sum of the **Inflows**. However, because by default GoldSim only reports values at scheduled timesteps (e.g., 10 days, 12 days), the Total_Outflow will not be displayed as 100 m^3/day until 12 days.

Hence, it is important to understand that the Total_Outflow represents the *instantaneous* outflow rate at the reported time. You cannot assume that this rate is constant over the next scheduled timestep. That is, it would be incorrect to assume that the Total_Outflow was 300 m^3/day between 10 and 12 days. In fact, at 10 days, the Total_Outflow was indeed 300 m^3/day, but it changed to 100 m^3/day at 11 days (between the scheduled updates). Because 11 days is an unscheduled timestep, you would not see this in a time history plot. However, if the Total_Outflow was integrated (using an Integrator or a Reservoir that represented the total amount of water that had outflowed), the following results would be obtained:

Time (days)	Reported Total Outflow (m^3/day)	Total Water Outflowed (m^3)
10	300	0
12	100	400
14	100	600

Note that the amount of water is properly conserved. At 12 days, the pond has been empty for 1 day (and hence the Total_Outflow during that period has been equal to the inflow rate of 100 m^3/day), so that a total volume of 300 m^3/day * 1 day + 100 m^3/day * 1 day = 400 m^3 has outflowed. At 14 days, the pond as been empty for 3 days, so that a total volume of 300 m^3/day * 1 day + 100 m^3/day * 3 day = 600 m^3 has outflowed.

Note: In some cases, it may be of interest to see the values (such as the Total_Outflow) that were computed at unscheduled updates. To facilitate this, GoldSim provides an option to do so (under a specified set of conditions) in the Advanced Time settings.

Read more: Including Unscheduled Updates in Time History Results (page 496).

Note: Most spreadsheet models implicitly compute *average* values (e.g., flows) over a step (or the change from one step to the next). You can compute average values such as these (e.g., in order to compare GoldSim with a spreadsheet model) by using Goldsim's Reporting Periods feature.

Read more: Defining Reporting Periods (page 479).

Note: As noted above, by default, GoldSim inserts an unscheduled update when the Pool reaches a **Lower Bound**. However, if desired, you can disable unscheduled updates (although it is generally not recommended). If you do so, the reported Total_Outflow is the average rate over the next scheduled timestep and can be assumed to be constant. . (This option is accessed via the **Advanced…** button in the **Time** tab of the Simulation Setting dialog).

Read more: Controlling Unscheduled Updates (page 489).

Note: You can record when Pools hit or depart from their **Upper** and **Lower Bounds** in the model's Run Log. This logging can be activated via the **General** tab of the Options dialog (accessed via **Model|Options** from the main menu).

Read more: The General Tab of the Options Dialog (page 466).

The calculation of a Total_Outflow can be further complicated because the **Lower Bound** can be specified to change with time (i.e., you could specify this input as being time-variable).

Note: If the **Lower Bound** is constant, the Quantity in the Pool will never fall below the **Lower Bound**. However, if the **Lower Bound** is changing with time, under some circumstances, it is possible for the Quantity of the Pool to fall below the **Lower Bound**. The primary purpose of the **Lower Bound** is to accurately compute the Total_Outflow. If the **Lower Bound** exceeds the amount in the Pool (because the **Lower Bound** has changed during a timestep), the Pool will not permit any outflows until it returns to the **Lower Bound** (via additions).

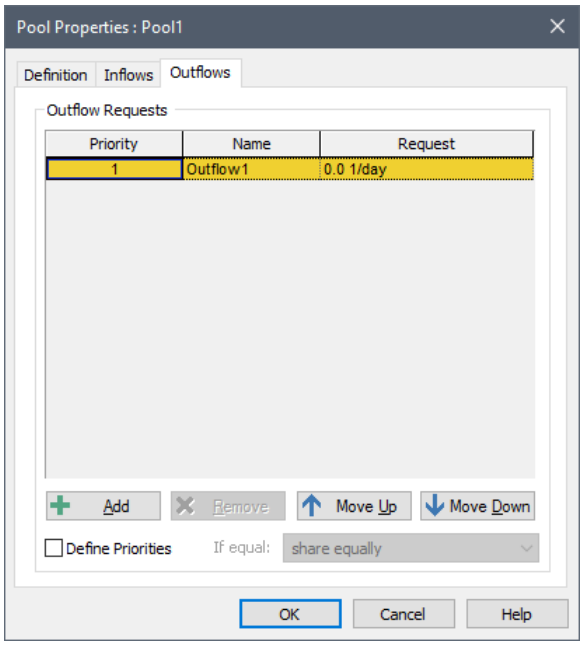
As is the case with **Upper Bounds**, GoldSim carries out such calculations by assuming that bounds remain constant over a timestep. A simple example illustrating this is provided in the section discussing how GoldSim computes the Overflow with a changing **Upper Bound**.

Read more: How a Pool Computes the Overflow (page 266).

Note: Although GoldSim conserves mass when computing the actual outflow, it does not imply that the result is perfectly accurate. In fact, the accuracy of the result is a function of the timestep, since GoldSim is approximating continuously varying functions (i.e., rates and bounds) using stair-step functions. This approximation is discussed further in Appendix F.

How a Pool Computes the Individual Outflows

The **Outflow Requests** from a Pool are specified using the **Outflows** tab:

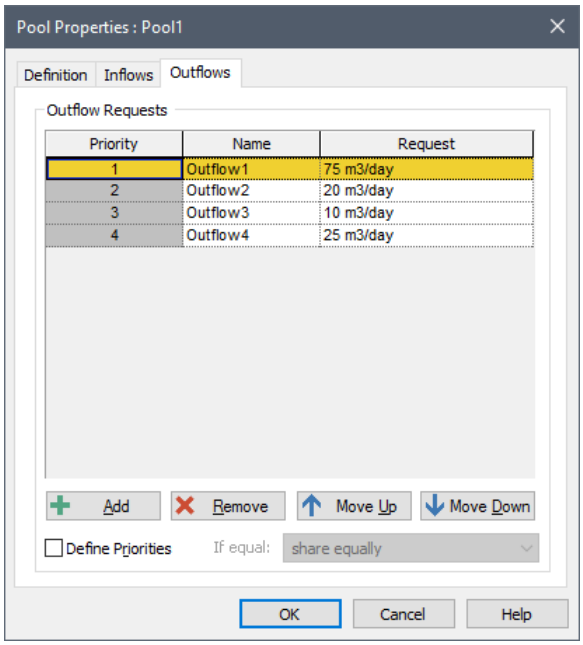


GoldSim sums the **Outflow Requests** to compute the Total_Request output. If the Pool stays above the **Lower Bound** (or there is no specified **Lower Bound**), then the Total_Outflow output is equal to the Total_Request. If the Pool reaches the **Lower Bound**, however, GoldSim compares the Total_Request to the amount of material available, and the Total_Outflow is computed such that it represents what can actually be withdrawn from the Pool at that time (which, depending on the **Inflows**, may be less than the Total_Request).

Read more: How a Pool Computes the Total Outflow (page 269).

Note that if the Total_Outflow is limited (such that it is less than the Total_Request), and there are multiple **Outflow Requests**, it becomes necessary to allocate the Total_Outflow among the requests. This is done based on the specified **Priority** for each **Outflow Request**. **Outflow Requests** with lower valued Priorities are met first (i.e., Priority 1 is met before Priority 2).

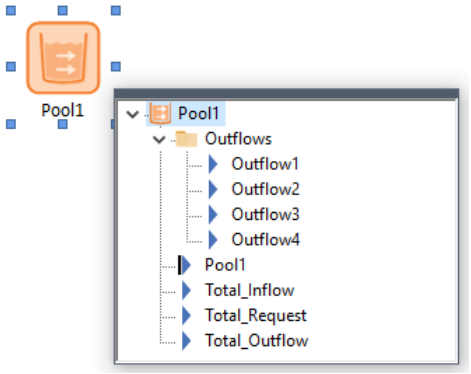
To illustrate this, consider the following example:



The Total_Request output (the sum of the individual **Outflow Request** inputs) is 130 m^3/day.

Let's further assume that throughout the simulation, the Pool is always above its **Lower Bound**. In this simple case, the Total_Outflow output would be the same as the Total_Request output (130 m^3/day). As a result, the Priority for each Request would never need to be considered (each individual outflow would receive its entire **Request**).

The outputs for this Pool would look like this:



Note that the "Outflows" folder contains each of the individual outflows.

Now let's complicate this example a bit more. Let's assume that the Pool is empty (at its **Lower Bound**), but the **Inflows** to the Pool sum to 100 m^3/day. In this case, since the Total_Request is equal to 130 m^3/day, the Pool would remain empty (more is requested than in coming in, and there is nothing available from storage). Moreover, the Total_Outflow would be limited to 100 m^3/day. As a result, it is necessary to allocate the Total_Outflow among the requests. This is done based on the specified **Priority** for each **Outflow Request**. **Outflow Requests** with lower valued Priorities are met first (i.e., Priority 1 is met before Priority 2).

In this case, Outflow1 would have a value of 75m^3/day (its entire request would be met), Outflow2 would have a value of 20m^3/day (its entire request would be met), Outflow3 would have a value of 5m^3/day (only part of its request would be met), and Outflow4 would have a value of 0m^3/day (none of its request would be met).

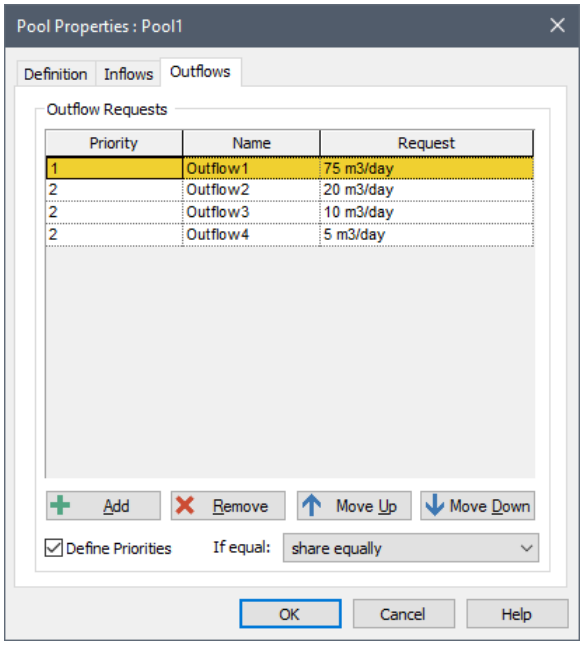
By default, each output has a fixed (and unique) **Priority** (which is an integer). The **Priority** of the outputs always decrease downward (with the first item having a **Priority** of 1). **Priority** 1 therefore represents the highest priority demand, 2 the next highest, and so on. You can move outflows up and down the **Priority** list using the **Move Up** and **Move Down** buttons.

If you check the **Define Priorities** checkbox, the **Priority** column becomes editable. In this case, the Priorities can be specified as constants or expressions and/or links, and may change with time. They do not need to be integers and can be any real value (positive or negative). Outflows with lower valued Priorities are met first (e.g., Priority -2.4 is met before Priority 5.7).

You can also assigned the same **Priority** to multiple **Outflow Requests**. If multiple **Outflow Requests** have the same **Priority**, you can specify the manner in which equal priorities are treated in the **If equal** field. There are two options: 1) "share equally"; or 2) "share proportional to requests".

If "share equally" (the default) is selected, each **Outflow Request** with equal **Priority** receives the same amount up until either its request is satisfied, or nothing more is available. The calculation is carried out recursively starting with the smallest request.

To illustrate this, consider the following example:



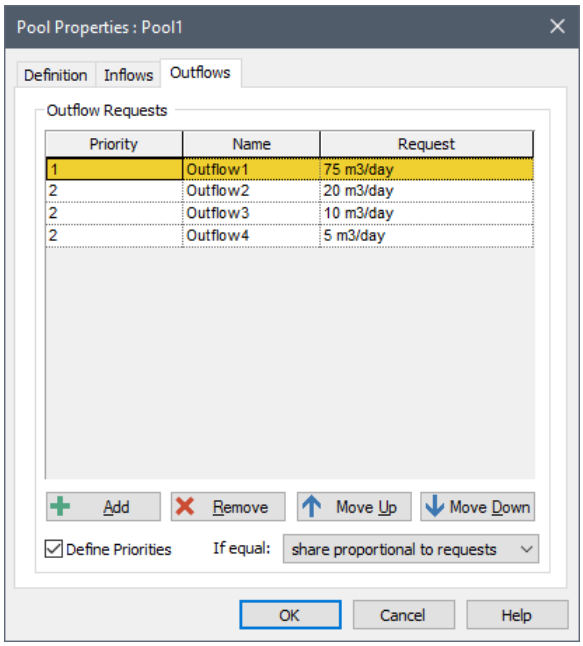
Again, let's assume that the Pool is empty (at its **Lower Bound**), but the **Inflows** to the Pool sum to 100 m^3/day. In this case, since the Total_Request is equal to 110 m^3/day, the Pool would remain empty (more is requested than in coming in, and there is nothing available from storage). Moreover, the Total_Outflow would be limited to 100 m^3/day. As a result, it is necessary to allocate the Total_Outflow among the requests. Note, however, that the final three requests all have the same **Priority**.

In this case, Outflow1 would have a value of 75m^3/day (its entire request would be met), Outflow2, Outflow3 and Outflow4 would share the remainder (25m^3/day) as follows:

- Outflow4 would receive its full request (5m^3/day); Outflow2 and Outflow3 would receive the same amount (5m^3/day). This leaves 10m^3/day to be allocated.
- Outflow2 and Outflow3 would then equally share the remaining 10m^3/day (such that each would receive a total of 10m^3/day). So Outflow3 and Outflow4 would meet their demands, and Outflow2 would not.

If "share proportional to requests" is selected, if there is not enough supply to meet all of the requests, it is shared proportionally according to the request.

To illustrate this, consider the same example as above, with proportional sharing:



In this case, Outflow1 would still have a value of 75m^3/day (its entire request would be met), Outflow2, Outflow3 and Outflw4 would share the remainder (25m^3/day) as follows:

- Outflow2 would receive 20/35 = 57.1% of the remaining 25 m^3/day.
- Outflow3 would receive 10/35 = 28.6% of the remaining 25 m^3/day.
- Outflow4 would receive 5/35 = 14.3% of the remaining 25 m^3/day.

The table below summarizes the results for these two examples (note that the Total_Inflow (and Total_Outflow) is 100m^3/day and the Total_ Request is 110 m^3/day):

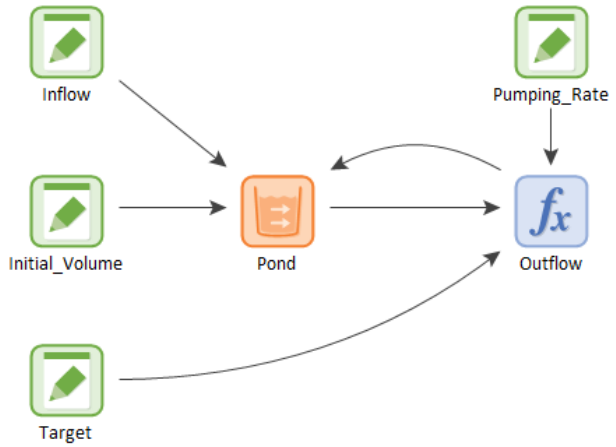
Outflow	Priority	Request (m^3/day)	Result with equal sharing (m^3/day)	Result with proportional sharing (m^3/day)
Ourflow1	1	75	75	75
Ourflow2	2	20	10	14.3
Ourflow3	2	10	10	7.1
Ourflow4	2	5	5	3.6

Note: The algorithm described above is the same algorithm used by the Allocator element. In fact, a Pool can be thought of as a combination of a Reservoir and an Allocator.

Avoiding Oscillatory Behavior When Using Pools

Some types of systems can exhibit oscillatory behavior, showing repetitive variation about a central value or between two or more different states. In some cases, this behavior is real. A pendulum is the classic example of such a system. It is also possible, however, to create logic that results in *unrealistic* oscillatory behavior. Most commonly, poor logic defining the **Inflows** and the **Outflow Requests** for a Pool can cause it to oscillate in an unrealistic manner.

To illustrate this, let's consider the example pictured below:



In this simple model, water flows into a pond at a constant rate (100 m^3/day), and we wish to actively control the volume of water in the pond (maintaining a target volume of 300 m^3) by turning a pump (that removes water from the pond) on and off in a specified manner. The pump, when on, pumps at a rate of 200 m^3/day.

The (single) **Outflow Request** from the pond is defined as follows:

Equation

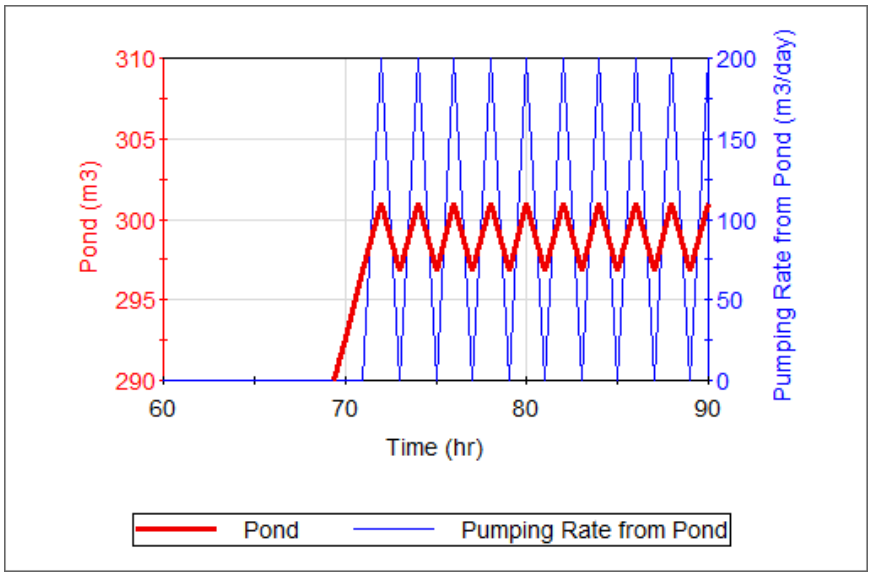
```
if(Pond>=Target, Pumping_Rate, 0 m3/day)
```

That is, when the pond volume is greater than or equal to the target volume, the pump is turned on. When it is below the target volume, it is turned off. Note that the Pumping_Rate is larger than the **Inflow**, so when the pump is turned on, the volume in the pond is reduced. This creates a ***feedback loop***between the

pond volume and the outflow – it is an active feedback control system that is analogous to those common in many engineered systems.

Read more: Evaluating Feedback Loops (page 361).

But will this logic work? At first glance, it seems to make sense, but if you were run the model and look at the results, you would quickly realize that a real system would be unlikely to be controlled by logic like this. The result looks like this:



As you can see, the pond fills up, and then oscillates right around 300 m3. As soon as it reaches the target, the pump turns on, the volume is reduced and the pump turns off, and so on. The timestep for this model is 1 hr, and the model oscillates back and forth every hour. In fact, if we reduced the timestep to 1 minute, as long as the pumping rate is high enough (and it is), it would oscillate every minute! Clearly, the system would never be designed to operate like this in the real world (e.g., the pump would not last very long if it was turned on and off every minute).

In this example, the goal is to control the Pool around a particular "target" level. Although this is a common objective (e.g., a thermostat), it is also quite common for feedback control systems like this to be used to control the behavior of a system as it approaches its bounds (and these are the situations most likely to result in oscillatory behavior). In this case, you can imagine the need to actively adjust flows as the volume approaches the bounds. Using similar logic as above, you might choose to turn off the pump when the pond empties and turn it on as soon as it exceeds zero:

Equation

```
if(Pond>0 m3, Pumping_Rate, 0 m3/day)
```

Unfortunately, such logic will often cause the model to oscillate even more rapidly than in the previous example. This is because GoldSim inserts unscheduled updates whenever a bound is reached. Logic such as this could result in the Pool continuously oscillating at the bound (with a timestep being inserted each time the bound is reached). This can result in timesteps being inserted practically continuously (e.g., every second or less)!

Read more: Understanding Timestepping in GoldSim (page 473).

So what is the proper way to model these kinds of systems? The key is to build logic that is realistic (i.e., logic that could actually be practically implemented in the real world). For example, if you really did want to manage a Pool to a target, what you would likely do is use what is referred to as a "deadband" or a target range within which the system is controlled. This is actually how a thermostat typically works (e.g., "turn the heat on when the temperature is 68 degrees and turn it off when it reaches 70 degrees"). You could implement this in GoldSim using a Status element.

Read more: Simulating a Deadband Using a Status Element (page 415).

When trying to control the behavior of a system as it approaches its bounds (as pointed out above, often the situations most likely to result in oscillatory behavior), it becomes particularly important to model the system realistically. In particular, inflows and outflows should either 1) be changed abruptly *before* the bound is reached (e.g., a pump turns off when the water level drops to a certain level but before the pond is actually empty); or 2) gradually ramped down such that when the Pool reaches its bound, the inflows and outflows have gradually changed to the appropriate value (e.g., gradually ramp the outflow rate down as the volume decreases until it reaches zero when the volume reaches the lower bound). If using the first approach, you would also likely implement a deadband, so that, for example, the pump turns off when the water level drops to a certain level (but before the pond is actually empty), and turns back on at some higher level.

An example model which illustrates the use of a deadband in a Pool element (PoolAdvanced.gsm) can be found in the General Examples/Stocks folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

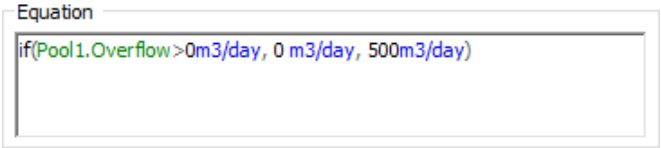
Using the Is_Full Output of a Pool

The Is_Full output is only available if you specify an **Upper Bound** for a Pool. It is a condition (False if the Pool is below the **Upper Bound**, and True if it is at the **Upper Bound**.

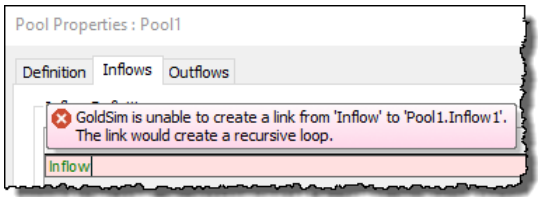
This output is useful because it is a special type of output called a ***state variable*** (the primary output of a Pool is also a state variable). This has the important implication that inputs to the Pool (e.g., the **Inflows**) can reference this output without causing a recursive error.

Read more: Evaluating Feedback Loops (page 361).

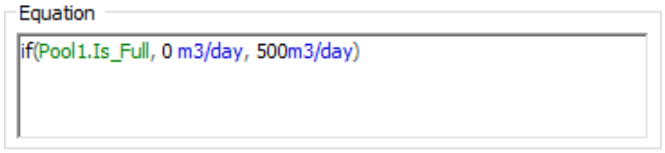
As an example, suppose that you wanted to add water to a Pool only if it was not overflowing; once it started to overflow, you wanted the inflow rate to go to zero. To accomplish this, you could define an Expression for the Inflow as follows:



Unfortunately, because the Overflow output is not a state variable, if you then tried to link this Expression into an **Inflows** field for the Pool, you would get this error:



However, you can solve this problem by using the Is_Full output:



If the Expression was defined as above, then you could link to this Expression into an **Inflows** field for the Pool without causing a recursive error.

Note: Although the Is_Full output allows you to create such feedback loops, you need to take care when using such logic to avoid creating unrealistic oscillatory behavior.

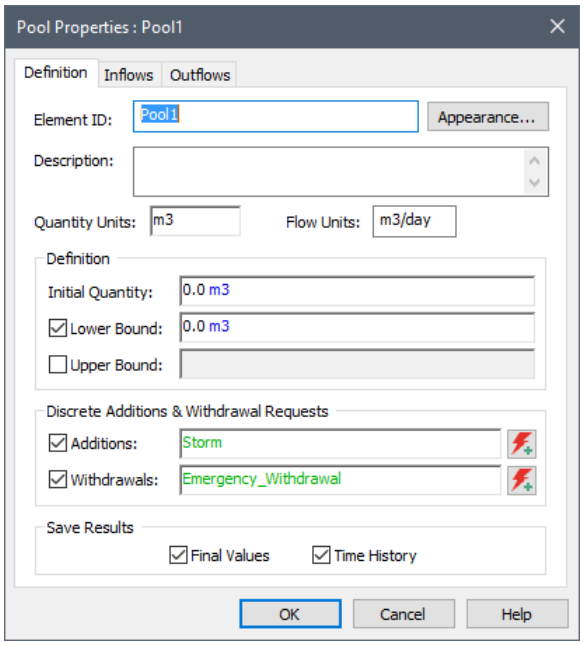
Read more: Avoiding Oscillatory Behavior When Using Reservoirs (page 254).

Specifying Discrete Additions and Withdrawals to a Pool

In addition to continuous **Inflows** and **Outflow Requests**, Pools can also accept discrete changes. In particular, Pools actually compute their Quantity by accounting for discrete changes as follows:

$$\text{Quantity}(t_n) = \text{Initial Quantity} + \sum_{i=1}^{n}\left[\text{Inflows}(t_i - \Delta t_i) - \text{Outflows}(t_i - \Delta t_i)\right]\Delta t_i + \sum \text{Discrete Additions} - \sum \text{Discrete Withdrawals}$$

Discrete Additions and Withdrawals are specified by checking the **Additions** and/or **Withdrawals** boxes (in the **Discrete Additions & Withdrawal Requests** section) and by specifying a link to a ***discrete change signal*** with an Add instruction:



Note that if you check a **Additions** or **Withdrawals** checkbox, GoldSim will add new outputs to the element (for **Additions**, Discrete_Overflow if there is an Upper Bound defined, and for **Withdrawals**, Discrete_Withdrawals).

An example model which illustrates the use of a discrete additions and withdrawals for a Pool element (PoolAdvanced.gsm) can be found in the General Examples/Stocks folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Read more: Basic Concepts of Discrete Event Modeling (page 366); Modeling Discrete Changes to a Pool (page 403).

Instantaneously Replacing the Current Quantity in a Pool

In some cases, you may want to instantaneously replace the current value (the Quantity) of a Pool with a specified value.

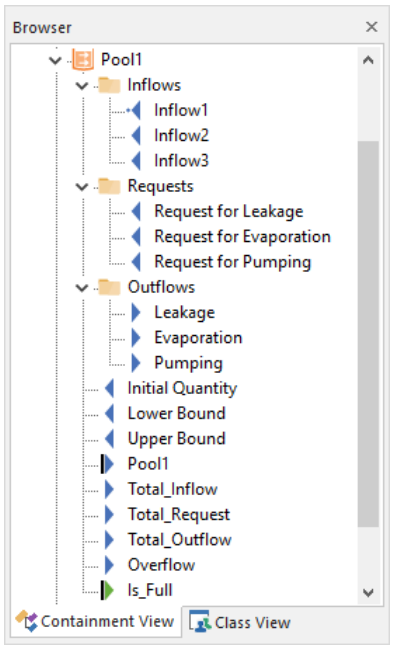
This can be accomplished by checking the **Additions** field and specifying a link to a ***discrete change signal*** with a Replace instruction

Read more: Basic Concepts of Discrete Event Modeling (page 366); Modeling Discrete Changes to a Pool (page 403).

Note: If you have specified an **Upper** or **Lower Bound**, and choose to Replace the current value of a Pool, the replacement value must be within the bounds (or GoldSim will display a fatal error message).

Browser View of a Pool Element

The browser view of a Pool element can have a large number of inputs and outputs(depending on which boxes are checked in the dialog, and how many **Inflows** and **Outflow Requests** you have). If the **Upper** and **Lower Bound** boxes are checked, the browser view looks like this:



The names for the individual Outflows are user-defined.

Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

Using Basic Function Elements

There are nine basic function elements that are used to manipulate data in a GoldSim model:

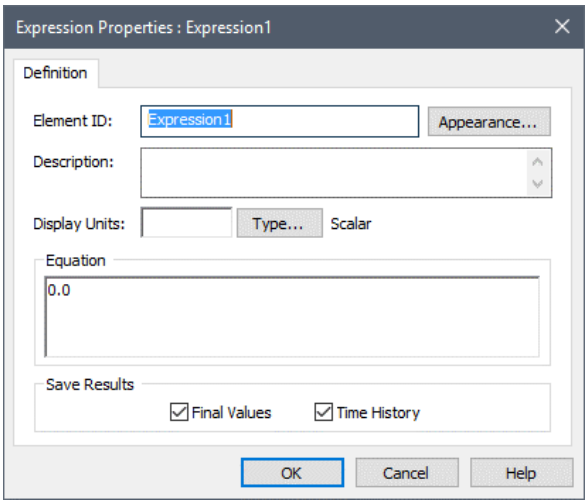
- Expression elements;
- Extrema elements;
- Selector elements;
- Splitter elements;
- Allocator elements;
- Sum elements; and
- Logical elements (And, Or, Not).

These elements are described in detail in the topics listed below.

Expression Elements

Expression elements are probably the most common function element that you will use in your models.

The properties dialog for an Expression element looks like this:



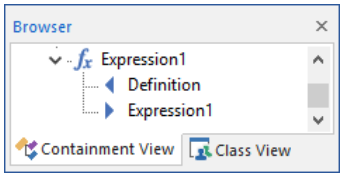
The properties dialog for an Expression is very simple, and is almost identical to that of the Data element. Other than the **ID** and **Description**, there is only a single input field. Typically, you will enter a mathematical expression into this field. (You could, of course, just enter a number. In such a case, however, it would be clearer to someone viewing your model if you used a Data element for this).

Note that the input field for an Expression (the "Equation") is always expanded to several lines to better accommodate and display large equations.

Expression elements have a single output, which can be a value or a condition, and can be specified as a scalar, a vector or a matrix. You can specify these attributes by pressing the **Type…** button. By default, a new Expression element is a scalar, dimensionless value.

Read more: Using Vectors and Matrices (page 848).

The browser view of an Expression element shows a single input (referred to as the Definition), and a single output:

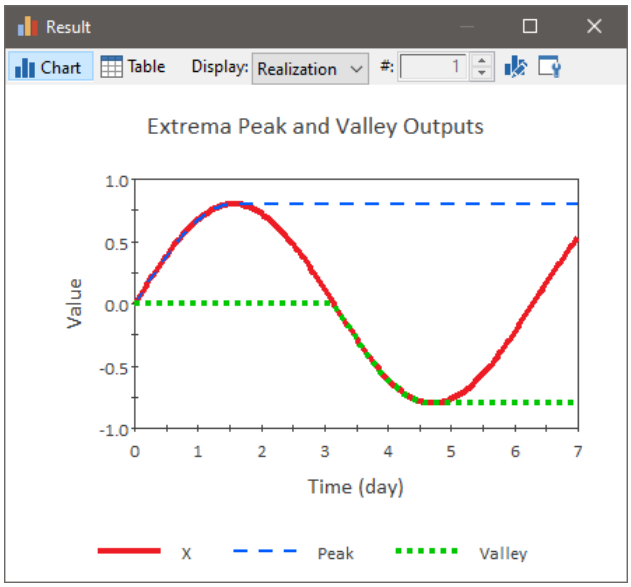


Note: Element inputs and outputs are only shown in the browser if you choose to **Show element subitems** (accessed via the browser context menu by right-clicking in the browser).

An example model which uses Expression elements (Expression.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

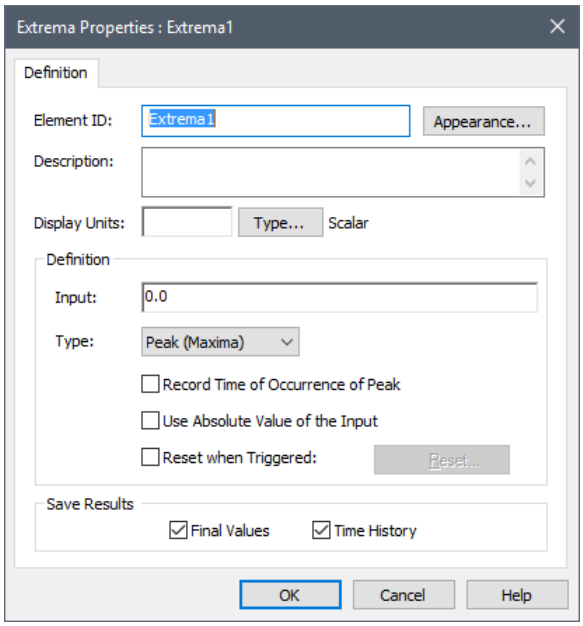
Extrema Elements

An Extrema element computes the maximum value (peak) or minimum value (valley) achieved by its input during a simulation. For example, in the figure shown below, the Peak and Valley curves are the outputs of Extrema elements with X as an input:



Extrema elements are very useful for tracking things like the peak contaminant concentration in a river, the peak number of customers in a check-out line, or the lowest water level reached in a water supply reservoir.

The properties dialog for an Extrema element looks like this:



An Extrema element has a single primary input (the value you wish to track). This input must have the same attributes (order and dimension) as the Extrema element, and can be a link or an expression. The **Type** determines whether Peak (maxima) or Valley (minima) values are tracked (as illustrated in the example shown above). Note that the default symbol for the Extrema changes depending on whether you are tracking a Peak or a Valley:

Peak

Valley

Extrema elements have two outputs, one of which is optional. The primary output is the actual peak or valley. It is always a value, but can be specified as a scalar, a vector or a matrix. You can specify these attributes by pressing the **Type…** button. By default, a new Extrema element is a scalar, dimensionless value. You can also use Extrema elements to operate on and/or create vectors and matrices.

Read more: Using Vectors and Matrices (page 848).

The secondary output (which is optional) is the time of the greatest peak or valley. This output is only created if **Record Time of Occurrence of Peak/Valley** is checked. If it is checked, this output represents the *elapsed time* at which the peak (or valley) *last* occurred. The output is always a value with dimensions of time. It has the same order (scalar, vector, matrix) as the primary output.

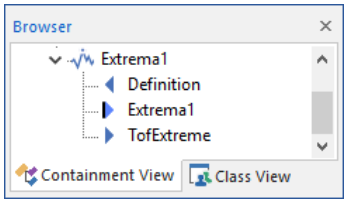
Extrema elements have two options which affect how the primary output of the Extrema is computed:

- **Use Absolute Value of the Input**: If this is checked, GoldSim uses the absolute value of the input to determine the Peak or Valley, but the primary output retains the sign of the input (i.e., it could be negative). Hence, if you were computing the Peak, the output would represent the value of the Input which has had the highest absolute value since the beginning of the simulation (or since the element has been reset – see below). If you were computing the Valley, the output would represent the value of the Input which has had the lowest absolute value since the beginning of the simulation (or since the element has been reset – see below).
- **Reset when Triggered**: If this is checked, the **Reset…** button becomes available, which provides access to a standard GoldSim Trigger dialog.

  Read more: Understanding Event Triggering (page 369).

  When an Extrema is reset by a trigger, the Peak/Valley calculation is restarted on the next update (ignoring everything that has occurred previously, as if it was the start of the simulation again).

The browser view of an Extrema element shows a single input and two outputs (if you choose to save the time of the peak/valley). Additional inputs are also present if the element is being reset:



"TofExtreme" is the (optional) time of extreme output.

Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

A simple example model which uses an Extrema element (Extrema.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Selector Elements

In many simulations, you will want to use *if..then* logic in your model to specify how a particular parameter changes as a function of some state of the system (e.g., time).

For example, you might want to use *if…then* logic to define how a particular variable changes with time: if(ETime < 10 yr, 5, 6). Simple relationships such as these can readily be entered into an Expression element. In some situations, however, you will need to define complex, nested *if..then* logic to represent your system. Consider, for example, the following complex nested *if..then* statement:

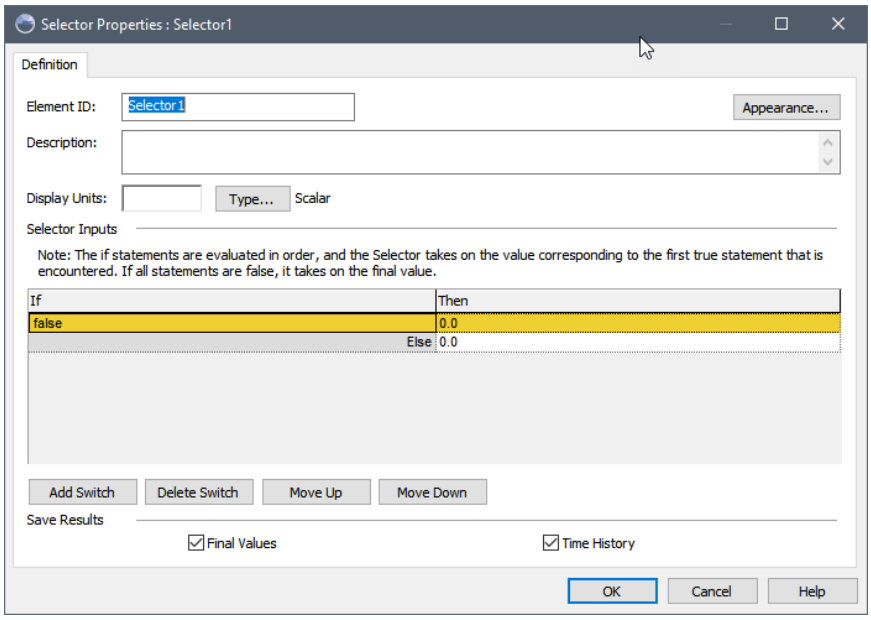
```
if  A <10
  then X = 5
else if A < 20
  then X = 6
else if A < 40 and B > 2
   then X = 7
else X=8
```

This would be represented within an Expression element using GoldSim's built-in *if..then* function and relational operators as follows:

```
if(A< 10, 5, if(a < 20, 6 , (if(a < 40 and b > 2, 7, 8 ))))
```

Needless to say, a nested *if…then* statement such as this is cumbersome to enter (and difficult to interpret once it has been entered). The Selector element was specifically designed to facilitate the representation of such logic

The properties dialog for a Selector element looks like this:



Selector elements have a single output, which can be a value or a condition, and can be specified as a scalar, a vector or a matrix. You can specify these attributes by pressing the **Type…** button. By default, a new Selector element is a scalar, dimensionless value. You can also use Selector elements to operate on and/or create vectors and matrices.

Read more: Using Vectors and Matrices (page 848).

Each switch (row) in the Selector dialog represents a single *if…then* statement and has two parts: the condition (the first column), and the result if the condition is true (the second column). The if statements are evaluated in order, and the Selector takes on the value corresponding to the *first* true statement that is encountered. All Selectors have a final *else* statement, which represents the result if all the conditions are false.

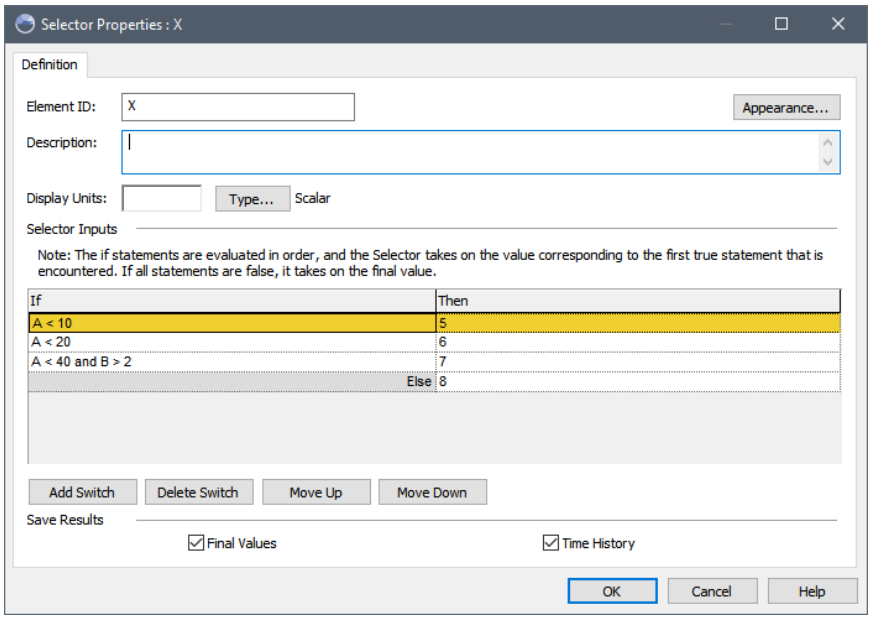
A new Selector has a single switch. A Selector with a single switch has the same functionality as a simple *if..then* statement: If(A then B else C).

You can add switches using the **Add Switch** button. New switches are added below the switch which is currently selected. If the final else is selected, however, the switch will be inserted above it. If the first switch is selected, you will be prompted for whether you want to insert the new switch above or below the selected switch.

To delete a switch, select it (it will turn yellow) and press **Delete Switch**. Note that the last result (the else) cannot be deleted.

You can use the **Move Up** and **Move Down** buttons to change the order of the switches (and the order is important!).

The example discussed above would be represented in a Selector as follows:



This is clearly easier to enter and read than using nested *if..then* functions.

Note: The dialog for a Selector is wider than other elements to allow long expressions to be easily displayed in the two columns. Note, however, that if an expression does not completely fit into one of the fields, like other input fields in GoldSim, the field will expand and the expression will wrap when you click into it. In addition, the Selector dialog is resizable. This allows you to stretch the dialog so as to see all of the expressions that you may have entered into the dialog at once.

Both the condition column and the result column can be entered as links or expressions. The first column (the condition) must either be:

- a link which is a scalar condition;
- a conditional expression; or
- the words "True" or "False".

Read more: Creating Conditional Expressions (page 134).

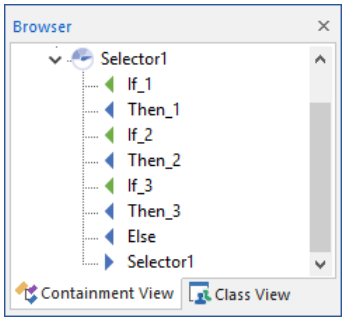
Note: If your conditions are complex, you might want to create them using GoldSim's logical elements.

Read more: Logical Elements (page 298).

The entries in the result column must have the same data type, order and dimensions as the element's output.

Note: Although the output of a Selector can be an array, the If column (the condition) must be a scalar. This means that you cannot do an item-by-item calculation on an array using a Selector. If you need to carry out an item-by-item if, then calculation on an array, you can do this by using an If(, ,) function in an Expression. If the first argument of the If function is an array, then the remaining two arguments must also be arrays (with the same Array Label Set), and GoldSim carries out an item by item calculation to construct the output array.

As shown below, the browser view of a Selector element shows a single output, and the following inputs: an *Else* (the result if all conditions are false), and two inputs for every switch (*If_n* and *Then_n*, where *n* is the switch number):



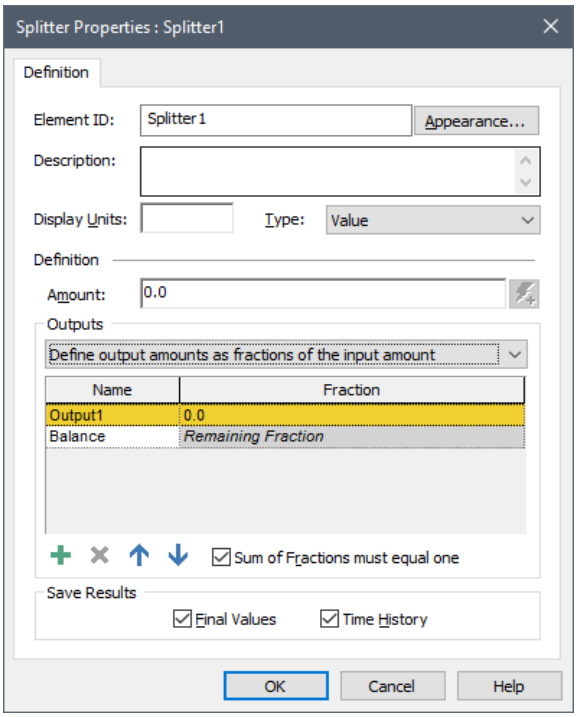
Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

A simple example model which uses a Selector element (Selector.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Splitter Elements

Splitter elements split an incoming signal between a number of outputs based on specified fractions or amounts. Typically, the signal will be a flow of material (e.g., water), but it could also be a discrete transaction.

The properties dialog for a Splitter element looks like this:



The incoming signal to a Splitter element (the **Amount**) must be a scalar. The **Type** drop-list allows you to specify whether the incoming signal is a Value or a Discrete Change Signal.

If it is a Discrete Change Signal, the icon for the Splitter indicates this by changing its color (from blue to red):

Multiple Discrete Signals button

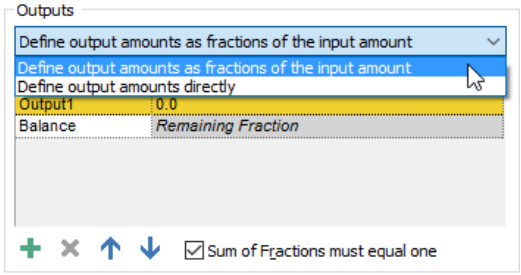
A Splitter can accept multiple discrete changes. This is indicated in the input field by separating the individual discrete change signals by semi-colons (e.g., Change1; Change2; Change3). You can also specify the multiple discrete changes using the Multiple Discrete Signals button, which displays a table listing the multiple discrete change signals.

Read more: Propagating Discrete Signals Between Elements (page 367).

The outputs of the Splitter element are specified in the "Outputs" section of the dialog. By default, a Splitter element initially has two outputs (named Output1 and Balance). You can add additional outputs by pressing the **Add** button (the plus sign) below the list. Outputs can be deleted using the **Delete** button (the X), and moved up and down in the list using the two buttons to the right of the **Delete** button.

The names of the outputs can be changed by editing the items in the **Name** column.

By default, output amounts are entered as fractions of the input amount. However, you can also specify the output amounts directly (as values). The drop-list directly above the list of outputs specifies how outputs are entered:



If output amounts are defined as fractions of the input amount, then:

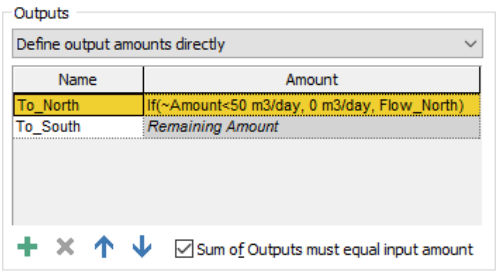
- For each output, you specify the **Fraction** of the incoming **Amount** that is assigned to that output. The Fractions can be specified as constants or expressions and/or links, and may change with time.
- If the **Sum of Fractions must equal one** checkbox is checked (the default), then the total amount of the input will be conserved, and:
  - Each Fraction must always be greater than or equal to zero.
  - You cannot specify the Fraction for the last output. GoldSim automatically assigns the remainder to this output such that the fractions add to one.
  - If the specified Fractions exceed one at any time during a simulation, GoldSim issues a fatal error.
- If the **Sum of Fractions must equal one** checkbox is cleared, then:
  - There are no constraints on the values for the Fractions (they can be negative or can exceed one).
  - You must specify the Fraction for the last output (GoldSim *does not* automatically assign the remainder to this output such that the fractions add to one).
  - The specified Fractions do not need to sum to one.

If output amounts are defined directly as amounts, then:

- For each output, you specify the **Amount** that is assigned to that output. The output Amounts can be specified as constants or expressions and/or links, and may change with time.
- If the **Sum of Outputs must equal input amount** checkbox is checked (the default), then the total amount of the input will be conserved, and:
  - You cannot specify the output Amount for the last output. GoldSim automatically assigns the remainder to this output such that the outputs add to input amount.
  - If the specified output Amounts exceed the input amount at any time during a simulation, GoldSim issues a fatal error.
- If the **Sum of Outputs must equal input amount** checkbox is cleared, then:
  - There are no constraints on the values for the Amounts (they can be negative or can exceed the input Amount).
  - You must specify the output Amount for the last output (GoldSim *does not* automatically assign the remainder to this output such that the output Amounts add to the input amount).

- The specified output Amounts do not need to sum to the input amount.

Under some circumstances, you may want to specify the outputs as some function of the input amount. GoldSim facilitates this by providing a locally available property called "Amount". This represents the current value in the Amount field. You would reference this value as "~Amount":



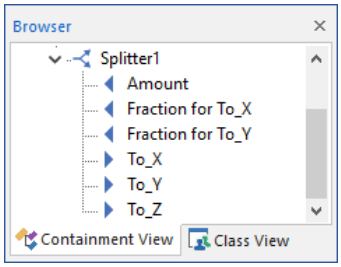
This can be particularly useful for routing discrete change signals based on their value.

Read more: Using Splitter Elements to Route Discrete Changes Based on Their Value (page 411).

Note: "Amount" is an example of a locally available property. As such, it only has meaning inside the **Fraction** field, and cannot be referenced anywhere else.

Read more: Understanding Locally Available Properties (page 874).

As shown below in the browser view of a Splitter element, a Splitter has an output for each item in the Outputs list:



Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

The outputs of a Splitter can be either values or discrete change signals (depending on how the **Type** field was defined).

Note: If a Splitter outputs discrete change signals, the outputs preserve the Instruction of the input signal.

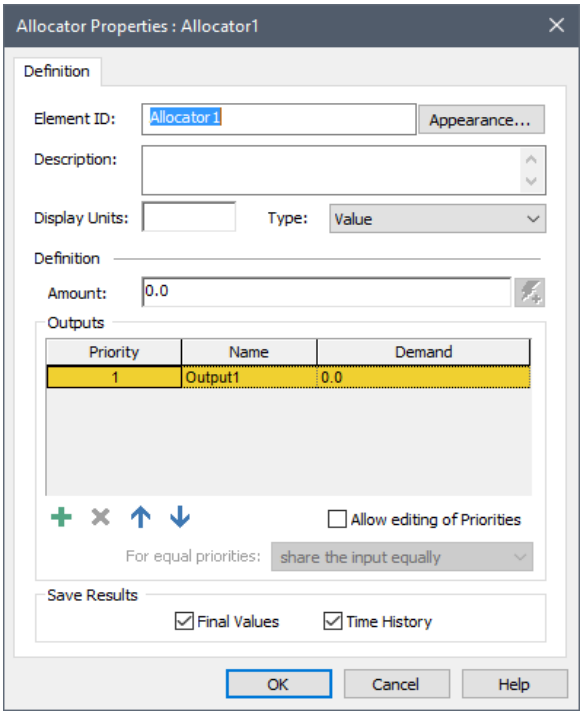
Note: If a Splitter outputs discrete change signals, signals with a zero value and an "Add" instruction are not propagated as outputs.

An example model which uses a Splitter element (Splitter.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Allocator Elements

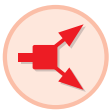
Allocator elements allocate an incoming signal to a number of outputs according to a specified set of demands and priorities. Typically, the signal will be a flow of material (e.g., water), but it could also be a discrete transaction.

The properties dialog for an Allocator element looks like this:



The incoming signal to an Allocator element (the **Amount**) must be a scalar. The **Type** drop-list allows you to specify whether the incoming signal is a Value or a Discrete Change Signal.

If it is a Discrete Change Signal, the icon for the Allocator indicates this by changing its color (from blue to red):



Multiple Discrete Signals button

An Allocator can accept multiple discrete changes. This is indicated in the input field by separating the individual discrete change signals by semi-colons (e.g., Change1; Change2; Change3). You can also specify the multiple discrete changes using the Multiple Discrete Signals button, which displays a table listing the multiple discrete change signals.

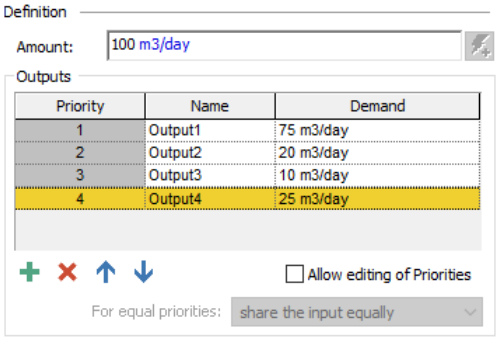
Read more: Propagating Discrete Signals Between Elements (page 367).

The outputs of the Allocator element are specified in the "Outputs" section of the dialog. By default, an Allocator element initially has one output (named Output1). You can add additional outputs by pressing the **Add** button (the plus sign) below the list. Outputs can be deleted using the **Delete** button (the ***X***), and moved up and down in the list using the two buttons to the right of the **Delete** button.

The names of the outputs can be changed by editing the items in the **Name** column.

For each output, you specify the **Demand** for that output. The Demand has the same type and dimensions as the incoming **Amount**. Demands can be specified as constants or expressions and/or links, and may change with time. Each output receives its requested Demand according to the specified **Priority**. Outputs with lower valued Priorities are met first (i.e., Priority 1 is met before Priority 2).

To illustrate this, consider the following example:



In this case, Output1 would have a value of 75m^3/day (its entire demand would be met), Output2 would have a value of 20m^3/day (its entire demand would be met), Output3 would have a value of 5m^3/day (only part of its demand would be met), Output4 would have a value of 0m^3/day (none of its demand would be met), and the "Unused" output would have a value of 0m^3/day.

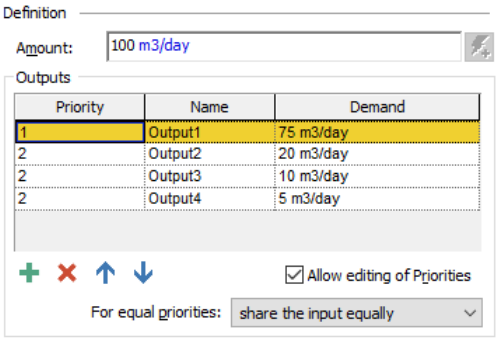
By default, each output has a fixed (and unique) Priority (which is an integer). The Priority of the outputs always decrease downward (with the first item having a Priority of 1). Priority 1 therefore represents the highest priority demand, 2 the next highest, and so on. New outputs are added below the output that is selected when pressing the Add button. You can move outputs up and down the Priority list using the Move Up and Move Down buttons (found directly below the list).

If you check the **Allow editing of Priorities** checkbox, the **Priority** column becomes editable. In this case, the Priorities can be specified as constants or expressions and/or links, and may change with time. They do not need to be integers and can be any real value (positive or negative). Outputs with lower valued Priorities are met first (e.g., Priority -2.4 is met before Priority 5.7).

If multiple outputs have the same Priority, you can specify the manner in which equal priorities are treated in the **For equal priorities** field. There are two options: 1) “share the input equally”; or 2) “share proportional to demands”.

If “share the input equally” (the default) is selected, each output with equal priority receives the same amount up until either its demand is satisfied, or nothing more is available. The calculation is carried out recursively starting with the smallest demand.

To illustrate this, consider the following example:

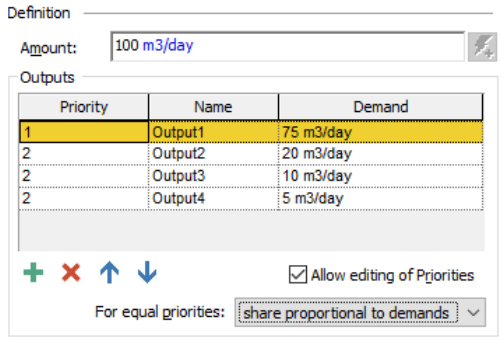


In this case, Output1 would have a value of 75m^3/day (its entire demand would be met), Output2, Output3 and Output4 would share the remainder (25m^3/day) as follows:

- Output4 would receive its full demand (5m^3/day); Output2 and Output3 would receive the same amount (5m^3/day). This leaves 10m3/day to be allocated.
- Output2 and Output3 would then equally share the remaining 10m^3/day (such that each would receive a total of 10m^3/day). So Output3 and Output4 would meet their demands, and Output2 would not.

If "share proportional to demands" is selected, if there is not enough supply to meet all of the demands, it is shared proportionally according to the demand.

To illustrate this, consider the same example as above, with proportional sharing:



In this case, Output1 would still have a value of 75m^3/day (its entire demand would be met), Output2, Output3 and Output4 would share the remainder (25m^3/day) as follows:

- Output2 would receive 20/35 = 57.1% of the remaining 25 m^3/day.
- Output3 would receive 10/35 = 28.6% of the remaining 25 m^3/day.
- Output4 would receive 5/35 = 14.3% of the remaining 25 m^3/day.

The table below summarizes the results for these two examples (note that the total supply is 100m^3/day and the total demand is 110 m^3/day):

Output	Priority	Demand (m^3/day)	Result with equal sharing (m^3/day)	Result with proportional sharing (m^3/day)
Output1	1	75	75	75
Output2	2	20	10	14.3
Output3	2	10	10	7.1
Output4	2	5	5	3.6

Under some circumstances, you may want to define a **Demand** by referencing the total amount available, or the remainder after the previous Priority has been met. GoldSim facilitates this by providing two locally available properties:

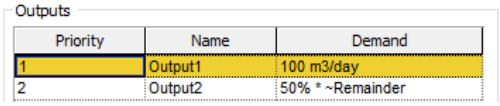
- "Total". This represents the current value in the Amount field. You would reference this value as "~Total".
- "Remainder". This represents the amount remaining (of the original amount) after all senior priorities (i.e., Demands with lower-valued Priorities) have been met. Hence, the Remainder takes on a different value in each row. You would reference this value as "~Remainder".

Note: In situations where several rows have equal priorities, the ~Remainder for a particular row is equal to the total amount available to the row divided by the number of remaining unmet equal priority rows. In this calculation, the equal priority rows are ordered not based on the order they where entered, but from smallest demand to largest demand.

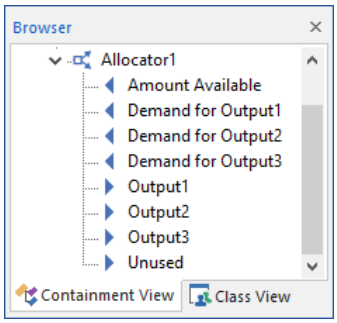
Note: Total and Remainder are examples of locally available properties. As such, they only have meaning inside the **Demand** field, and cannot be referenced anywhere else.

Read more: Understanding Locally Available Properties (page 874).

For example, if Output1 had a Demand of 100 m^3/day, and Output2 had a Demand that was half of what was remaining after Output1's demand was met, you could define the Demands as follows:



As shown below in the browser view of an Allocator element, there is an output for each item in the Outputs list. There is also an additional output (called "Unused") that represents the portion of the incoming signal that was unused (i.e., unallocated, or left over after the demands were met).



Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

The outputs of an Allocator can be either values or discrete change signals (depending on how the **Type** field was defined).

Note: If an Allocator outputs discrete change signals, the outputs (including the Unused output) preserve the Instruction of the input signal.

Note: If an Allocator outputs discrete change signals, signals with a zero value and an "Add" Instruction are not propagated.

Several example models which use a Allocator element (Allocator.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu). This file includes the use of an Allocator to simulate competing demands on a Reservoir.

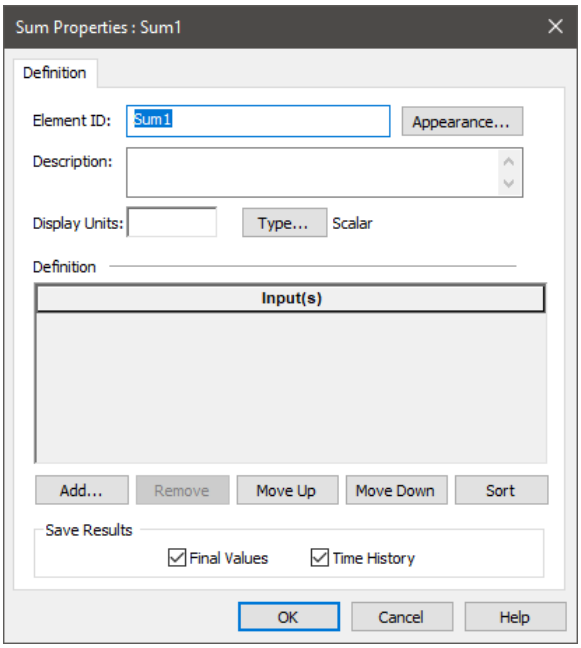
Note: The algorithm described above is the same algorithm used to allocate the outflows from the Pool element. In fact, a Pool can be thought of as a combination of a Reservoir and an Allocator.

Read more: Pool Elements (page 258).

Sum Elements

Sum elements add values together. Although this can also be done using an Expression, a Sum element provides a somewhat more convenient and user-friendly way to create a sum if a large number of items are involved. More importantly, it provides a powerful visual indication of what operation it is carrying out, and this adds to the transparency of your model.

The properties dialog for a Sum element looks like this:

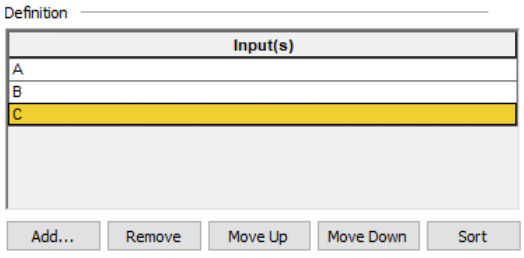


Sum elements have a single output, which must be a value, and can be specified as a scalar, a vector or a matrix. You can specify whether the output is a scalar, vector or matrix by pressing the **Type…** button. By default, a new Sum element is a scalar, dimensionless value. You can also use Sum elements to operate on and/or create vectors and matrices.

Read more: Using Vectors and Matrices (page 848).

You add an item to the Sum by pressing the **Add…** button. A browser tree showing all of the elements in the model will be displayed.

Note that this tree is organized by *containment* in the same manner as the main browser. To insert a link from this dialog, you select a specific output object (or an element having a primary output), and then press **OK**. If you press **Cancel**, GoldSim will insert a new blank (zero) item. In either case, the dialog will close and the item will be added to the list of inputs for the Sum:



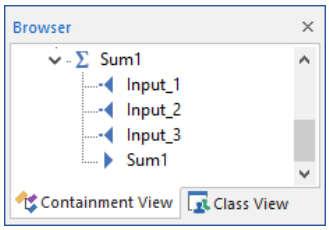
You can remove an item from the Sum by selecting the item and pressing the **Remove** button. Pressing the **Ctrl** key when pressing the **Remove** button allows you to remove all items.

You can move an item up or down in the list by selecting it and using the **Move Up** and **Move Down** buttons. The **Sort** button sorts all items alphabetically. (The order obviously does not affect the output, but can be useful for organizing how the list is displayed.)

The inputs to the Sum must all have the same attributes (data type, order, dimensions) as the output. Note that the inputs can be expressions (in addition to

simply links). You can edit any of the input fields after the input is added (and can insert links using the context menu for the input field).

As shown below, the browser view of a Sum element shows a single output, and an input for each item in the Sum:



Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

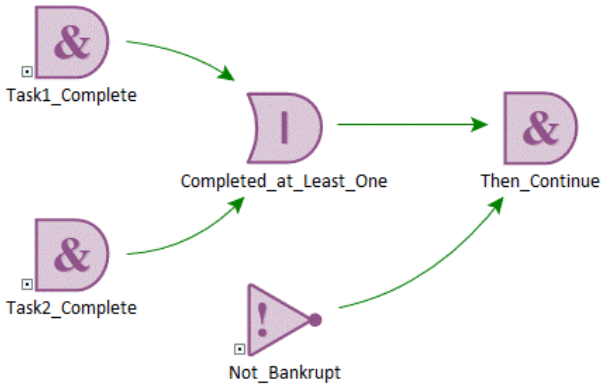
An example model which uses a Sum element (Sum.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Logical Elements

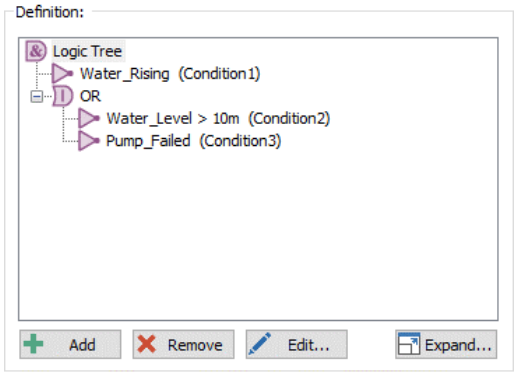
GoldSim provides a number of operators which allow you to create conditional expressions (e.g., A>B, A>B and C < D, A==B). Conditional expressions are powerful because they allow you to add conditional logic to your models.

Read more: Creating Conditional Expressions (page 134).

If the conditional expression is simple, you can create the expression directly in the input field to an element. If, however, your conditional expression is very complex and/or it is important to make your conditional logic very transparent, GoldSim's three logical elements (And, Or, Not) are very useful. You use these three simple elements to visually display conditional logic:



In addition to the And, Or and Not elements, GoldSim provides an additional element that provides an alternative way to create complex logic by using a logic tree (consisting of And, Or, Not and N-Vote gates):

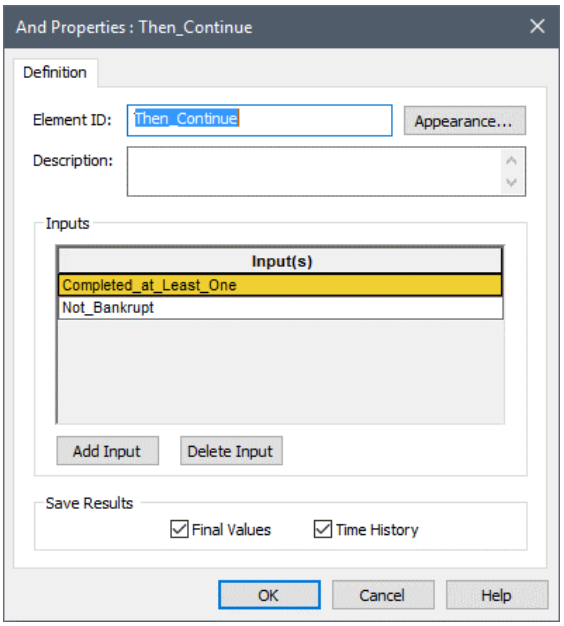


Each of the Logical elements is discussed below. An example model which uses all four Logical elements (Logical.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

And Elements

And elements perform a logical And operation on a list of conditions. Their output is True if and only if all of their inputs are True. Although this can also be done using an Expression, an And element provides a somewhat more convenient and user-friendly way to do this, particularly if a large number of items are involved. More importantly, the element explicitly illustrates the operation being carried out, increasing the transparency of your model and allowing you to create easy-to-read conditional logic diagrams.

The properties dialog for an And element looks like this:



And elements have a single output, which is always a scalar condition. If all of the input conditions to an And element are True, the output is True; otherwise, the output is False.

You add an input to the element by pressing the **Add Input** button. A browser tree showing all of the elements in the model will be displayed.

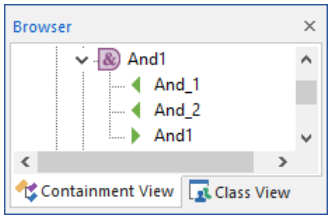
Note that this tree is organized by containment in the same manner as the main browser. To insert a link from this dialog, you select a specific output object (or an element having a primary output), and then press **OK**. If you press **Cancel**,

GoldSim will insert a new blank (False) item. In either case, the dialog will close and the item will be added to the list of inputs for the element.

The inputs to the And element must all be conditions. Note, however, that the inputs can be conditional expressions (in addition to simply links). You can edit any of the input fields after the input is added (and can insert links using the context menu for the input field).

Note: An And element with no defined input conditions evaluates to False.

The browser view of an And element shows a single output, and an input for each input condition:



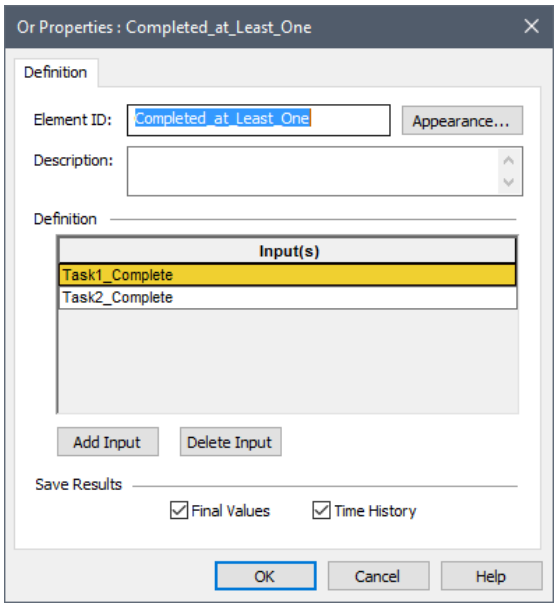
Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

An example model which uses the And element, as well as other logical elements (Logical.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Or Elements

Or elements perform a logical Or operation on a list of conditions. Their output is True if any of their inputs are True. Although this can also be done using an Expression, an Or element provides a somewhat more convenient and user-friendly way to do this, particularly if a large number of items are involved. More importantly, the element explicitly illustrates the operation being carried out, increasing the transparency of your model and allowing you to create easy-to-read conditional logic diagrams.

The properties dialog for an Or element looks like this:



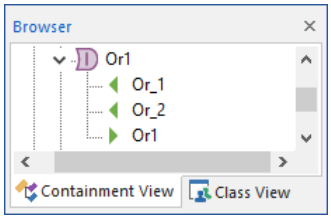
Or elements have a single output, which is always a scalar condition. If all of the input conditions to an Or element are False, the output is False; otherwise, the output is True. You add an input to the element by pressing the **Add Input** button. A browser tree showing all of the elements in the model is displayed.

Note that this tree is organized by containment in the same manner as the main browser. To insert a link from this dialog, you select a specific output object (or an element having a primary output), and then press **OK**. If you press **Cancel**, GoldSim will insert a new blank (False) item. In either case, the dialog will close and the item will be added to the list of inputs for the element.

The inputs to the Or must all be conditions. Note, however, that the inputs can be conditional expressions (in addition to simply links). You can edit any of the input fields after the input is added (and can insert links using the context menu for the input field).

Note: An Or element with no defined input conditions evaluates to False.

As shown below, the browser view of an Or element shows a single output, and an input for each input condition:



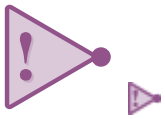
Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

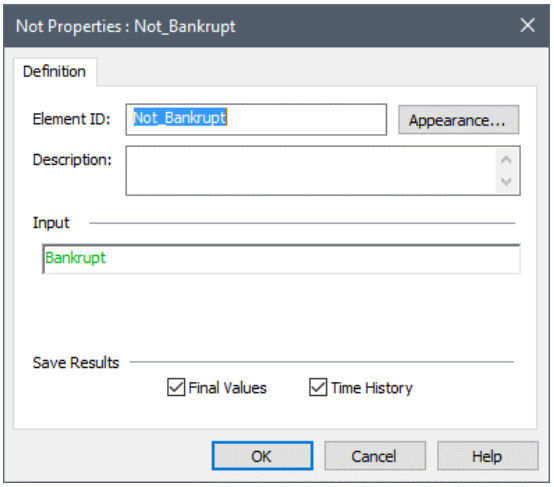
An example model which uses the Or element, as well as other logical elements (Logical.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Not Elements

Not elements are very simple. They perform a logical Not operation on a single input argument. That is, the output of a Not element is simply the opposite of its conditional input. Although this can also be done using an Expression, a Not element explicitly illustrates the operation being carried out, increasing the transparency of your model and allowing you to create easy-to-read conditional logic diagrams.

The properties dialog for a Not element looks like this:



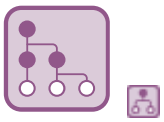


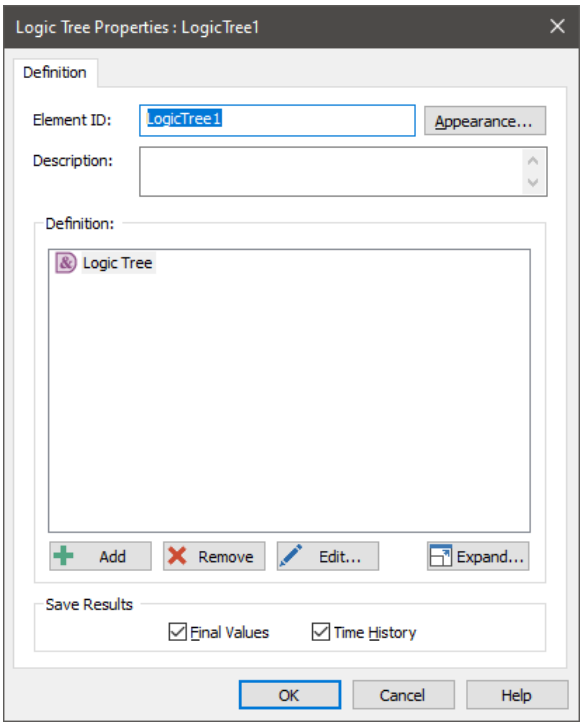
The input to a Not element must be a scalar condition. It can, however, be an expression. Not elements have a single output, which is also a scalar condition. If the input to a Not is True, the output is False; if the input is False, the output is True.

An example model which uses the Not element, as well as other logical elements (Logical.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Logic Tree Elements

In addition to the And, Or and Not logical elements, GoldSim has an additional element that provides an alternative way to create complex logic: the ***Logic Tree*** element.

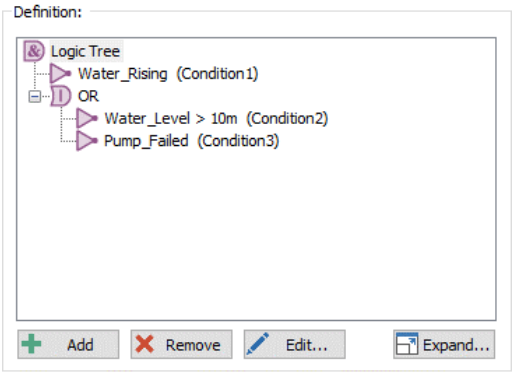




Logic Tree elements have a single output, which is a scalar condition (True or False). The logical framework of Logic Trees is constructed using a number of ***gate nodes*** (e.g.,, AND-gates, OR-gates). The various gate nodes have ***child nodes*** (sub-nodes) and the gates are evaluated based on the value (True or False) of their child nodes and the type of gate (e.g., in order for an AND-gate to be True, all of the child nodes defining the gate must be True).

Gates can be nested with no limit (hence, creating a "tree"), which allows very complex logic to be represented. The various nodes in the tree are evaluated hierarchically to determine if the output of the element is True or False.

To illustrate this, consider the simple logic tree shown below:



In this example, there are two gate nodes: the top AND-gate (the top of a logic tree is always an AND-gate) and an OR-gate (that is one of the children of the AND-gate). "Water_Rising" is a child of the AND-gate and "Pump_Failed" and "Water_Level > 10 m" are children of the OR-gate. "Water_Rising" and "Pump_Failed" are element outputs defined as conditions and "Water_Level > 10 m" is a conditional expression.

Hence, the logic expressed here is:

If

(Water_Rising) **AND** (Water_Level>10m **OR** Pump_Failed)

Then

The Logic Tree is True

Else

The Logic Tree is False

The sections below describe the details of how logic trees are created.

An example model which uses the Logic Tree element, as well as other logical elements (Logical.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Adding, Removing and Editing Nodes in the Logic Tree Element

A logic tree consists of two types of nodes: ***gate nodes*** and ***variable nodes***.

Gate nodes are used to construct the logical framework of the tree. Gate nodes require ***child nodes*** that are either other gate nodes or variable nodes.

There are three types of gate nodes:

AND-Gate. An AND-Gate is true when all of its child nodes are true. The child nodes can be variable nodes, or other gate nodes.

OR-Gate. An OR-Gate is true when at least one of its child nodes is true. The child nodes can be variable nodes, or other gate nodes.

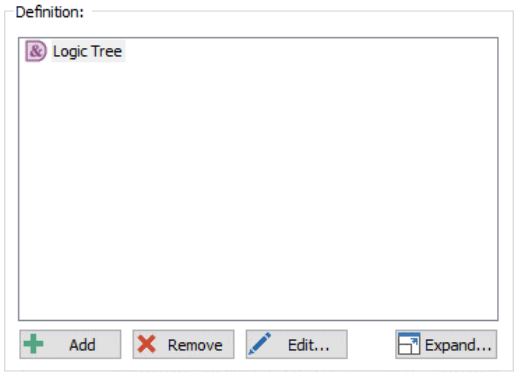
N-Vote Gate. An N-Vote Gate is true when N (which is user-specified) or more of its inputs are true**.** The child nodes can be variable nodes, or other gate nodes.

There are two types of variable nodes, each of which requires an input:

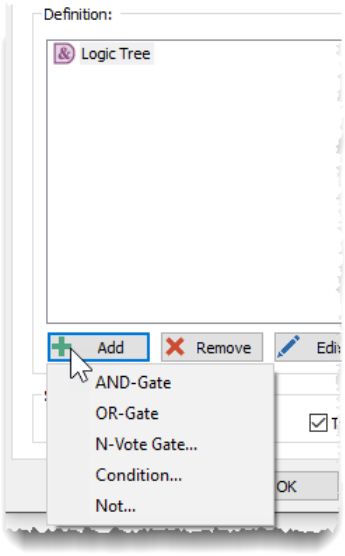
Condition. A Condition node is true when the specified condition evaluates to true. The input must be a Condition output or a conditional expression.

Not. A Not node is true when the specified condition evaluates to false. The input must be a Condition output or a conditional expression.

When a Logic Tree element is initially created, the logic tree will consist of a single AND-Gate:

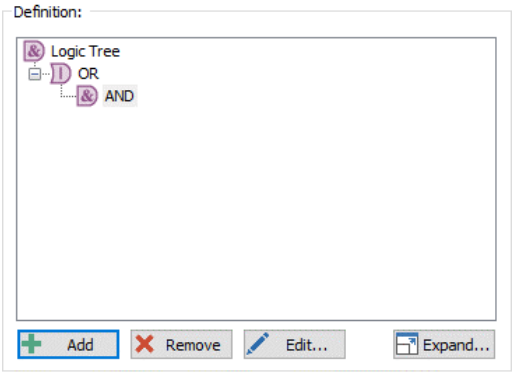


Clicking the **Add** button displays a menu which allows you to select the desired node type to the tree:



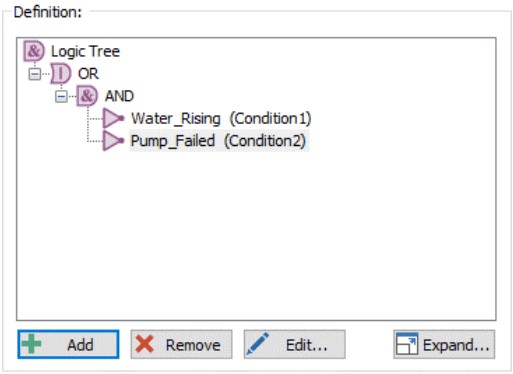
Where the new node will appear is determined by the type of node that is selected prior to pressing the **Add** button:

- If a gate node is selected prior to pressing the **Add** button, the new node will appear as child node to the selected gate node:



In this example, the OR-Gate was selected when an AND-Gate was added. The AND-Gate is therefore added as a child node to the OR-Gate..

- If a variable node is selected prior to pressing the **Add** button, the new node will appear as child node to the selected node's parent (i.e., as a siblimng of the selected node):



In this example, a Condition node ("Water_Rising") was selected when another Condition node ("Pump_Failed") was added. The second Condition node is therefore added as a sibling of the first Condition node.

Adding and using AND-Gates and OR-Gates is straightforward.

An N-Vote Gate is true when N or more of its inputs are true. The inputs can be conditions, or other gates. With an N-Vote gate, you need to specify the number of inputs that must be true in order for the gate to be true. The following dialog appears when the N-Vote gate option is selected:

The number of required votes can be edited by typing directly into the text box, or by using the arrows to the right of the text box to increment the number of votes up or down. The number of votes must be an integer, so non-integer numbers are automatically truncated. Once the node has been placed, it will display the number of votes required, as shown below:

Note: The top node of a Logic Tree is always an AND-Gate. If you want the top node to be an OR-Gate or or an N-Vote Gate simply add that single gate to the top of the tree under the top-level AND-Gate.

Note: A gate node with no children always evaluates to False. Hence, a Logic Tree element (which by default contains a single empty AND-Gate) defaults to False.

When a Condition or Not node is added, a small dialog appears:

This dialog allows you to enter a conditional expression (an expression which evaluates to true or false), or create a link to a condition-type output of another

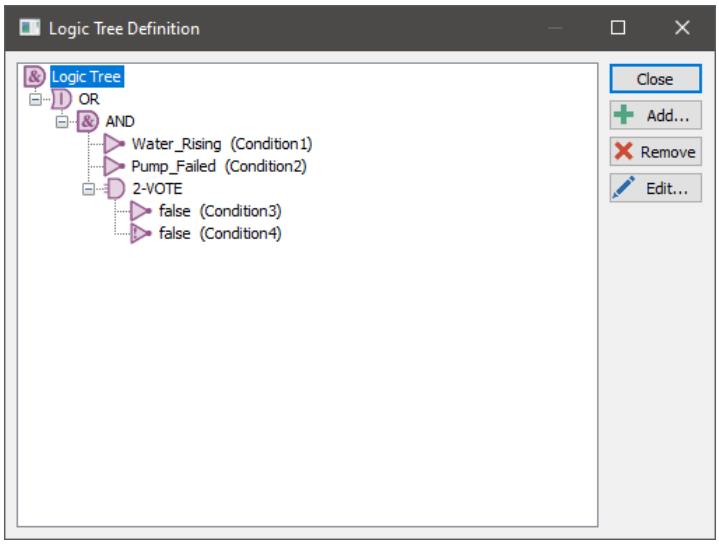
GoldSim element. A Condition node is true when the specified condition evaluates to true. A Not node is true when the specified condition evaluates to false.

After adding a variable node, you can edit it by selecting the variable node in the logic tree and pressing the **Edit** button (if a gate node is selected it will be ignored).

Pressing the **Remove** button removes the node (and if it is a gate node, all of its children).

Expanding the View of the Logic Tree

If you have a very large logic tree with a number of hierarchical levels, it might be useful to edit and view the tree in an expanded "pop-out" window. You can do this by pressing the **Expand** button.. When you do so, GoldSim will display the tree in a separate (and resizable and scrollable) window:



Clicking the **Close** button in the upper-right corner of the dialog exits the expanded viewing window.

Using Lookup Table Elements

Lookup Table elements are a type of input element that allow you to define your input in terms of a lookup table (or response surface). You define the table in terms of either one, two, or three independent variables.

For example, consider the following table:

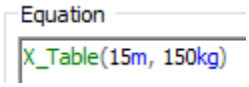
Mass [kg]

Length [m]	100	200	500	1000
0	3	5.5	6	8.5
10	4.4	6.7	7.8	10.1
20	5.8	7.7	9.3	12.5
40	7.3	8.6	11.3	14.2
60	8.5	10.9	14.5	17.5
100	10.1	15.6	17.8	21.7

This table defines the value of a dependent variable in terms of two independent variables. Hence, it is a two-dimensional lookup table. If the row variable was equal to 40 m, and the column variable was equal to 500 kg, the independent variable would take on a value of 11.3; if the row variable was equal to 60 m, and the column variable was equal to 1000 kg, the independent variable would take on a value of 17.5; and so on.

When you define a table like this in GoldSim, it determines the value of the dependent variable for any given values of the independent variables by interpolating between the data points supplied in the table. For example, if the row variable was equal to 30 m, and the column variable was equal to 500 kg, the independent variable would take on a value of 10.3 (assuming linear interpolation).

Lookup Table elements are unique in that you don't reference them in the same manner that you reference the outputs of other elements. Instead, you reference them in the same manner that you would reference a built-in function (like sin or min). That is, once you define a table like the one above, you reference it in input expressions for other elements as if it were a custom function:



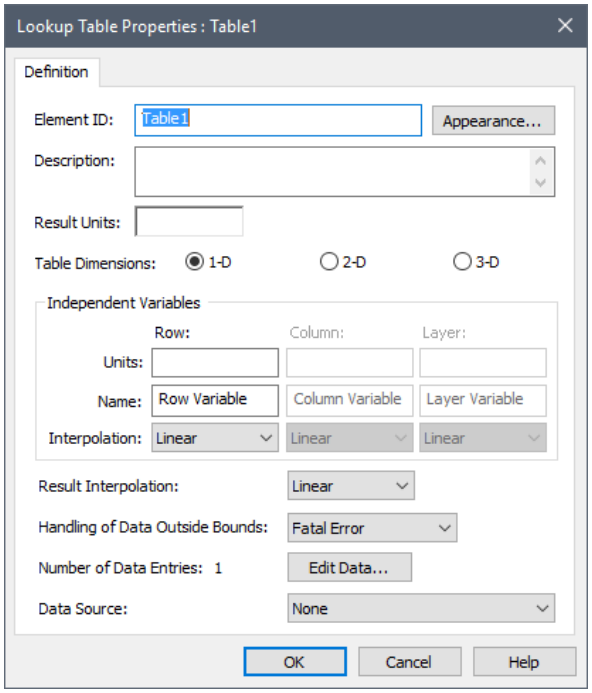
This expression instructs GoldSim to use the lookup table defined by the element X_Table and compute an output value based on a value for the row variable of 15m and a value for the column variable of 150kg.

An example model which uses a Lookup Table element (BasicTable.gsm) can be found in the General Examples/LookupTable folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

The manner in which you define and reference a Lookup Table is discussed in detail in the sections below.

Steps for Defining a Lookup Table

The dialog for a Lookup Table element looks like this:



The following steps are required to define a Lookup Table:

1. You first specify the **Table Dimensions**. To do so, you select one of three radio buttons: 1-D, 2-D or 3-D. This determines how many independent variables the Lookup Table has.
2. You specify the **Units** in which the data in the table will be specified for each independent variable. For a 1-D Table, you must specify the

Row Units. For a 2-D table, you must specify the **Row** and **Column Units**. For the 3-D Table, you must specify the **Row**, **Column** and **Layer Units**. In all cases, you must also specify the **Result Units**. These are the units in which the data in the table will be specified for the dependent variable (i.e., the result or output of the table).

3. You can optionally specify a **Name** for each independent variable. This simply adds labels to the data table (in step 4 below) to make it easier for you to enter (and view) the data.
4. You specify data points which define your table. This consists of a dependent variable value for each of a number of specified combinations of the independent variables. You can specify this data table manually (by typing or pasting in the data), you can import the data from a text file, or you can link the data directly to an external data source (such as a spreadsheet file).
5. GoldSim determines the value of the dependent variable for any combination of values of the independent variables by interpolating between the data point supplied in the table. You must specify how you want to carry out the interpolation (e.g., linear, log, next lower), and how you want GoldSim to handle combinations of variables that are outside the range of data supplied in the table (e.g., should GoldSim extrapolate?).

Steps 4 and 5 are discussed in detail in the sections below.

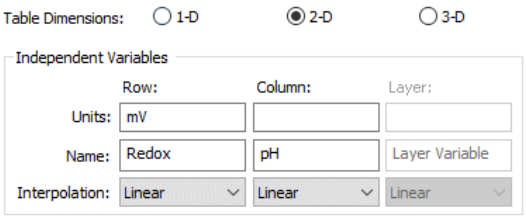
Specifying Data for a Lookup Table

To specify the data for a Lookup Table (i.e., define the entries for the actual table), you must first specify the **Table Dimensions**. To do so, you select one of three radio buttons: 1-D, 2-D or 3-D.

This determines how many independent variables the Lookup Table has.

After doing so, you specify the **Units** in which the data in the table will be specified for each independent variable. For a 1-D Table, you must specify the **Row Units**. For a 2-D table, you must specify the **Row** and **Column Units**. For the 3-D Table, you must specify the **Row**, **Column** and **Layer Units**.

You can optionally specify a **Name** for each independent variable. This simply adds labels to the data table (in step 4 below) to make it easier for you to enter (and view) the data:



In all cases, you must also specify the **Result Units**. These are the units in which the data in the table will be specified for the dependent variable (i.e., the result or output of the table).

Once you have done this, you can specify the data table manually (by typing or pasting in the data) or you can import the data from a text file.

The manner in which this is done for each type of table is discussed in detail in the sections below.

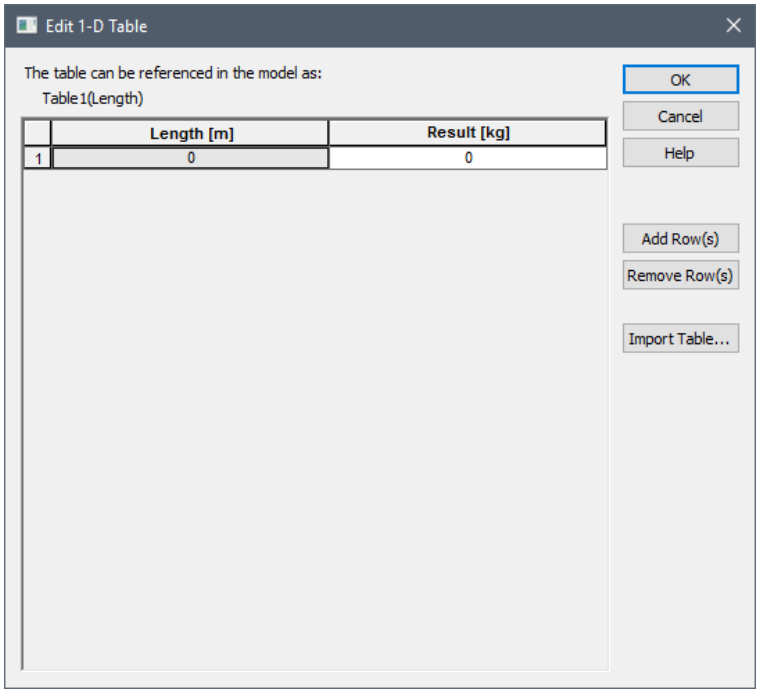
Note: In addition to defining the data table manually or importing from a text file, you can also link the data directly to an external data source (such as a spreadsheet file).

Read more: Linking a Lookup Table to an External Data Source (page 318).

Specifying Data in a 1-D Lookup Table Manually

You specify the data in a 1-D Lookup Table element manually by pressing the **Edit Data…** button.

The following dialog will be displayed:



*In this table, the **Result Units** are kg and the **Row Units** are m. Note also that the independent variable has been assigned a **Name** of "Length".*

By default, the table is created with a single row of zeros.

You add rows to the table using the **Add Row(s)** button. If you hold down the **Ctrl** key when you press this button, you will be prompted for the number of rows to add (otherwise, a single row will be added). To delete one or more rows, select them and press the **Remove Row(s)** button.

The first column of the table is where you enter the values for the independent (row) variable; the second column is where you enter the values for the dependent variable (the result).

The fields in the table only accept numbers (they do not accept links). You should not append units to the numbers. The assumed units for the values that you enter are the units specified for the two variables on the main Lookup Table dialog. These units are displayed in the column headers.

You can paste data from a spreadsheet, Word document or comma delimited text file into a 1-D table. To paste data from the Windows clipboard into a table, simply click once in the cell representing the upper left-hand corner of the region of the table into which you wish to paste the data, and press **Ctrl+V**.

When you paste data into a table, GoldSim will overwrite any data existing in the target region, and if necessary, will automatically expand the size of the table (i.e., add rows) to accommodate all of the data being pasted.

In addition to entering the data by hand, or pasting from another application, you can also import data directly from a specially formatted text file, a spreadsheet or a database. This is discussed further below.

The values of the Independent Variable must increase monotonically as you move downward in the table. When you press **OK** to close the dialog, GoldSim automatically sorts the rows into the correct order, and also deletes all empty rows.

Note: If, after defining a 1-D Table, you change the units for one of the variables without changing the dimensions (e.g., from feet to meters), GoldSim will automatically convert the existing data in the table to the new units. For example, if one of the entries for a dependent variable was 1 ft, and you changed the units for the dependent variable to meters, GoldSim would automatically convert the entry to 0.3048 meters. If the units are changed in such a way that the dimensions for the variable are different, the numbers will not be changed.

Note: If you are defining a 1-D Table, and the Row Variable represents the simulation time (i.e., Time or Etime), instead of using a Lookup Table element, you should use a Time Series element. This element is essentially a one-dimensional lookup table that is specifically designed to represent Time Series data (i.e., 1-D lookup tables in which the independent variable is time).

Note: When a Lookup Table is linked to a spreadsheet or database, you cannot edit the data once it has been imported; you can only view it. If you wish to edit the data, you must first remove the link to the spreadsheet or database (by changing **Data Source** to "None").

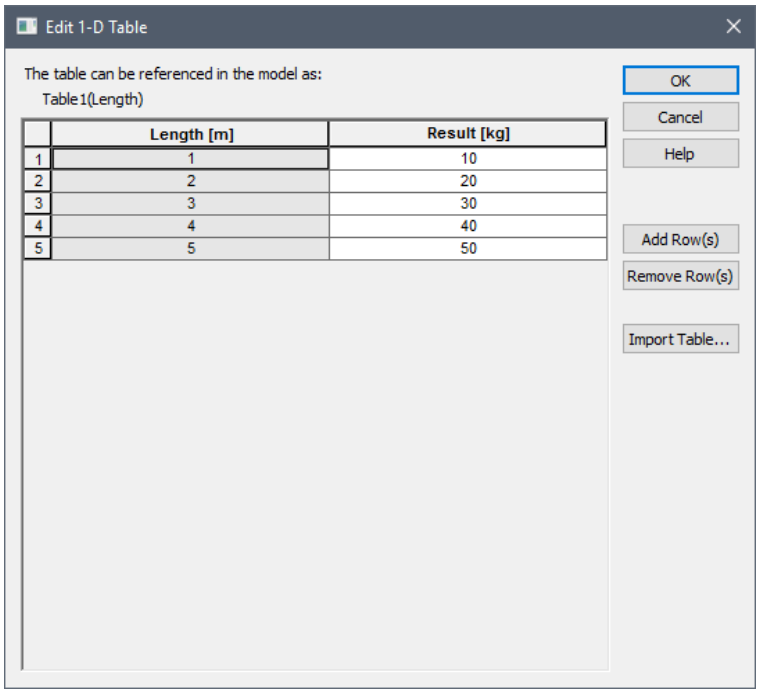
Read more: Using Time Series Elements (page 192).

Importing 1-D Lookup Table Data from a Text File

GoldSim allows you to directly import a text file representing a 1-D Lookup Table. The format for this text file is as follows:

- number of dimensions (in this case, 1)
- the number of rows
- row value1, row value 2, …, row value n
- dependent value 1, dependent value 2, …, dependent value n

For example, the following table:



could be defined using the following text file:

```
! Example File
1
5
1, 2, 3, 4, 5
10, 20, 30, 40, 50
```

The data in the file can be comma delimited or space delimited, and lines beginning with "!" are ignored.

To import the text file press the **Import Table…** button in the Edit 1-D Table dialog. You will be prompted for the name of the text file.

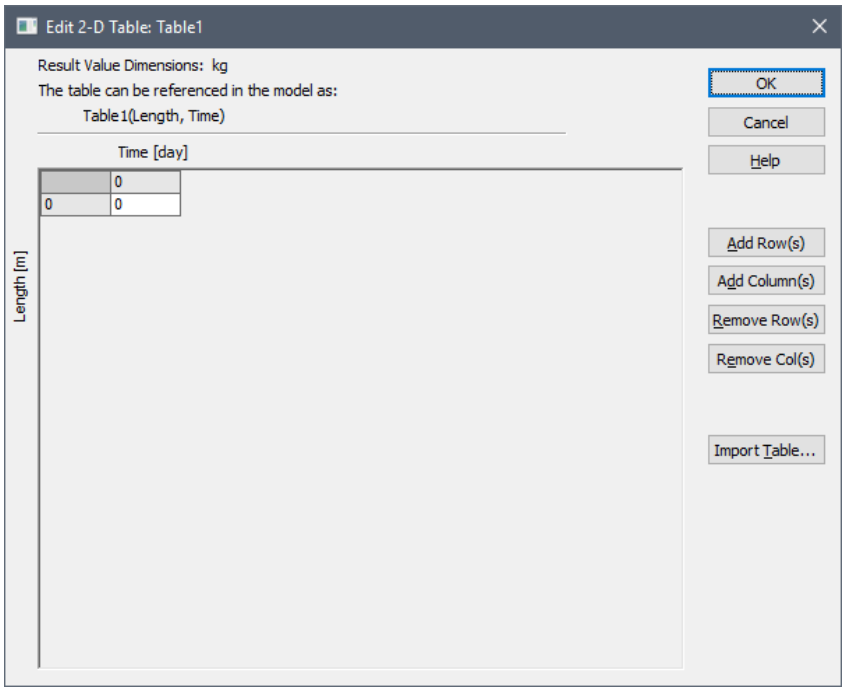
Note: In addition to importing from a text file into a Lookup Table directly from the Edit dialog, you can also link a text file to a Lookup Table, so that it is imported automatically when the file changes.

Read more: Linking a Lookup Table to a Text File (page 323).

Specifying Data in a 2-D Lookup Table Manually

You specify the data in a 2-D Lookup Table element manually by pressing the **Edit Data…** button, which will display a dialog for defining the data in the table.

The following dialog will be displayed:



*In this table, the **Result Units** are kg, the **Row Units** are m, and the **Column Units** are day. Note also that the row variable has been assigned a **Name** of "Length" and the column variable has been assigned a **Name** of "Time".*

By default, the table is created with a single column and a single row, and all the data values set to zero.

Within this dialog, you add rows and columns to the table using the **Add Row(s)** and **Add Column(s)** buttons. If you hold down the **Ctrl** key when you press these buttons, you will be prompted for the number of rows or columns to add (otherwise, a single row or column will be added).To delete one or more rows or columns, select them and press the **Remove Row(s)** or **Remove Col(s)** button.

The first column of the table is where you enter the values for the independent (row) variable; the first row of the table is where you enter the values for the second independent (column) variable, and the remainder of the table is where you enter the values for the dependent variable (the result).

The fields in the table only accept numbers (they do not accept links). You should not append units to the numbers. The assumed units for the values that you enter are the units specified for the three variables on the main Lookup Table dialog. These units are displayed in the row and column headers (for the Row and Column Variables) and at the top of the dialog (for the Dependent Variable).

You can paste data from a spreadsheet, Word document or comma delimited text file into a 2-D table. To paste data from the Windows clipboard into a table, simply click once in the cell representing the upper left-hand corner of the region of the table into which you wish to paste the data, and press **Ctrl+V**.

When you paste data into a table, GoldSim will overwrite any data existing in the target region, and if necessary, will automatically expand the size of the table (i.e., add rows and columns) to accommodate all of the data being pasted.

In addition to entering the data by hand, or pasting from another application, you can also import data directly from a specially formatted text file. This is discussed further below.

The values of the Row and Column Variables must increase monotonically as you move downward or across in the table. When you press **OK** to close the dialog, GoldSim automatically sorts the rows and columns into the correct order, and also deletes all empty rows and columns.

Note: If, after defining a 2-D Table, you change the units for one of the variables without changing the dimensions (e.g., from feet to meters), GoldSim will automatically convert the existing data in the table to the new units. For example, if one of the entries for a dependent variable was 1 ft, and you changed the units for the dependent variable to meters, GoldSim would automatically convert the entry to 0.3048 meters. If the units are changed in such a way that the dimensions for the variable are different, the numbers will not be changed.

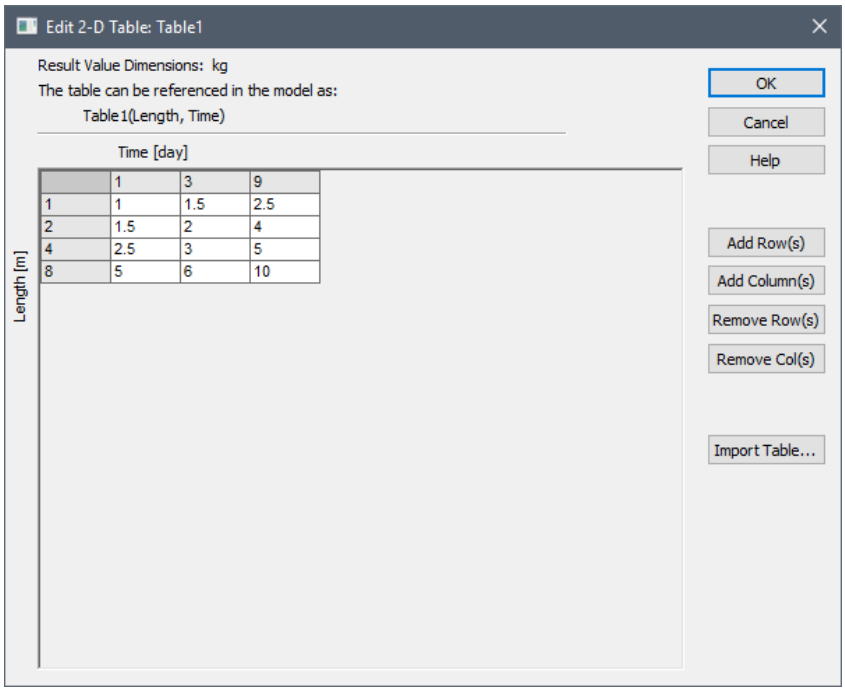
Note: When a Lookup Table is linked to a spreadsheet or database, you cannot edit the data once it has been imported; you can only view it. If you wish to edit the data, you must first remove the link to the spreadsheet or database (by changing **Data Source** to "None").

Importing 2-D Lookup Table Data from a Text File

GoldSim allows you to directly import a text file representing a 2-D Lookup Table. The format for this text file is as follows:

- number of dimensions (in this case, 2)
- the number of columns, the number of rows
- column value 1, column value 2, …, column value n
- row value1, row value 2, …, row value n
- dependent(row 1, column 1), …, dependent(row 1,column n)
- dependent(row 2, column 1), …, dependent(row 2,column n)
- …
- dependent(row n, column 1), …, dependent(row n, column n)

For example, the following table:



	1	3	9
1	1	1.5	2.5
2	1.5	2	4
4	2.5	3	5
8	5	6	10

could be defined using the following text file:

```
! Example File
2
3, 4
1, 3, 9
1, 2, 4, 8
1, 1.5, 2.5
1.5, 2, 4
2.5, 3, 5
5, 6, 10
```

The data in the file can be comma delimited or space delimited, and lines beginning with "!" are ignored.

To import the text file press the **Import Table…** button in the Edit 2-D Table dialog. You will be prompted for the name of the text file.

Note: In addition to importing from a text file into a Lookup Table directly from the Edit dialog, you can also link a text file to a Lookup Table, so that it is imported automatically when the file changes.

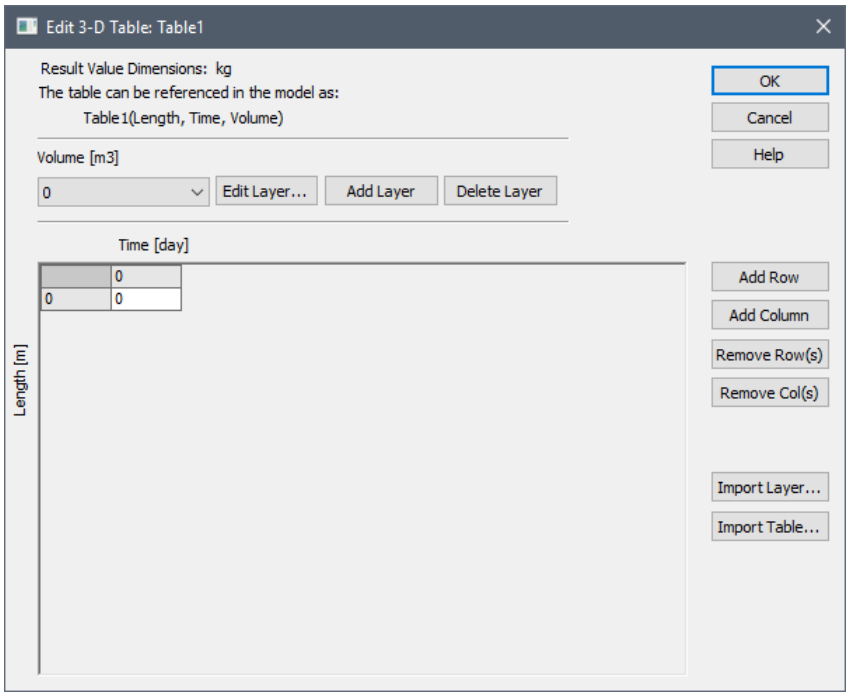
Read more: Linking a Lookup Table to a Text File (page 323).

Specifying Data in a 3-D Lookup Table Manually

You specify the data in a 3-D Lookup Table element manually by pressing the **Edit Data…** button, which will display a dialog for defining the data in the table.

A 3-D table can be thought of as a 2-D table with multiple layers or slices. The Layer Variable defines the layer or "slice" of the look-up table, the Row Variable defines the rows, and the Column variable defines the columns.

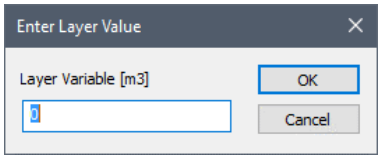
The following dialog will be displayed:



*In this table, the **Result Units** are kg, the **Row Units** are m, the **Column Units** are day and the **Layer Units** are m3. Note also that the row variable has been assigned a **Name** of "Length", the column variable has been assigned a **Name** of "Time" and the layer variable has been assigned a **Name** of "Volume".*

By default, the table is created with a single column, a single row and a single layer, and all the data values set to zero.

Within this dialog, you view one 2-D layer or slice of the table at a time. Each 2-D layer is associated with a particular value of the Layer Variable. When you first create a 3-D Table, there is by default, a single layer (a single value for the Layer Variable), and it is equal to 0. You can edit the value for a Layer Variable by pressing the **Edit Layer…** button, which will display the following dialog:



You can only enter a number into this field and should not append units. The assumed units for the values that you enter are the units specified for the Layer Variables on the main Lookup Table dialog. These units are displayed just above the Layer Variable edit field.

You can add additional layers by pressing the **Add Layer** button (which will display the same dialog as shown above). The **Delete Layer** button deletes the current layer. You can edit the value of an existing layer variable by pressing the **Edit Layer…** button.

You add rows and columns to the table using the **Add Row(s)** and **Add Column(s)** buttons. If you hold down the **Ctrl** key when you press these buttons, you will be prompted for the number of rows or columns to add (otherwise, a single row or column will be added). To delete one or more rows or columns, select them and press the **Remove Row(s)** or **Remove Col(s)** button. Note that all Layers have the same rows and columns.

Within this dialog, the first column of the table is where you enter the values for the independent (row) variable; the first row of the table is where you enter the values for the second independent (column) variable, and the remainder of the table is where you enter the values for the dependent variable (the result).

The fields in the table only accept numbers (they do not accept links). You should not append units to the numbers. The assumed units for the values that you enter are the units specified for the three variables on the main Lookup Table dialog. These units are displayed in the row and column headers (for the Row and Column Variables) and at the top of the dialog (for the Dependent Variable).

You can paste data from a spreadsheet, Word document or comma delimited text file into a Layer of a 3-D table. To paste data from the Windows clipboard into a table, simply click once in the cell representing the upper left-hand corner of the region of the table into which you wish to paste the data, and press **Ctrl+V**.

When you paste data into a table, GoldSim will overwrite any data existing in the target region, and if necessary, will automatically expand the size of the table (i.e., add rows and columns) to accommodate all of the data being pasted.

In addition to entering the data by hand, or pasting from another application, you can also import data directly from a specially formatted text file. This is discussed further below.

The values of the Row, Column and Layer Variables must increase monotonically as you move downward or across in the table. When you press **OK** to close the dialog, GoldSim automatically sorts the rows and columns into the correct order, and also deletes all empty rows and columns.

Note: If, after defining a 3-D Table, you change the units for one of the variables without changing the dimensions (e.g., from feet to meters), GoldSim will automatically convert the existing data in the table to the new units. For example, if one of the entries for a dependent variable was 1 ft, and you changed the units for the dependent variable to meters, GoldSim would automatically convert the entry to 0.3048 meters. If the units are changed in such a way that the dimensions for the variable are different, the numbers will not be changed.

Note: When a Lookup Table is linked to a spreadsheet or database, you cannot edit the data once it has been imported; you can only view it. If you wish to edit the data, you must first remove the link to the spreadsheet or database (by changing **Data Source** to "None").

Importing 3-D Lookup Table Data from a Text File

GoldSim allows you to directly import a text file representing a 3-D Lookup Table. The format for this text file is as follows:

- number of dimensions (must be 3)

- the number of columns, the number of rows, number of layers
- column value 1, column value 2, …, column value n
- row value1, row value 2, …, row value n
- layer value1, layer value 2, …, layer value n
- dependent(row 1, column 1, layer 1), …, dependent(row 1,column n, layer 1)
- dependent(row 2, column 1, layer 1), …, dependent(row 2,column n, layer 1)
- …
- dependent(row n, column 1, layer 1), …, dependent(row n, column n, layer 1)
- .
  .
  .
- dependent(row 1, column 1, layer n), …, dependent(row 1,column n, layer n)
- dependent(row 2, column 1, layer n), …, dependent(row 2,column n, layer n)
- …
- dependent(row n, column 1, layer n), …, dependent(row n, column n, layer n)

The data in the file can be comma delimited or space delimited, and lines beginning with "!" are ignored.

To import the text file press the **Import Table…** button in the Edit 3-D Table dialog. You will be prompted for the name of the text file.

You can also import a text file representing a two-dimensional look-up table into a layer. To do this, you define a 2-D table in a text file and press the **Import Layer…** button. You will be prompted for the file to import. The data from the table overwrites the information in the current layer.

Read more: Importing 2-D Lookup Table Data from a Text File (page 314).

Note: In addition to importing from a text file into a Lookup Table directly from the Edit dialog, you can also link a text file to a Lookup Table, so that it is imported automatically when the file changes.

Read more: Linking a Lookup Table to a Text File (page 323).

Linking a Lookup Table to an External Data Source

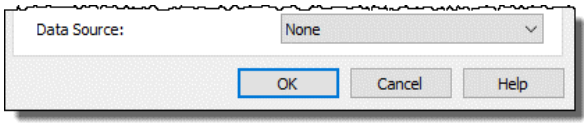
In addition to allowing you to specify the data for a Lookup Table manually (by typing or pasting in the data, or manually importing the data from a text file), GoldSim also allows you to link the data directly to an external data source.

GoldSim provides four options for doing this:

- You can link the table to a spreadsheet file;
- You can link the table to a text file;
- You can link the table to a database; and

- You can link the table to an external program (a DLL) which outputs the table directly to the Lookup Table element.

You link a Lookup Table to an external source by selecting a data source type from the **Data Source** field at the bottom of the Lookup Table dialog:



By default, this is set to "None". To link the Lookup Table to a Data Source, you select a different option from this list box (MS-Excel, Extended GoldSim Database, External DLL or ASCII Text File).

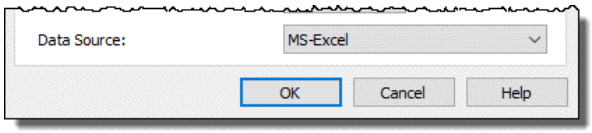
When you do so, a new tab is added to the dialog that allows you to define the properties of the Data Source link.

The four options for linking to an external Data Source are described in detail below.

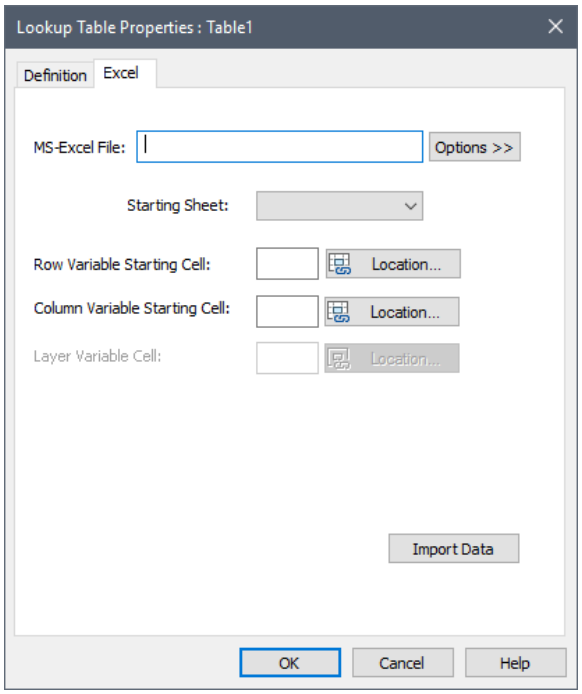
Read more: Linking a Lookup Table to a Spreadsheet (page 319); Linking a Lookup Table to a Text File (page 323); Linking a Lookup Table to a Database (page 324); Defining a Lookup Table Using an External Function (page 325).

Linking a Lookup Table to a Spreadsheet

You link a Lookup Table to a spreadsheet by selecting "MS-Excel" from the **Data Source** field at the bottom of the Lookup Table dialog:



When you do so, a new tab (Excel) is added to the dialog that allows you to define the properties of the spreadsheet link:



You must first enter the name of a Microsoft Excel spreadsheet file by pressing the **Options >>** button. This will provide options for either selecting an existing file, or creating (and then selecting) a new file.

Note: If you select a file in the same directory as (or a subdirectory below) your GoldSim .gsm file, GoldSim will subsequently display just a local path. If you select a file in a directory above your .gsm file, it will display the full path.

Once you have selected a file, you can subsequently use the **Options >>** button to select a different file. You can also use the **Options>>** button to open the selected file in Excel.

Note: GoldSim supports both .xlsx and .xls Excel files. However, if you have an older version of Excel (prior to Office 2007), you will need to install Microsoft's Office Compatibility Pack in order to read .xlsx files. Excel 2007 and later support an extended worksheet size (1,048,576 rows by 16,384 columns) than earlier versions (65,536 rows by 256 columns). If you wish to import data from an extended worksheet range into GoldSim, you must use Excel 2007 or newer, and the file format must be .xlsx. Note that GoldSim does not officially support versions of Excel prior to Excel 2003.

Warning: You should never try to open a spreadsheet that is linked to GoldSim while a simulation is running. In addition, prior to running a GoldSim model that is linked to a spreadsheet, all referenced spreadsheets should be closed. If you try to interact with a spreadsheet that is being used by GoldSim during a simulation, all interaction with the spreadsheet is blocked by GoldSim. However, under some circumstances this may not be possible and could lead to errors. Hence, as a general rule, you should not use Excel while a Goldsim model that references Excel is running.

It is easiest to understand how to define the spreadsheet linkage by considering 1-D, 2-D and 3-D tables separately.

Defining 1-D Tables

- You must specify the **Row Variable Starting Cell**. This represents the first value of the Row Variable. Row variable data must be contiguous and proceed down in a column.
- You can specify the cell (e.g., A2) directly by typing it into the **Starting Cell** field. In this case, you must also select the sheet from the **Starting Sheet** drop-list. Alternatively, you can press the **Location…** button, which opens the spreadsheet and provides a dialog allowing you to directly select the desired cell.
- Dependent data are assumed to be in the column immediately to the right of the Row Variable column.
- The import of data stops when a cell is encountered that is empty or contains non-numeric data.

Defining 2-D Tables

- You must specify the **Row Variable Starting Cell** and the **Column Variable Starting Cell**. These represent the first value of the Row Variable and Column Variable, respectively. Row variable data must be contiguous and proceed down in a column. Column variable data must be contiguous and proceed to the right across a column. The **Column Variable Starting Cell** must be above the **Row Variable Starting Cell** in the spreadsheet.
- You can specify a cell (e.g., B1) directly by typing it into the **Starting Cell** fields. In this case, you must also select the sheet from the **Starting Sheet** drop-list. Alternatively, you can press the **Location…** button adjacent to either field, which opens the spreadsheet and provides a dialog allowing you to directly select the desired cell.
- Dependent data for a particular Row and Column Variable is assumed to be at the intersection of these two variables in the sheet. For example, if the **Row Variable Starting Cell** was A2 and the **Column Variable Starting Cell** was in the B1, the dependent variable for the first row and the first column would be imported from B2:

	A	B	C	D	E	F
1	1	3	6	9	12	15
2	10	3	4	5	6	7
3	20	8	9	10	11	12
4	30	15	17	19	21	23
5	40	16	18	20	22	25
6	50	21	23	27	29	33

If the Row Variable Starting Cell was specified as A2, the Row Variable values would be imported as 10, 20, 30, 40 and 50. If the Column Variable Starting Cell was specified as B1, the Column Variable values would be imported as 3, 6 ,9, 12, and 15. B2 would be imported as representing the dependent variable when the Row Variable was equal to 10 and the Column Variable was equal to 3.In this file A1 would never be used.

- The import of data stops when a cell is encountered that is empty or contains non-numeric data.

Defining 3-D Tables

- You must specify the **Row Variable Starting Cell**, the **Column Variable Starting Cell** and the **Layer Variable Starting Cell**. These represent the first value of the Row Variable, Column Variable and Layer Variable, respectively. Row variable data must be contiguous and proceed down in a column. Column variable data must be contiguous and proceed to the right across a column. The **Column Variable Starting Cell** must be above the **Row Variable Starting Cell** in the spreadsheet. Layers are represented in separate sheets. The value for the Layer Variable for each sheet must always be in the same cell.
- You can specify a cell (e.g., B1) directly by typing it into the **Starting Cell** fields. Alternatively, you can press the **Location…** button adjacent to either field, which opens the spreadsheet and provides a dialog allowing you to directly select the desired cell.
- The **Starting Sheet** represents the location of the data for the first Layer Variable. Additional Layers are assumed to be to the right of the **Starting Sheet**.

- The values of the Row and Column Variables must be the same in every Layer sheet. If they are not, GoldSim will not import the table.
- Dependent data for a particular Row and Column Variable in a particular Layer sheet is assumed to be at the intersection of these two variables in the sheet. For example, if the **Row Variable Starting Cell** was A2 and the **Column Variable Starting Cell** was in the B1, the dependent variable for the first row and the first column would be imported from B2:

	A	B	C	D	E	F
1	1	3	6	9	12	15
2	10	3	4	5	6	7
3	20	8	9	10	11	12
4	30	15	17	19	21	23
5	40	16	18	20	22	25
6	50	21	23	27	29	33

If the Row Variable Starting Cell was specified as A2, the Row Variable values would be imported as 10, 20, 30, 40 and 50. If the Column Variable Starting Cell was specified as B1, the Column Variable values would be imported as 3, 6 ,9, 12, and 15. B2 would be imported as representing the dependent variable when the Row Variable was equal to 10 and the Column Variable was equal to 3. In this file, A1 represents the value of the Layer Variable for this sheet.

- The import of data stops when a cell is encountered that is empty or contains non-numeric data (where it expects to find a layer number)

Note: When data is imported from Excel into a Lookup Table, it is assumed that the values for the independent and dependent variables in Excel are in the same units as those specified in the Lookup Table dialog.

Note: When data is imported from Excel into a Lookup Table, it will stop the import and report an error if the values of the independent variables do not increase monotonically as you move downward/across the table. That is, unlike the case when you enter the data directly, GoldSim will not automatically sort the entries.

GoldSim automatically imports data from the spreadsheet at the start of a simulation if either 1) any of the properties on the Excel tab have been modified; or 2) the Excel file itself has been changed since the last import. You can also import data manually at any time prior to running a simulation (e.g., so you can view it) by pressing the **Import Data** button in the Excel tab.

Note: When you link a Lookup Table to a spreadsheet, the **Edit Data…** button changes to **View Data…**. If you press this button to access the dialog displaying the data, you will note that they are no longer editable. Once you are linked to a spreadsheet in this way, you can not edit the data manually unless you change **Data Source** back to "None". When you do so, GoldSim keeps the imported data and makes it editable.

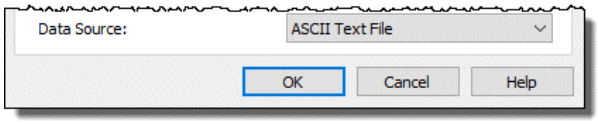
If you want to ensure that you do not import data from the spreadsheet that has been inadvertently edited since you last imported the data, you can choose to

"Lock onto" a spreadsheet file (by checking "Lock onto selected file" from the **Options>>** button). If you are locked onto a file, GoldSim will not allow the simulation to run if the file has been modified in any way (the file is set to read only when it is locked onto). In order to run a simulation with a changed file, you must first remove the lock (by clearing "Lock onto selected file" from the **Options>>** button).

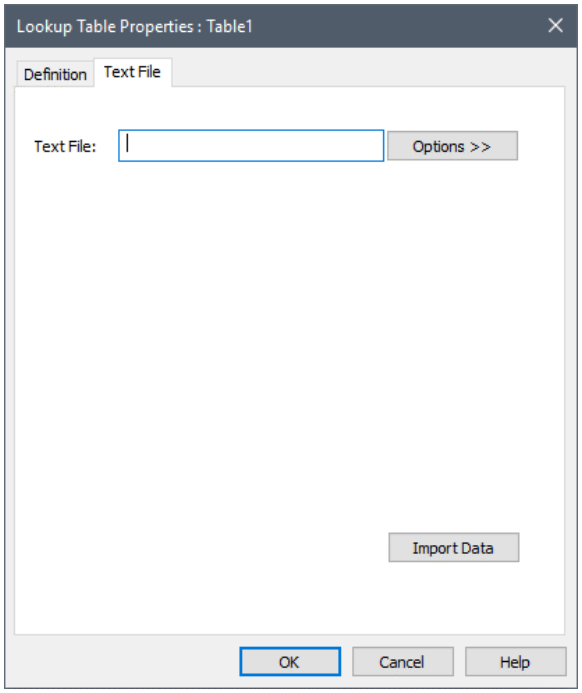
The example file (ImportTable.gsm) in the General Examples/LookupTable folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) illustrates how the Lookup Table data can be imported from a spreadsheet.

Linking a Lookup Table to a Text File

You link a Lookup Table to a text file (at runtime) by selecting "ASCII Text File" from the **Data Source** field at the bottom of the Lookup Table dialog:



When you do so, a new tab (Text File) is added to the dialog that allows you to define the name of the text file:



You must first enter the name of a text file by pressing the **Options >>** button.

Note: If you select a file in the same directory as (or a subdirectory below) your GoldSim .gsm file, GoldSim will subsequently display just a local path. If you select a file in a directory above your .gsm file, it will display the full path.

Once you have selected a file, you can subsequently use the **Options >>** button to select a different file. You can also use the **Options>>** button to open the selected file in your default text editor.

The format for the text file is identical to the format used when importing into a Lookup Table directly from the Editing dialog.

Read more: Importing 1-D Lookup Table Data from a Text File (page 311); Importing 2-D Lookup Table Data from a Text File (page 314); Importing 3-D Lookup Table Data from a Text File (page 317).

Note: When data is imported from a text file into a Lookup Table, it will stop the import and report an error if the values of the independent variables do not increase monotonically as you move downward/across the table. That is, unlike the case when you enter the data directly, GoldSim will not automatically sort the entries.

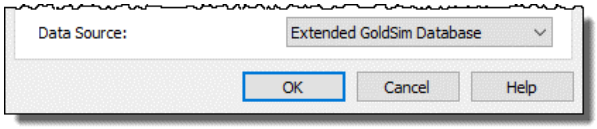
GoldSim automatically imports data from the text file at the start of a simulation if either 1) the filename has been changed; or 2) the file itself has been changed since the last import. You can also import data manually at any time prior to running a simulation (e.g., so you can view it) by pressing the **Import Data** button in the Text File tab.

Note: When you link a Lookup Table to a text file, the **Edit Data…** button changes to **View Data…**. If you press this button to access the dialog displaying the data, you will note that they are no longer editable. Once you are linked to a text file in this way, you can not edit the data manually unless you change **Data Source** back to "None". When you do so, GoldSim keeps the imported data and makes it editable.

If you want to ensure that you do not import data from the text file that has been inadvertently edited since you last imported the data, you can choose to "Lock onto" a text file (by checking "Lock onto selected file" from the **Options>>** button). If you are locked onto a file, GoldSim will not allow the simulation to run if the file has been modified in any way (the file is set to read only when it is locked onto). In order to run a simulation with a changed file, you must first remove the lock (by clearing "Lock onto selected file" from the **Options>>** button).

Linking a Lookup Table to a Database

You link a Lookup Table to a database by selecting "Extended GoldSim Database" from the **Data Source** field at the bottom of the Lookup Table dialog:



When you do so, a new tab (Database) is added to the dialog.

A Lookup Table is one of several types of elements that can be linked to a database. All elements that can import data from a database use a common set of structures and rules for doing so. Hence, in order to use this capability in GoldSim, you must be familiar with these rules and database structures.

An Extended GoldSim Database is one of several available database structures supported by GoldSim, and the only structure that supports Lookup Tables.

Note: Only 1-D and 2-D Lookup Tables can be linked to a database. GoldSim does not support linking a 3-D Lookup Table to a database.

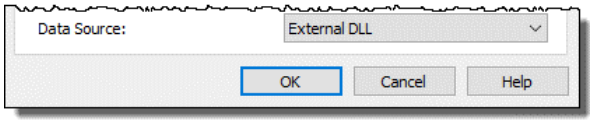
Read more: Linking Elements to a Database (page 1107).

Note: When you link a Lookup Table to a database, the **Edit Data…** button changes to **View Data…**. If you press this button to access the dialog displaying the data, you will note that they are no longer editable. Once you are linked to a database in this way, you can not edit the data manually unless you change **Data Source** back to "None". When you do so, GoldSim keeps the imported data and makes it editable.

Defining a Lookup Table Using an External Function

In some cases, you may wish an external program to directly generate the data that you can use to dynamically define a Lookup Table element. To facilitate this, GoldSim allows you to output the table from a DLL using an External element.

You link a Lookup Table to an external function by selecting "External DLL" from the **Data Source** field at the bottom of the Lookup Table dialog:



When you do so, a new tab (External DLL) is added to the dialog. You use this tab to specify the name of the External element output that defines the table.

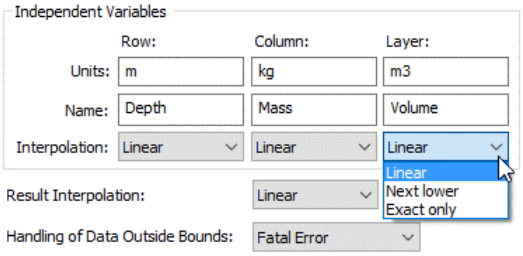
In order to do so, you must first be familiar with creating DLLs and linking them to GoldSim using External elements.

Read more: Using an External Element to Define Lookup Tables (page 1011).

Note: When a Lookup Table is linked to an external DLL, you can view the data once the model has been run. If you subsequently wish to edit the data, you can do so by first removing the link to the external DLL (by changing **Data Source** to "None").

Controlling Interpolation and Extrapolation for a Lookup Table

By default, the interpolation carried out by GoldSim to determine the value of the Dependent Variable for a given value of the Independent Variable (i.e., the argument) is done linearly with respect to both variables. However, you can change the interpolation to be used for any or all of the variables. This is done via the **Interpolation** drop-lists for the independent variables and the **Result Interpolation** drop-list for the dependent variable:



For the independent variables, GoldSim provides the following interpolation options:

Linear: This is the default, and if selected, GoldSim will linearly interpolate between table values to determine the appropriate value.

Next lower: This option results in a "stair-step" function, with no interpolation at all. If this option is selected, given an input argument for the table, GoldSim uses the largest independent variable entry in the table that is less than or equal to the input argument. For example, if your independent variable entries were 10, 20 and 30, and the input argument was 17, GoldSim would assume an independent variable value of 10.

Exact only: If this option is selected, the Lookup table will only accept arguments that exactly match independent variable entries in the table. If there is not an exact match, rather than interpolating between points, GoldSim issues a fatal error.

The only options available for Result Interpolation are **Linear** and **Log**.

The general guidance below can be used to determine when to use **Linear** or **Log** interpolation for the Result variable:

- If you plot the Results against an independent variable, and it becomes approximately a straight line, select **Linear** for both the Result and the Independent Variable.
- If you plot the logarithm of the Results against an independent variable, and it becomes approximately a straight line, select **Log** for Result and **Linear** for the Independent Variable.

Note: If an independent variable appears to vary logarithmically, enter the logs of the independent variable when defining points in the Lookup Table (and use the log of the independent variable as an argument when referencing the table).

When you define a Lookup Table, you must also specify how GoldSim is to handle references to the table that are outside the bounds of the table. For example, if your Row Variable varied between 1 and 10, and you used the Lookup Table to evaluate a value for the Row Variable equal to 15, how should GoldSim handle this?

The **Handling of Data Outside Bounds** field specifies how GoldSim is to handle such an instance. GoldSim provides three options for 1-D Tables, and two options for 2-D and 3-D Tables:

Fatal Error: This is the default. If you try to reference a point outside the bounds of the table, GoldSim will display a Fatal Error message when you try to run the simulation.

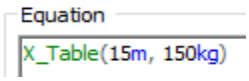
Do Not Extrapolate: If you try to reference a point outside the bounds of the table, GoldSim will not extrapolate. Instead, it will compute the value for the dependent variable based on the values for the independent variables at the nearest portion of the defined region. That is, it assigns a value from the nearest "edge" of the table.

Extrapolate: This option is only available for 1-D Tables. GoldSim extrapolates beyond the range of the specified data by using the two closest data pairs.

An example model which illustrates various interpolation and extrapolation options (TableInterpolation.gsm) can be found in the General Examples/LookupTable folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Referencing a Lookup Table

Lookup Table elements are unique in that you don't reference them in the same manner that you reference the outputs of other elements. Instead, you reference them in the way that you would reference a built-in function (like sin or min). That is, once you define a table, you reference it in input expressions for other elements as if it were a custom function:



This is referred to as a ***table function***. This expression instructs GoldSim to use the 2-D lookup table defined by the element X_Table and compute an output value based on a value for the row variable of 15m and a value for the column variable of 150kg.

Of course, once you have defined the table, you can reference it at multiple locations (i.e., in the input fields for various elements) using different input arguments (different independent variables) in the same manner as you would use the built-in functions provided by GoldSim multiple times. For example, elsewhere in the model you could reference X_Table(10ft, 135kg).

The argument(s) to a table function must have dimensions that are the same as those of the independent variables with which the Lookup Table was originally defined. Hence, in the example above, if you referenced the table as X_Table(10 day, 150 kg), GoldSim would produce an error message, since based on the way that X_Table was defined, the first argument (the Row Variable) must have dimensions of length.

The dimensions of the table function are determined by the Result Units specified when the Lookup Table was defined.

Table functions are always referenced as follows:

1-D Tables: *Tablename*(Row Variable)

2-D Tables: *Tablename*(Row Variable, Column Variable)

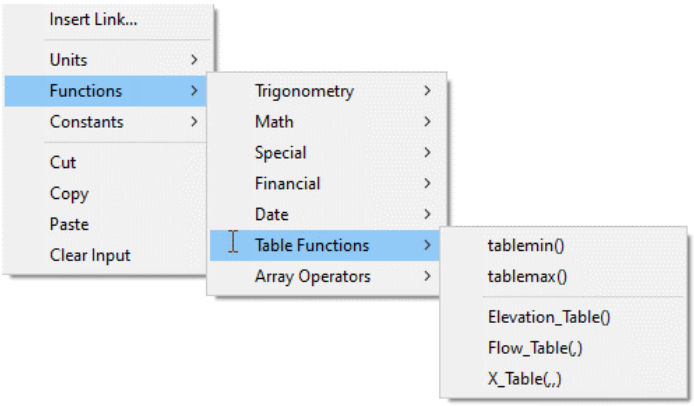
3-D Tables: *Tablename*(Row Variable, Column Variable, Layer Variable)

The arguments to a table function do not need to be numbers; they can be links from other elements.

Table functions can also accept arrays as input arguments (and subsequently produce arrays as outputs). For example, if ABC was a two-dimensional lookup table, ABC(1,2) would return a scalar value. However, if X and Y were vectors (e.g., of "Days"), then ABC(X,Y) would return a vector of days. The items would be evaluated by the lookup table on a term-by-term basis.

Read more: Using Vectors and Matrices (page 848).

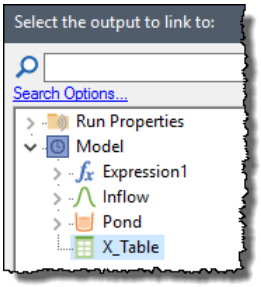
When you create a Lookup Table, GoldSim automatically lists the table function in the Function menu that is accessible from the context menu within an input field:



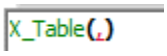
Read more: Built-in Functions (page 126).

There are two ways to add a Lookup Table to an expression:

1. You can use the context menu to insert a Table function (as shown above).
2. You can use the Insert Link cursor to reference the table directly:



In either case, the table is inserted as a function (i.e., with parentheses for arguments, and commas if there are multiple arguments):



In addition to the Lookup Tables you have created, there are two additional specialized functions in the Table Functions list (tablemin and tablemax). Both of these functions require as their argument the name of a Lookup Table element. They return the mimnimum and maximum vlaue, respectively, of the dependent variable.

Read more: Returning the Minimum or Maximum Value of the Dependent Variable (page 333).

In addition to referencing a Lookup Table as described above, GoldSim also provides some specialized ways to reference a 1-D table (i.e., to do an "inverse lookup" and to compute the integral or derivative of a 1-D Table). These options are discussed below.

Inverse Lookup: Referencing a 1-D Lookup Table Using the Dependent Variable

In some cases, you may want to do an inverse lookup into a Lookup Table. For example, suppose that you had defined a Lookup Table in which the independent variable is the volume of water in a pond, and the dependent variable is the water elevation in the pond (hence, the values in the table are determined by the shape of the pond). You would then use the Table to return a

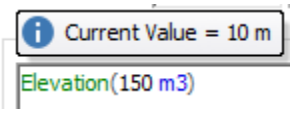
value for the water elevation for a specified value of the volume. However, what if you wanted to know the corresponding volume for a specified value of the water elevation?

GoldSim supports this by allowing you to carry out a reverse lookup; that is, you can reference a 1-D table by sending it a value for the *dependent variable*, and the function will return the corresponding value for the *independent variable*.

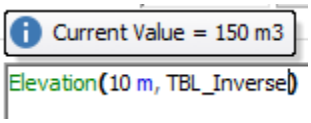
To implement this, you must add a second argument to the table function:

Tablename(Row Variable, TBL_Inverse)

Using the example described above, if you had a Lookup Table (named Elevation) in which the independent variable is the volume of water in a pond, and the dependent variable is the water elevation in the pond, then the following expression would return the elevation corresponding to a volume of 150 m^3:



and the following expression would return the volume corresponding to an elevation of 10 m:



Several points should be noted:

- If the argument is outside of the range of the table, GoldSim issues a fatal error (regardless of the **Handling of Data Outside Bounds** field setting).
- If the table is non-monotonic, the function returns the first value of the row variable that corresponds to the argument.
- The TBL_Inverse argument can only be used with 1-D tables. It cannot be used by 2-D and 3-D tables.

An example model which illustrates the inverse function (TableFunctions.gsm) can be found in the General Examples/LookupTable folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Computing the Integral or Derivative of a 1-D Lookup Table

In some cases, you may want to compute the integral or derivative of the function defined by a Lookup Table.

To implement these, you can add a second argument to the table function:

Tablename(Row Variable, TBL_Derivative): This returns the derivative of the function at the specified row value.

Tablename(Row Variable, TBL_Integral): This returns the integral of the table function up to the specified row value.

Tablename(Result Variable, TBL_Inv_Integral): This returns the row value corresponding to a specified integral for the table result (the result variable).

For example, if you had a Lookup Table (named Volume) in which the independent variable was a length and the dependent variable was a volume, then the following expression would return the derivative of the corresponding function (an area) when the independent variable was 5 m:

```
Volume(5 m, TBL_Derivative)
```

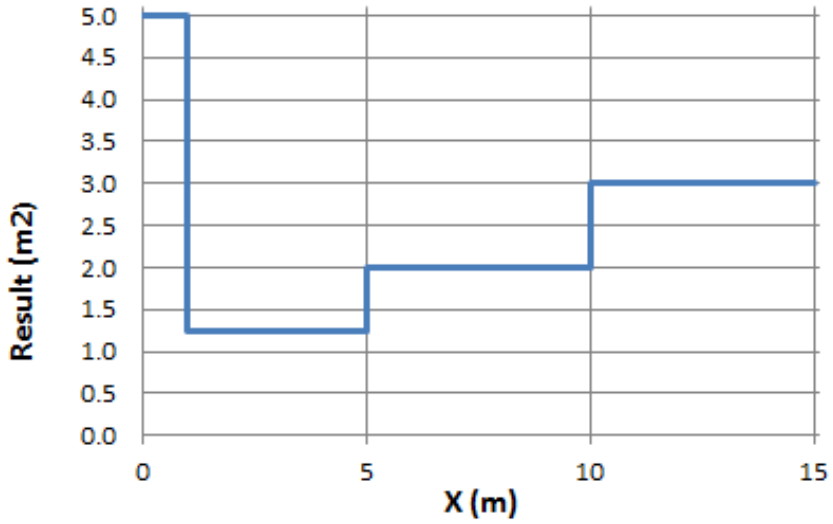
Note: These arguments can only be used with 1-D tables. They cannot be used by 2-D and 3-D tables.

The best way to illustrate how these functions are calculated is to consider a simple example. Consider the following 1-D Table (named "Volume), in which the independent variable has dimensions of length and the dependent variable has dimensions of volume:

	Depth [m]	Result [m3]
1	0	10
2	1	15
3	5	20
4	10	30
5	15	45

Computing the Derivative

The plot below shows how GoldSim would compute Volume(X, TBL_Derivative) for different values of X:



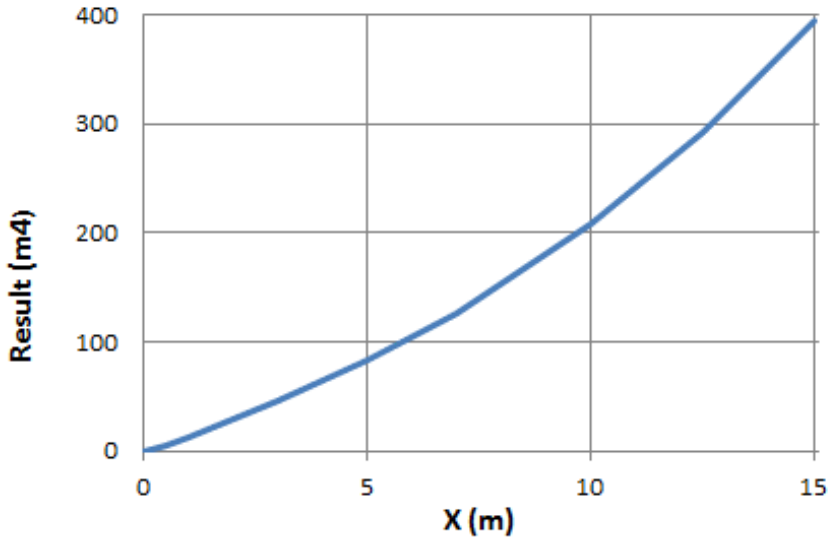
Several points should be noted:

- For TBL_Derivative, the dimensions of the input argument must be that of the Independent Variable. The dimensions of the output of the function are Dependent Variable dimensions / Independent Variable dimensions. In this example, since the Independent Variable was a length and the Dependent Variable was a volume, the result of the function has dimensions of an area.
- If the input is outside of the range of the table, the function returns the value at the edge of the table (regardless of the **Handling of Data Outside Bounds** field setting).
- The derivative function always returns a value of zero if the table's Interpolation is set to "Next lower".

- The derivative function returns an error if the Interpolation is set to "Exact only".

Computing the Integral

The plot below shows how GoldSim would compute Volume(X, TBL_Integral) for different values of X:

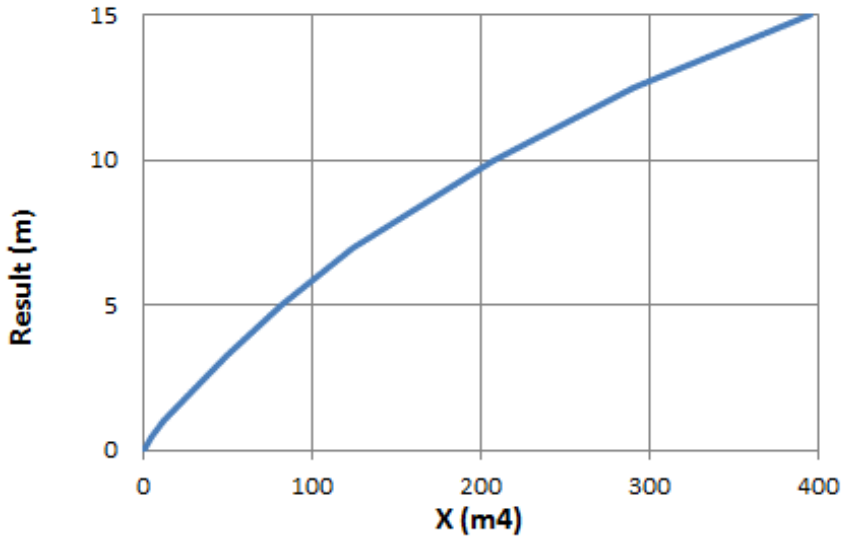


Several points should be noted:

- For TBL_Integral, the dimensions of the input argument must be that of the Independent Variable. The dimensions of the output of the function are Dependent Variable dimensions * Dependent Variable dimensions. In this example, since the Independent Variable was a length and the Dependent Variable was a volume, the result of the function has dimensions of length^4.
- The integral function integrates from the start of the table up to the lesser of the given argument and the end of the table. If the argument is less than the first row value for the table, the function returns zero.
- If the input is outside of the range of the table, the function returns the value at the edge of the table (regardless of the **Handling of Data Outside Bounds** field setting).
- The integral function returns an error if the Interpolation option is set to "Exact only".

Computing the Inverse Integral

The plot below shows how GoldSim would compute Volume(X, TBL_Inv_Integral) for different values of X:



Several points should be noted:

- For TBL_Inv_Integral, the dimensions of the input argument must be Dependent Variable dimensions * Independent Variable dimensions. In this example, since the Independent Variable was a length and the Dependent Variable was a volume, the dimensions of the input argument must be length^4. The dimensions of the output of the function are those of the Independent Variable.
- If the input (the integral) is outside of the range produced by the table's inputs, the function returns the value at the edge of the table (regardless of the **Handling of Data Outside Bounds** field setting). For example, in the example provided above, a value of 15m (the last data point in the table) corresponds to an integral value of 395m^4. As a result, if the first argument to Table(X, Inv_Integral) was greater than 395m^4, the function would return 15m.
- If the integral of the table is non-monotonic, the inverse integral returns the lowest value whose integral matches the argument.
- The inverse integral function returns an error if the Interpolation option is set to "Exact only".

One practical application of the use of these functions is when creating tables that describe how the surface area, volume and water elevation in a pond or reservoir are related. In these kinds of problems, you often would compute the volume, and then use a table to output the surface area and elevation corresponding to that volume. One way to do this in a consistent way using the table functions would be to define a table (named, say, Area_from_Elevation) that outputs the surface area as a function of the water elevation (i.e., the independent variable would be elevation and the dependent variable would be surface area). Given a volume (V), you could then use this table to compute the elevation and surface area as follows:

Elevation = Area_from_Elevation(V, TBL_Inv_Integral)

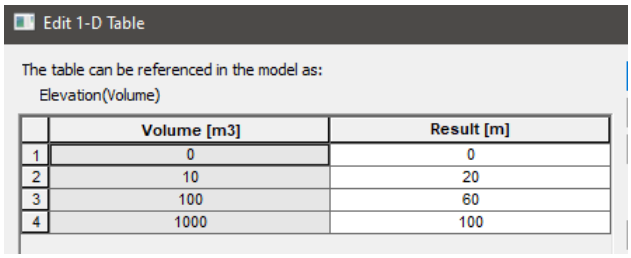
Surface_Area = Area_from_Elevation(Elevation)

An example model which illustrates these functions (TableFunctions.gsm) can be found in the General Examples/LookupTable folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Returning the Minimum or Maximum Value of the Dependent Variable

Sometimes you may want to return the minimum or maximum value of the dependent variable defined in your Lookup Table.

GoldSim provides two special functions to support this. To illustrate their use, consider the following 1-D Lookup table:



	Volume [m3]	Result [m]
1	0	0
2	10	20
3	100	60
4	1000	100

The special functions that are provided require as their argument the name of the Lookup Table element. In this example, the name of the element is Elevation.

Tablemin(Elevation) would return 0 m

Tablemax(Elevation) would return 100 m

We could combine this with the Inverse Lookup functionality when referencing a Lookup Table to return the the independent variable associated with the minimum or maximum value of the dependent variable. For example,

Elevation(Tablemin(Elevation), TBL_INVERSE) would return 0 m3

Elevation(Tablemax(Elevation), TBL_INVERSE) would return 1000 m3 m

Read more: Inverse Lookup: Referencing a 1-D Lookup Table Using the Dependent Variable (page 328).

Note that these two functions (Tablemin and Tablemax) can be used with 1-D, 2-D and 3-D Lookup Tables.

An example model which illustrates these functions (TableFunctions.gsm) can be found in the General Examples/LookupTable folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Building a Dynamic Lookup Table

Because all the values defining a Lookup Table must be constants, the definition of the table cannot change dynamically.

In some situations, however, you may need to change the definition of the table as a function of time. There are two ways to build dynamic lookup table logic:

- You can define multiple Lookup Table elements, and use if,then logic to switch between the different tables as a function of time; or
- You can use a vector to define a lookup table. GoldSim provides several array functions that allow you to interpolate into the entries in a vector. Since vector entries can change with time, this allows you to use this functionality to create a dynamic lookup table.

Read more: Using a Vector as a Lookup Table (page 864).

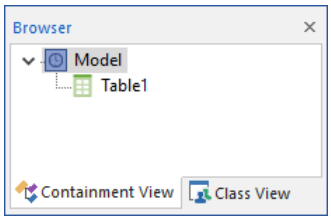
Browser View of a Lookup Table Element

A Lookup Table is an unusual element in that it does not have any inputs that accept links from other elements (since the entries to the table must be numbers). As a result, when you view a Lookup Table in the graphics pane, you will note that it never has an input port.

Read more: Understanding Input and Output Ports (page 76).

In addition, the output of a Lookup Table itself is not an actual value; rather it is simply a definition that does not take on a value unless you add the appropriate arguments.

As a result, the browser view of a Lookup Table is unusual in that it does not show any inputs or outputs (even when you have chosen the option to display these in the browser by selecting **Show Element Subitems**):



Note: If the table is defined using an external function, the Table does have an input port and a single input – the table definition.

Read more: Defining a Lookup Table Using an External Function (page 325).

Using Delay Elements

Delay elements simulate processes that delay continuous or discrete signals and flows. That is, their outputs lag their inputs. Therefore, like Stocks, their outputs are functions of prior values of their inputs. As a result, Delays impart inertia and memory to a system, and can internally generate dynamic behavior within a system. Without elements like Delays and Stocks, your models could respond to outside (exogenous) drivers, but could not generate any dynamics of their own internally.

Depending on the structure of your model, a Delay can lead to instability and oscillation, or it can act to filter out unwanted noise.

GoldSim provides four Delay elements:

- **Information Delays** are intended to represent processes such as delays in measuring or reporting variables (e.g., reporting the inventory in a warehouse, or snow pack levels), and the gradual adjustment of perceptions based on available information (e.g., sales forecasts).
- **Material Delays** are intended to represent delays in the physical movement (flow) of material through a system (letters though the mail system, parts on an assembly line, salmon in a river, water moving through a pipe). Material is conserved as it moves through a Material Delay. Information is not conserved in an Information Delay.
- **Event Delays** provide a mechanism for delaying a discrete event signal (i.e., a discrete signal that indicates that something, such as an accident or a bank deposit, has occurred). Among other things, Event Delays can be used to simulate queues.
- **Discrete Change Delays** provide a mechanism for delaying a discrete change signal (i.e., a discrete signal that can instantaneously change the value of a Stock element).

Information Delays and Materials Delays are used to delay continuous signals and flows (and are discussed in the sections below).

Event Delays and Discrete Change Delays are used for representing delays in discrete signals. Use of these two elements requires an understanding of how GoldSim simulates discrete events.

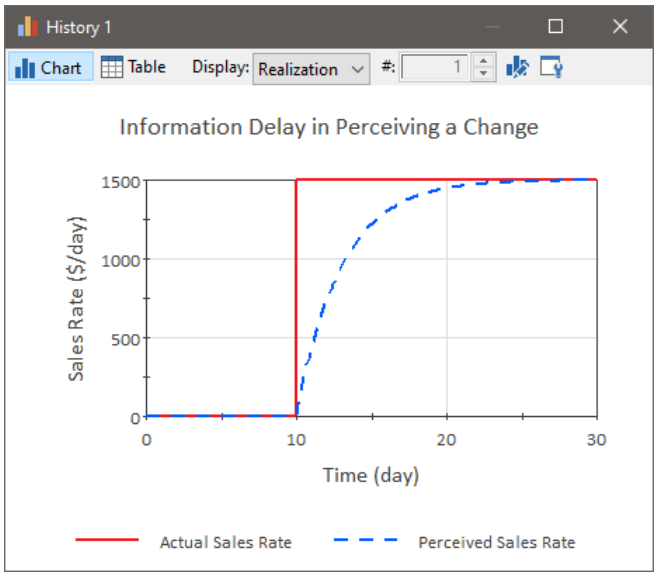
Read more: Chapter 5: Simulating Discrete Events (page 365).

Information Delay Elements

Information Delay elements are intended to be used to simulate delays in measuring, reporting, and/or responding to information. Such delays exist because it invariably takes time to collect, assimilate and act on new information.

These delays often have a critical impact on the dynamic behavior of systems. For example, many systems that are observed to oscillate involve such information delays. Example applications include processes such as delays in measuring or reporting variables (e.g., reporting the inventory in a warehouse, or snow pack levels), and the gradual adjustment of perceptions based on available information (e.g., sales forecasts).

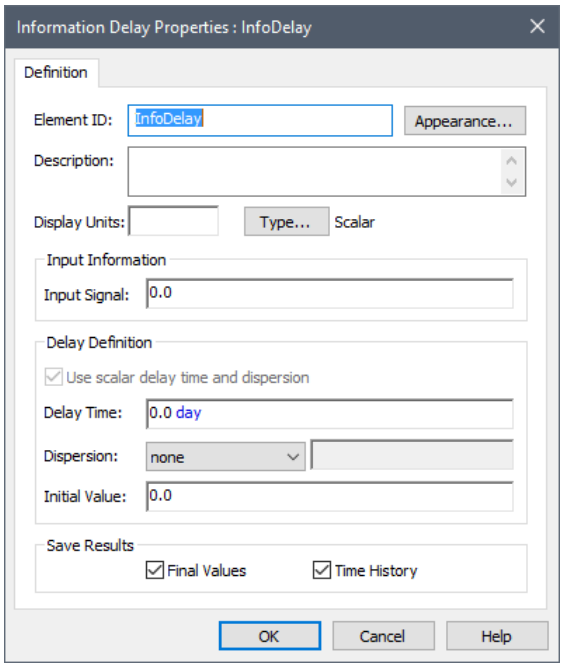
Reporting yesterday's rainfall total today is an example of an information delay, with a delay time of one day. In the business world, a classic example of an information delay is the delay in perceiving a change in a variable (e.g., the sales rate). The figure below illustrates the information delay associated with a manager's perception of a change in the sales rate:



In all of these examples, the reported or perceived value (i.e., the output of the Information Delay) is computed based on the historical values of its inputs.

Note that because Information Delays usually represent processes such as perception, measurement and reporting, by definition, these elements are typically used to simulate human actions. In particular, they are often used to represent the decision-making process of someone (or some group) in the system being simulated. Hence, models that simulate a purely physical process in which humans play no part rarely use Information Delay elements.

The properties dialog for an Information Delay element looks like this:



An Information Delay requires an **Input Signal** and a **Delay Time**. If desired, you can optionally define the degree of **Dispersion**. The single output of the Information Delay is the delayed signal, which has the same dimensions and order as the signal itself.

The best way to understand how to use Information Delays is to examine the behavior of the element in a number of simple examples. A file containing these examples (InformationDelay.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Specifying the Inputs to an Information Delay

Within the Information Delay properties dialog, the **Display Units** determine the dimensions of the Information Delay's output. This output can only be specified as a value (it cannot be a condition), and can be specified as a scalar, a vector or a matrix. You can specify whether the Information Delay is a scalar, vector or matrix by pressing the **Type…** button. By default, the output of a new Information Delay element is a scalar, dimensionless value. You can, however, use Information Delay elements to operate on and create vectors and matrices.

Read more: Using Vectors and Matrices (page 848).

The **Input Signal** and the **Initial Value** inputs to the Information Delay must have the same attributes (order and dimensions) as the output.

Note: The **Initial Value** must be a number or a link from a static variable (e.g., a constant Data element or a Stochastic).

The **Delay Time** must have dimensions of time and must be positive.

Note: The Delay Time for an Information Delay must be greater than or equal to the timestep. That is, GoldSim cannot delay a signal for a smaller time period than a timestep. If you enter a Delay Time which is less than a timestep, GoldSim internally treats the Delay Time as being equal to a timestep. Delay Times that are less than or equal to zero will result in a fatal error.

The **Dispersion** drop-list provides three choices: "None" (the default), "Erlang n", and "Std. Deviation".

If one of the latter two is selected, you must enter a value which quantifies the degree of dispersion to the right of this field. If "Erlang n" is selected, you must enter a dimensionless value greater than or equal to 1. If "Std. Deviation" is selected, you must enter a value with dimensions of time. The value must be greater than or equal to zero and less than or equal to the Delay Time.

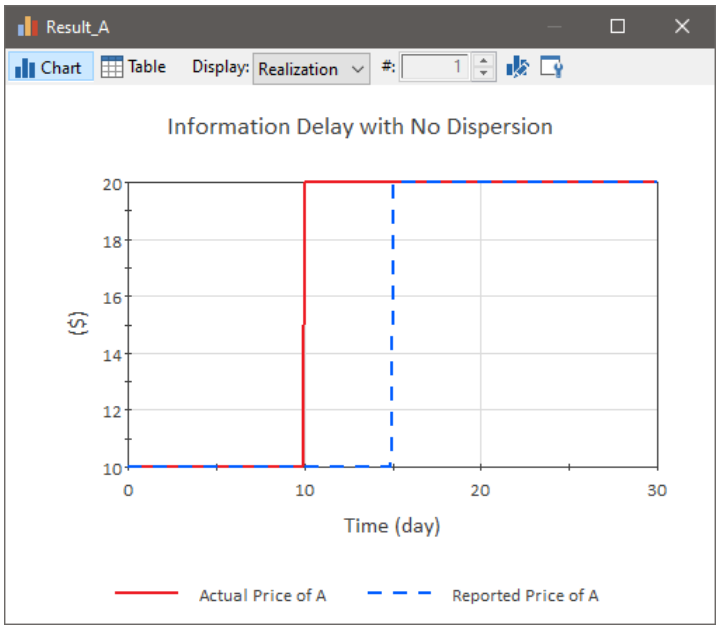
If the Information Delay is specified as being an array (i.e., a vector or a matrix), you can specify whether the **Delay Time** and **Dispersion** are defined as scalars (with the same value being applied to all items of the array), or as arrays (with different values applied to each item of the array). This is done via the **Use scalar delay time and dispersion** checkbox. If this box is checked (the default), the Delay Time and Dispersion must be entered as scalars. If the box is cleared (which is only possible if the element is specified as an array), the Delay Time and Dispersion must be entered as arrays.

Modeling Information Delays without Dispersion

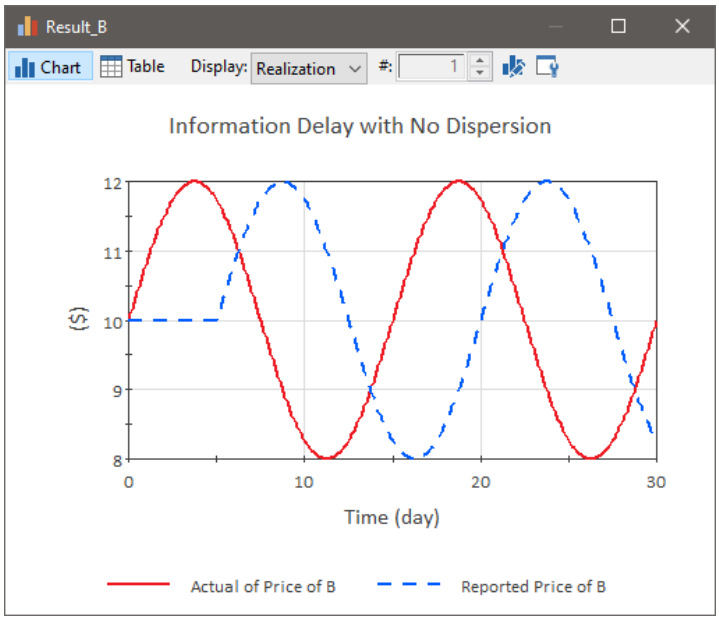
The simplest use of an Information Delay element is to represent the delay of a non-dispersed signal. To simulate such a system, the **Dispersion** must be set to "None". In this case, the output at any time t is simply the input lagged by the Delay Time:

Output(t) = Input(t -Delay Time)

An example of such a delay is any process where a variable is instantaneously measured (e.g., the inventory in a warehouse) but not reported or received by a manager or decision-maker until after a Delay Time. In the example shown below, the variable changes as a step, but there is a 5 day delay in reporting the value:



In the somewhat more interesting example shown below, the variable varies continuously (as a sine curve with a period of 15 days), and there is a 5 day delay in reporting the value. The Initial Value of the output of the Delay is set to 10:



Modeling Information Delays with Dispersion

In many cases, an information signal is dispersed, "smoothed" or "smeared" such that the output represents a weighted average of previous values for the input signal. (With no dispersion, the weight for the input value at t – Delay Time is one, and all other previous inputs have a weight of zero).

To specify that the information is dispersed, you must select either "Erlang n" or "Std. Deviation" from the **Dispersion** drop-list. These are two alternative ways to quantify the degree of dispersion in the signal.

Read more: Mathematics of Information Delays (page 341).

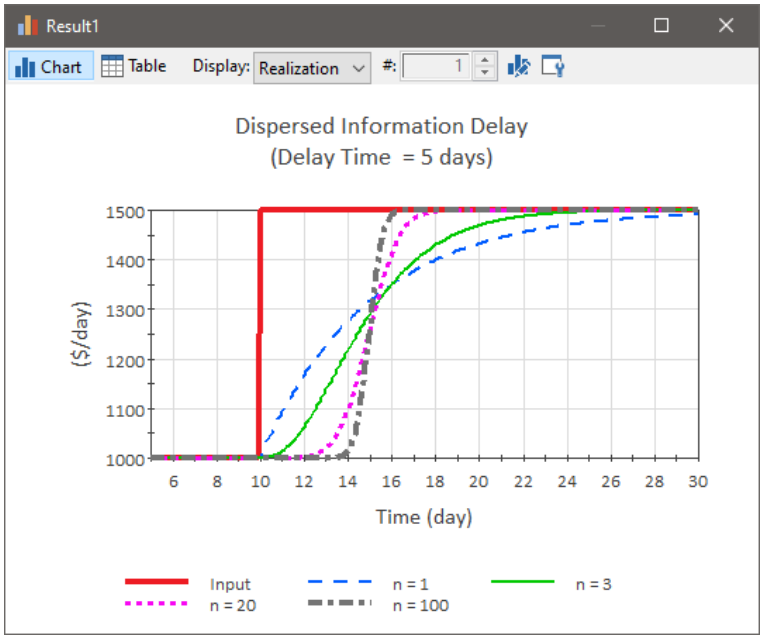
If "Erlang n" is selected, you must enter a dimensionless value greater than or equal to 1. As n increases, the degree of dispersion decreases. As n goes to infinity, the dispersion goes to zero. The maximum amount of dispersion allowed is represented by n = 1.

If "Std. Deviation" is selected, you must enter a value with dimensions of time. The value must be greater than or equal to zero and less than or equal to the Delay Time. As the Std. Deviation decreases, the degree of dispersion decreases. When the Std. Deviation goes to zero, the dispersion goes to zero. The maximum amount of dispersion allowed is represented by Std. Deviation = Delay Time.

The Erlang n and the Std. Deviation are related by the following equation:

$$n = \left(\frac{\text{Delay Time}}{\text{Std. Deviation}} \right)^2$$

The figure below shows the response of an Information Delay to a step function for various values of n:



Note that n = 1 (the highest level of dispersion allowed) is a special case referred to as ***exponential smoothing***. In this case, the calculation carried out by the Information Delay element to compute its output is equivalent to exponentially weighting the previous values (i.e., the most recent value has the highest weight, and the weights of older values decrease exponentially). Exponential smoothing is a commonly used forecasting model.

Read more: Simulating Forecasts Using Information Delays (page 342).

Specifying Initial Values for Information Delays

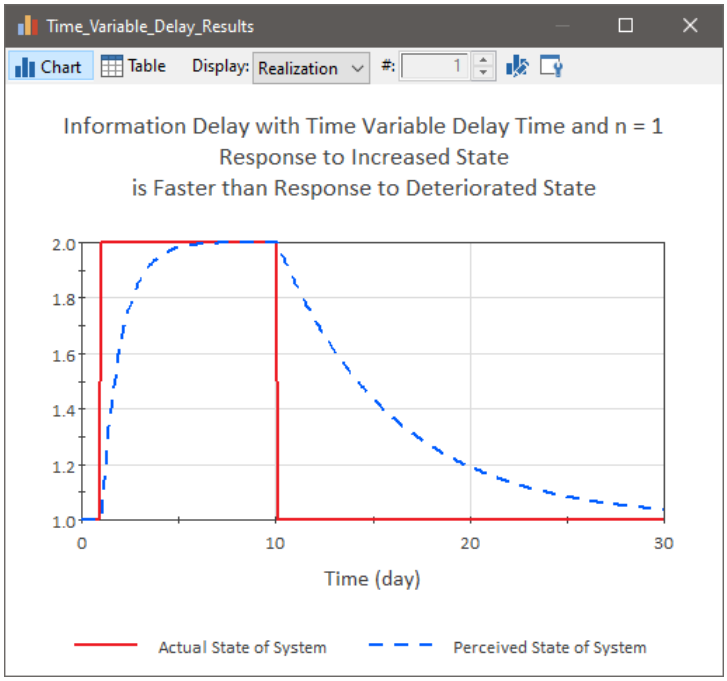
Information Delays always have a specified Initial Value. The Initial Value is assumed to have been the value of the input signal prior to the start of your simulation. That is, it is the initial output of the Information Delay element. The default is zero.

The ability to define an Initial Value is important since the actual processes that you will be simulating may not necessarily start when your simulation begins. That is, in many cases, the process probably will have been ongoing for some time prior to the time that you decide to simulate it.

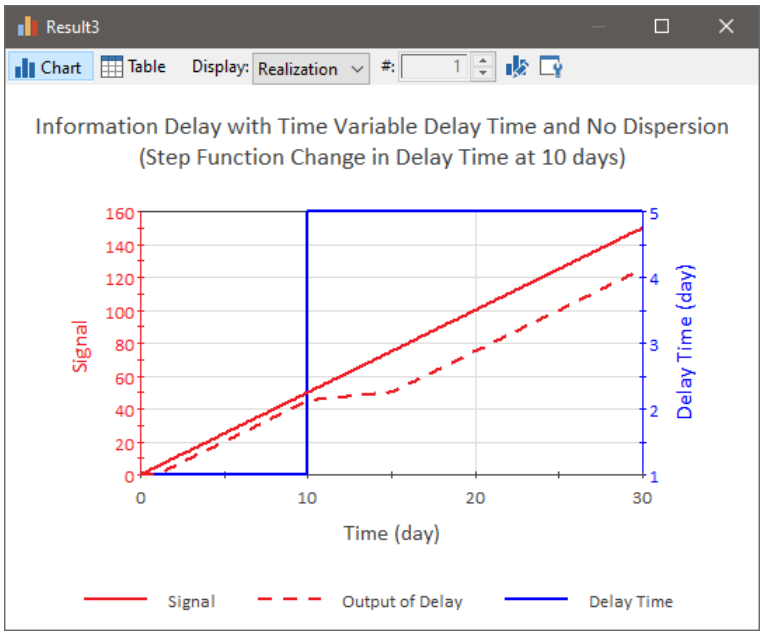
As a result, whatever your Information Delay actually represents (e.g., a perception, a forecast) will have some real value at the start of the simulation, and this value is not necessarily zero (the default). Therefore, you should take care to properly define an Initial Value for your Information Delay.

Information Delays with Time-Variable Delay Times

In some cases, the Delay Time for your Information Delay may change as a function of time. For example, a company may recognize and respond to improving economic conditions faster than deteriorating conditions. The figure below shows a situation in which the time to perceive a change in the system is faster when the current perceived state is less than the actual state (i.e., the state of the system has improved) and slower when the current perceived state is greater than the actual state (i.e., the state of the system has deteriorated).



To better understand how an Information Delay behaves when the Delay Time changes, it is worthwhile to consider a simple example. In this example, we assume no dispersion in the signal. The signal is a linear function of time. Prior to 10 days, the Delay Time is equal to 1 day. After 10 days, the Delay Time is equal to 5 days. The simulated result is shown below (Info_Delay is the output of the Delay element):



To understand this result, let's assume that the signal represents some measurement, and before the measurement gets reported, it must pass through a chain of ten individuals. Prior to 10 days, it takes 1 day for the information to move through these individuals. After 10 days, it takes 5 times longer (e.g., perhaps they change from working 5 days per week to one day per week). Any measurement received before 9 days is delayed exactly one day. Any measurement received after 10 days is delayed exactly 5 days. Any measurement received between 9 and 10 days (during the tenth day), is delayed from 1 to 5 days. Measurements received early in the 10^{th} day nearly made it all the way through the chain of individuals before their work rate decreased (the delay time increased). These signals are delayed for a little more than 1 day. Measurements received late in the 10^{th} day were not very far along the chain of individuals before their work rate decreased. These signals are delayed nearly 5 days.

Mathematics of Information Delays

In the absence of dispersion and assuming a constant Delay Time, the output of an Information Delay is simply computed as follows:

Output(t) = Input(t - Delay Time)

If the signal is dispersed (or the Delay Time is variable), the solution involves a convolution integral of the form:

$$\text{Output}(t) = \int_0^t \text{Input}(\tau)\, f(t-\tau)\, d\tau$$

f(t) is the gamma probability distribution, which is equivalent to (and a generalization of) the Erlang distribution that is frequently used in simulation models. f(t) represents the probability density of the time of "release" from the delay of an input at time 0:

$$f(t) = \frac{t^{n-1} e^{-t/\beta}}{\beta^n \Gamma(n)}$$

where:

n is the Erlang value (specified by the user);

$\beta = D/n$;

D is the mean delay time; and

Γ is the gamma function (*not* the Gamma distribution).

The Erlang distribution is equivalent to the distribution of passage times through a cascaded series of n mixing cells, each of which has a mean residence time of D/n. The gamma distribution represents the time until the occurrence of n sequential Poisson-process events, where each event's random time is represented by an exponential distribution with mean D/n.

The gamma distribution is a generalized version of the Erlang distribution, and does not require n to be an integer. Note that for n=1, the distribution is exponential, and for increasing values of n it becomes less skewed, approaching normality for large n.

The standard deviation of the gamma probability distribution is equal to $D/\sqrt{n}$. The degree of dispersion for an Information Delay can be specified in terms of either n or the standard deviation.

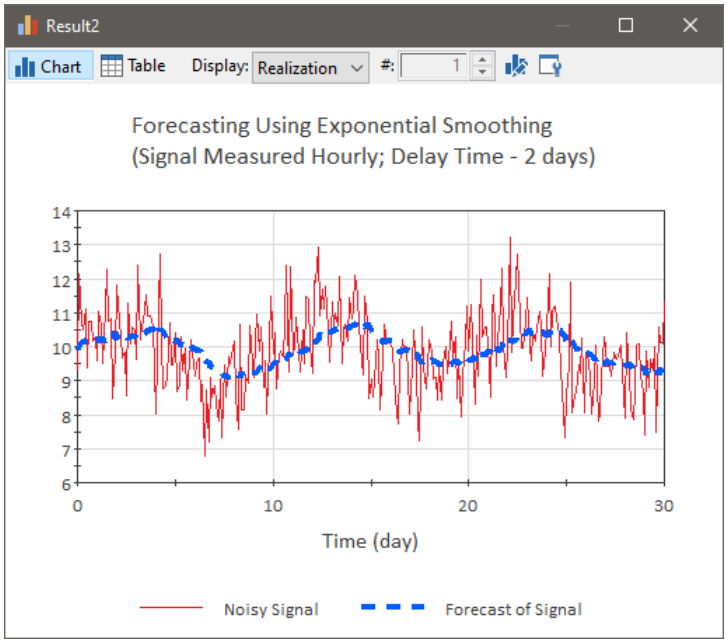
Read more: Modeling Information Delays with Dispersion (page 338).

GoldSim actually solves the convolution integral by first carrying out a transformation of the time axis. This allows for accurate representation of variable Delay Times.

Simulating Forecasts Using Information Delays

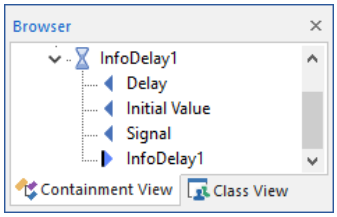
Many business decisions use forecasts of future behavior (e.g., the sales rate for a product) based on past observations. In order to simulate such systems using GoldSim, it is necessary to simulate the forecasting process itself. For example, when modeling a supply chain, it is necessary to simulate how orders are placed. In the real world, these orders are placed not based on the current demand (which may not even be measurable), but on a forecast of future demand.

An Information Delay can be used to represent a very commonly used forecasting method known as *exponential smoothing*. In exponential smoothing, the forecast is based on an exponentially-weighted average of past observations. Mathematically, this is equivalent to the output of an Information Delay with n =1. An example of such a simulated forecast is presented below:



Browser View of an Information Delay Element

As shown below, the browser view of an Information Delay element shows a single output, and has three inputs (the Signal, the Initial Value, and the length of the Delay:



Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

Material Delay Elements

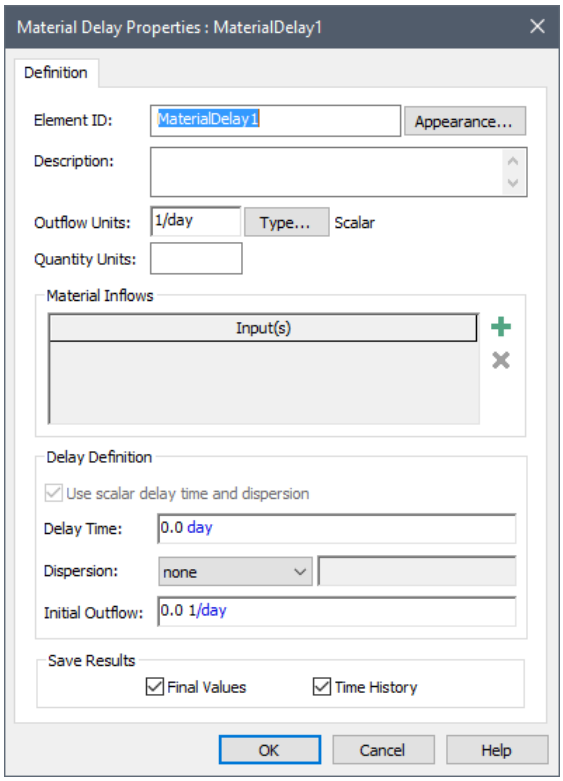
Material Delay elements are intended to be used to simulate delays in the physical movement (flow) of material. These delays often have a critical impact in the dynamic behavior of systems.

You would use a Material Delay element to simulate processes like the movement of parts on a conveyor belt, the flow of water through an aquifer, the movement of cars from one location to another, and the movement of letters through the mail system.

Material is conserved as it moves through a Material Delay. In some cases, the material may be dispersed while in transit. For example, if you send 100 letters all at once, they will not be delivered at the same time. Rather, there will be some variability in the time at which they are delivered (i.e., the delay time).

In other cases, the material is not dispersed. If a conveyor belt moves at a fixed speed, there will be no variability in the transit times for items that are placed on the conveyor.

The properties dialog for a Material Delay element looks like this:



A Material Delay requires one or more **Inflows** and a **Delay Time**. You can optionally define the degree of **Dispersion**.

The element has two outputs: the primary output of the Material Delay is the lagged flow (the Outflow), which has the same dimensions and order as the Inflow. The secondary output is the amount of material in transit within the Material Delay.

The best way to understand how to use Material Delays is to examine the behavior of the element in a number of simple examples. A file containing these examples (MaterialDelay.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Specifying the Inputs to a Material Delay

Within the Material Delay properties dialog, two sets of Display Units must be specified for a Material Delay (the **Outflow Units** and the **Quantity Units**), one for each of the element's outputs. The **Outflow Units** determine the dimensions of the Material Delay's primary output.

Note: GoldSim encourages (but does not require) you to specify Outflow Units for a Material Delay whose dimensions are consistent with a flow of materials. In particular, it expects the units to have dimensions of mass/time, volume/time, energy/time, currency/time, or 1/time. When you first specify the Outflow Units, GoldSim will warn you if your units do not have one of these dimensions. GoldSim will not, however, prevent you from using other units.

Read more: Differentiating Between Material and Information Flow (page 155).

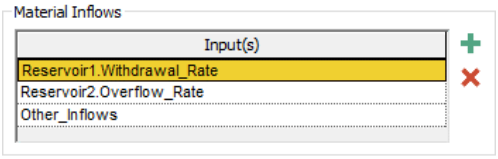
The primary output (the Outflow) can only be specified as a value, but can be specified as a scalar, a vector or a matrix. You can specify whether the Material Delay is a scalar, vector or matrix by pressing the **Type…** button. By default, the output of a new Material Delay element is a scalar, dimensionless value. You can also use Material Delay elements to operate on and create vectors and matrices.

Read more: Using Vectors and Matrices (page 848).

The **Quantity Units** determine the Display Units for the secondary output of the element, the Amount_in_Transit. The dimensions of this output must be the same as those of the Outflow multiplied by Time. For example, if the Outflow Units have dimensions of Mass/Time, the Quantity Units must have dimensions of Mass.

A Material Delay can have multiple Inflows. You add an Inflow to the element by pressing the **Add Material Inflow** button (the green +). A browser tree showing all of the elements in the model will be displayed.

Note that this tree is organized by containment in the same manner as the main browser. To insert a link from this dialog, you select a specific output object (or an element having a primary output), and then press **OK**. If you press **Cancel**, GoldSim will insert a new blank item. In either case, the dialog will close and the item will be added to the list of Inflows in the properties dialog for the element:



The Inflows must have the same attributes (order and dimensions) as the primary output (the Outflow). Although you can edit any of the input fields after the Inflow is added, the Inflows must all be single links to another element (i.e., you cannot enter an expression here). In addition, the Inflows must be non-negative.

Inflows can be deleted using the **Remove Material Inflow** button (the red X).

The **Initial Outflow** to the Material Delay must have the same attributes (order and dimension) as the Outflow.

Note: The **Initial Outflow** must be a number or a link from a static variable (e.g., a constant Data element or a Stochastic).

The **Delay Time** must have dimensions of time and must be positive.

Note: The **Delay Time** for a Material Delay must be greater than or equal to the timestep. That is, GoldSim cannot delay a signal for a smaller time period than a timestep. If you enter a **Delay Time** which is less than a timestep, GoldSim internally treats the **Delay Time** as being equal to a timestep. **Delay Times** that are less than zero will result in a fatal error.

The **Dispersion** drop-list provides three choices: “None” (the default), “Erlang n”, and “Std. Deviation”.

If one of the latter two is selected, you must enter a value that quantifies the degree of dispersion to the right of this field. If "Erlang n" is selected, you must enter a dimensionless value greater than or equal to 1. If "Std. Deviation" is selected, you must enter a value with dimensions of time. The value must be greater than or equal to zero and less than or equal to the **Delay Time**.

If the Material Delay is specified as being an array (i.e., a vector or a matrix), you can specify whether the **Delay Time** and **Dispersion** are defined as scalars (with the same value being applied to all items of the array), or as arrays (with different values applied to each item of the array). This is done via the **Use scalar delay time and dispersion** checkbox. If this box is checked (the default), the **Delay Time** and **Dispersion** must be entered as scalars. If the box is cleared (which is only possible if the element is specified as an array), the **Delay Time** and **Dispersion** must be entered as arrays.

Modeling Material Delays without Dispersion

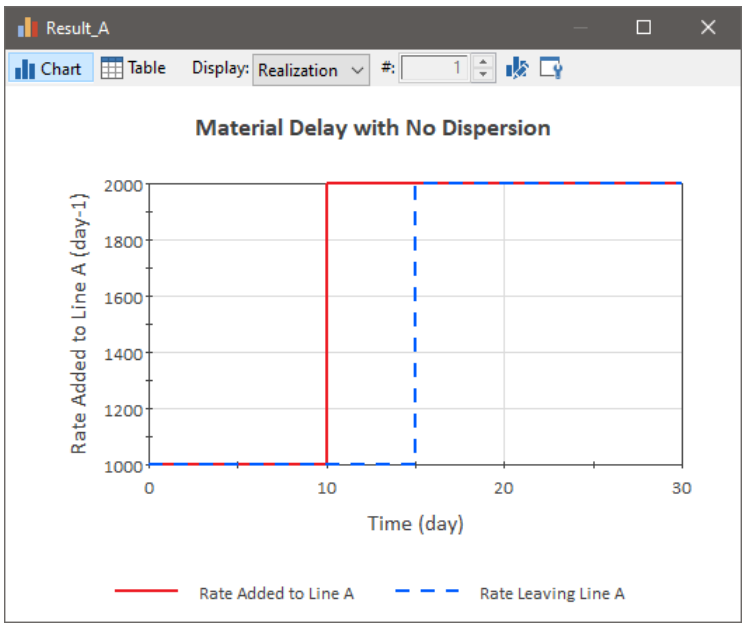
The simplest use of a Material Delay element is to represent the delay of a non-dispersed material flow. To simulate such a system, the **Dispersion** must be set to "None".

In this case, the Outflow at any time t is simply the Inflow lagged by the Delay Time:

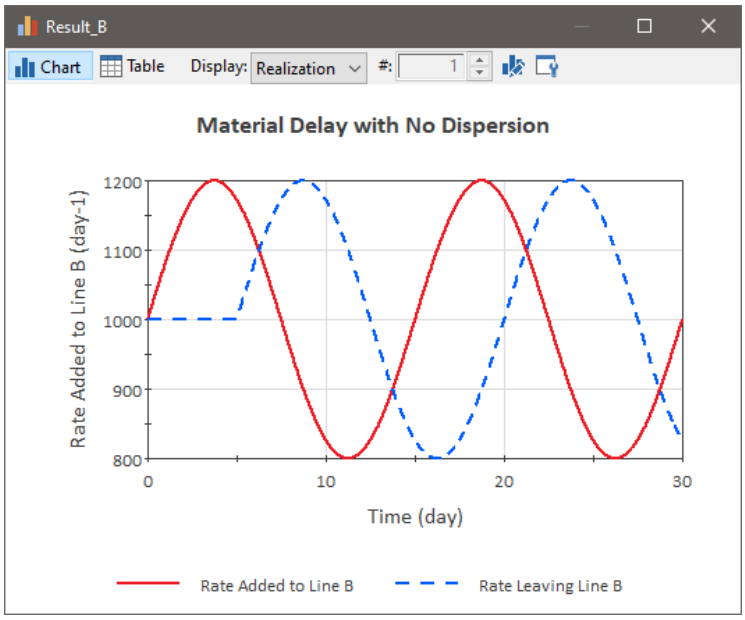
Outflow(t) = Inflow(t -Delay Time)

An example of such a delay is an assembly line that moves at a constant speed (regardless of the rate at which material enters the line).

In the example shown below, the rate changes as a step (at 10 days), and it takes exactly 5 days to traverse the line:



In the somewhat more interesting example shown below, the rate of addition to the line varies continuously (as a sine curve with a period of 15 days). Again, it takes 5 days to traverse the line:



Modeling Material Delays with Dispersion

In many cases, a material flow is dispersed, "smoothed" or "smeared" such that the output represents a weighted average of previous values for the input signal. (With no dispersion, the weight for the input value at t – Delay Time is one, and all other previous inputs have a weight of zero).

To specify that the material is dispersed, you must select either "Erlang n" or "Std. Deviation" from the **Dispersion** drop-list. These are two alternative ways to quantify the degree of dispersion while the flow traverses the delay.

Read more: Mathematics of Material Delays (page 354).

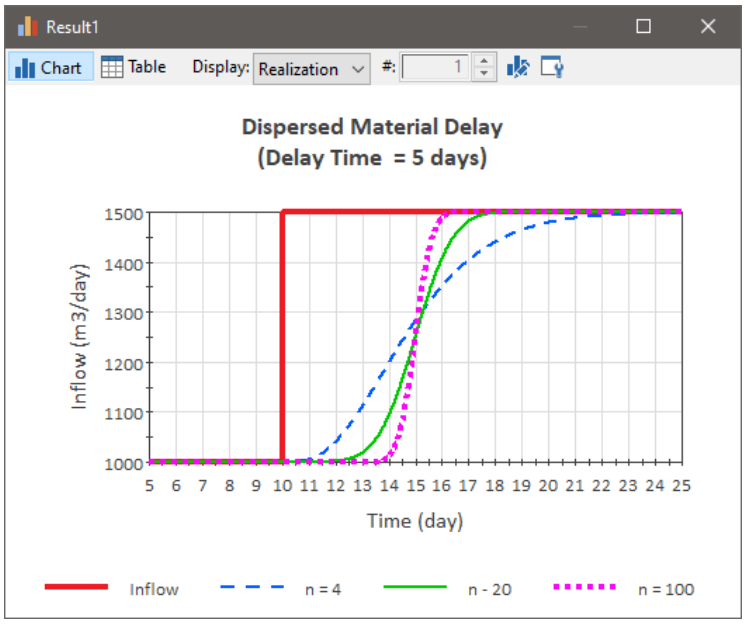
If the "Erlang n" is selected, you must enter a dimensionless value greater than or equal to 4. As n increases, the degree of dispersion decreases. As n goes to infinity, the dispersion goes to zero. The maximum amount of dispersion allowed is represented by n = 4.

If "Std. Deviation" is selected, you must enter a value with dimensions of time. The value must be greater than or equal to zero and less than or equal to the half of the Delay Time. As the Std. Deviation decreases, the degree of dispersion decreases. When the Std. Deviation goes to zero, the dispersion goes to zero. The maximum amount of dispersion allowed is represented by Std. Deviation = 0.5 * Delay Time.

The Erlang n and the Std. Deviation are related by the following equation:

$$n = \left(\frac{\text{Delay Time}}{\text{Std. Deviation}} \right)^2$$

The figure below shows the response of a Material Delay to a step function at ten days for various values of n:



Specifying Initial Outflows for Material Delays

A Material Delay can be assigned an Initial Outflow (the default is zero). The ability to do so is important since the actual processes that you will be simulating may not necessarily start when your simulation begins.

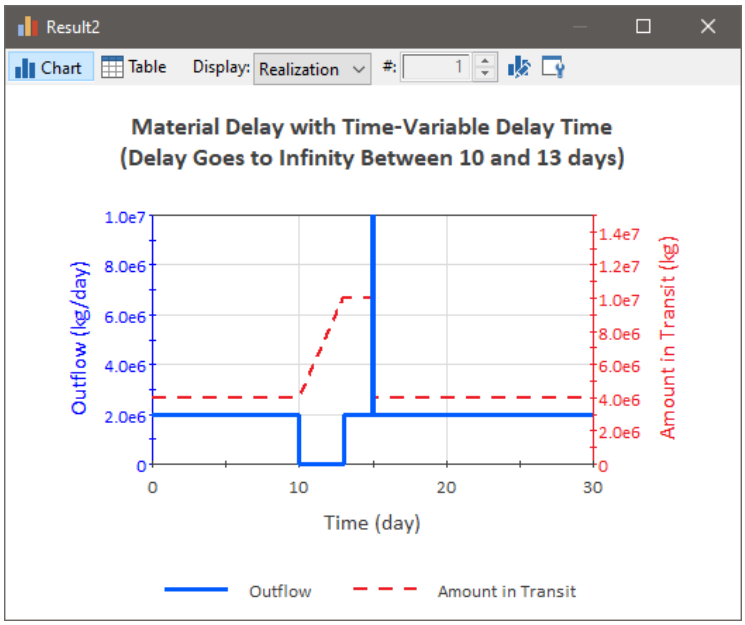
In many cases, the process may have been ongoing for some time prior to the start of the simulation. As a result, your Material Delay (e.g., an assembly line, an aquifer, a pipe) probably already contains some material (and is outflowing material) at the start of the simulation.

GoldSim allows you to specify the **Initial Outflow** for a Material Delay. The Initial Outflow is related to the initial amount of material in transit by the following equation:

$$\text{Initial Outflow} = \frac{\text{Initial Amount in Transit}}{\text{Initial Delay Time}}$$

Material Delays with Time-Variable Delay Times

In some cases, the Delay Time for your Material Delay may change as a function of time. For example, suppose a conveyor moves dirt from one location to another. It is loaded at a constant rate of 2E6 kg/day. The conveyor moves rather slowly, so that it takes 2 days for dirt which is loaded at one end to be offloaded at the other end. Let's further assume that at 10 days, the conveyor breaks down, and it takes 3 days to fix it. The figure below plots the Outflow Rate and the Amount in Transit for this simple model:



To understand this result, let's first examine the Outflow curve. Prior to time = 10 days, the Outflow Rate is constant and equal to the Inflow Rate (i.e., it is at steady state). At time = 10 days, the conveyor shuts down, and hence the Outflow goes to zero. After time = 13 days, the conveyor starts up again, and the Outflow resumes its original rate. At time = 15 days, however, a large spike of material outflows, and then the Outflow returns to the steady state value again. Where did this spike come from?

To understand this, examine the Amount in Transit output. Notice that while the conveyor is stopped, the Amount in Transit continues to increase. This is because the Inflow Rate has remained constant at 2E6 kg/day. This mass has to go somewhere (Material Delays conserve mass), so it is "piled up" at the start of the conveyor. Conceptually, it is as if the conveyor was continuing to be loaded, even though it was no longer moving (i.e., a large pile was growing on the first section of the conveyor. It is this "pile" that is released as a spike at time = 15 days (the height of the spike is actually off the scale shown here). Once the conveyor restarted, it took 2 days for the pile to traverse the conveyor.

Of course, this simple example is not very realistic. In reality, they would stop loading the conveyor (e.g., they would pile it next to the conveyor). This is true, and in that case, we would need to control the Inflow Rate. In the simple model above, the Inflow Rate was assumed to remain constant in order to explain the functionality of the element. A more realistic way to represent this particular system is to represent an inflow limit for the Material Delay (that might change with time). In this example, the inflow limit would go to zero when the conveyor stopped. The manner in which you could implement this is discussed below.

Representing a Material Delay with an Inflow Limit

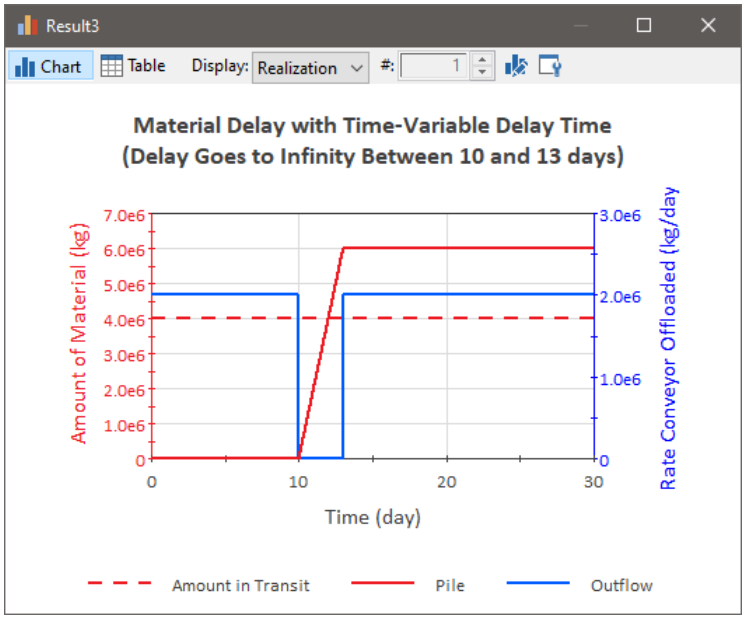
In some situations, a Material Delay may have a physical limit with regard to the Inflow rate that it can accept. For example, an assembly line has a maximum rate at which it can accept and process parts. A road also has a maximum rate at which cars can move along it. A conveyor belt has a maximum rate at which it can accept material (e.g., it will have some weight limit), and when it stops moving, this maximum rate goes to zero.

These kinds of systems can be easily modeled by combining a Reservoir (or a Pool) with a Material Delay (the example discussed here assumes a Reservoir).

The Inflow Rate is specified as the Addition Rate for the Reservoir. The maximum rate at which the Material Delay can accept material is specified as the Withdrawal Rate from the Reservoir. The Withdrawal Rate output of the Reservoir then becomes the Input Rate for the Material Delay. In this case, the Reservoir element represents a "pile" at the start of the Material Delay. If the Inflow Rate is greater than the rate at which the Delay can accept material, the pile grows; otherwise it shrinks (and may disappear completely).

As an example, consider a conveyor that moves dirt from one location to another. It is loaded at a constant rate of 2E6 kg/day. The conveyor moves rather slowly, so that it takes 2 days for dirt which is loaded at one end to be offloaded at the other end. Let's further assume that at 10 days, the conveyor breaks down, and it takes 3 days to fix it. An example of how such a structure can be used to more realistically model this simple system is included in the file MaterialDelay.gsm which can be found in the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

The result looks like this:



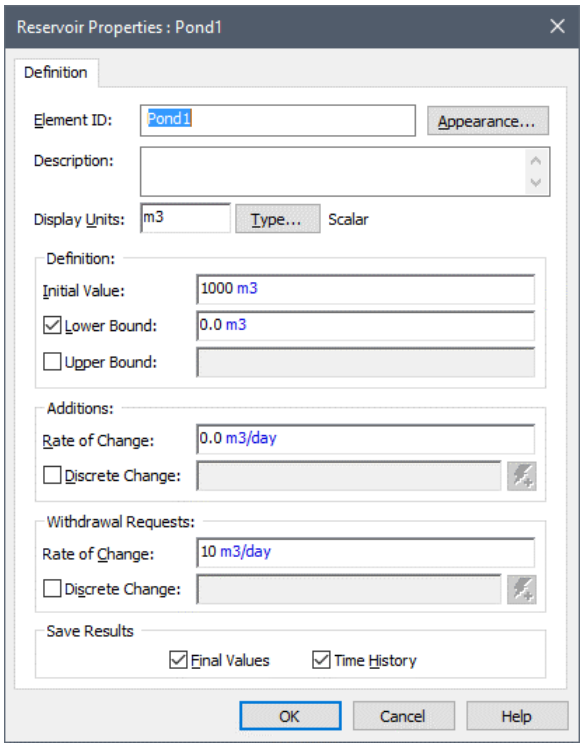
In this case, while the conveyor is stopped, material accumulates in the Pile (it is not placed on the conveyor). The size of the Pile increases while the conveyor is stopped, and then remains constant (since inflow to the Pile = outflow from the Pile) once the conveyor restarts.

Using Material Delays to Close Feedback Loops and Model Recirculating Systems

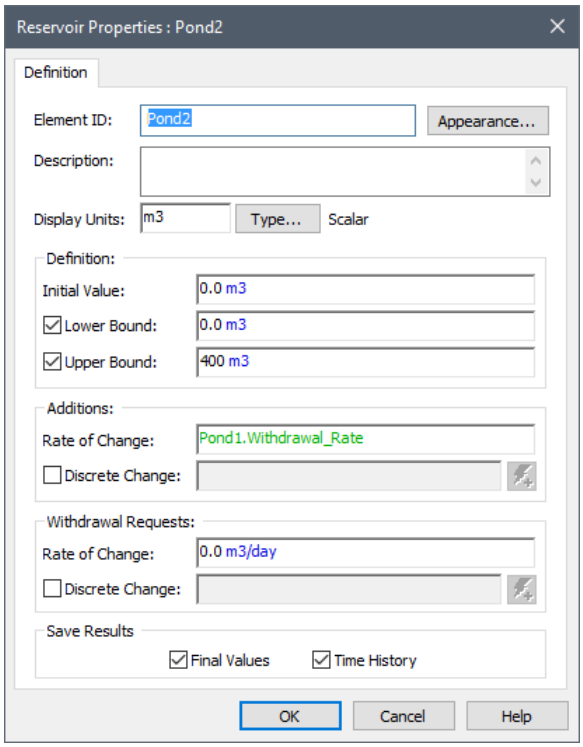
In some cases, it may be necessary to represent a recirculating system (e.g., a system in which water or some other material recirculates in a loop). Under some circumstances, if you try to create such a system, GoldSim may prevent you from "closing" the loop by reporting that the system is recursive. GoldSim can represent such looping systems, but in order to do so, the loop must contain a ***state variable***. A Material Delay can be used to model such a recirculating system by providing a mechanism to "close" the feedback loop.

Read more: Evaluating Feedback Loops (page 361).

This is best illustrated by examining a simple example. Consider a system consisting of two ponds. The first pond (Pond1) has an initial volume (Initial Value) of 1000 m^3 and a Withdrawal Request (due to pumping) of 10 m^3/day:



The second pond (Pond2) accepts the Withdrawal_Rate output from Pond1 as an Addition and has an Upper Bound of 400 m^3:

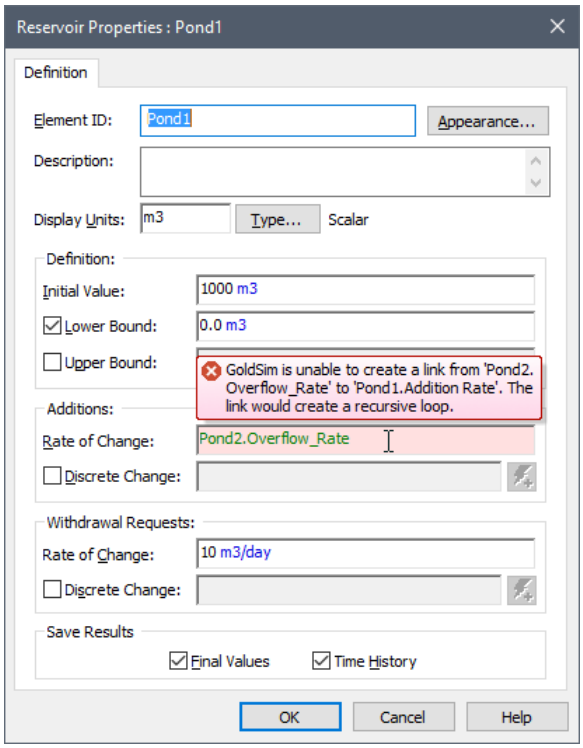


Read more: Using the Withdrawal Rate Output of a Reservoir (page 244).

Because Pond2 has an Upper Bound, it has an Overflow_Rate output.

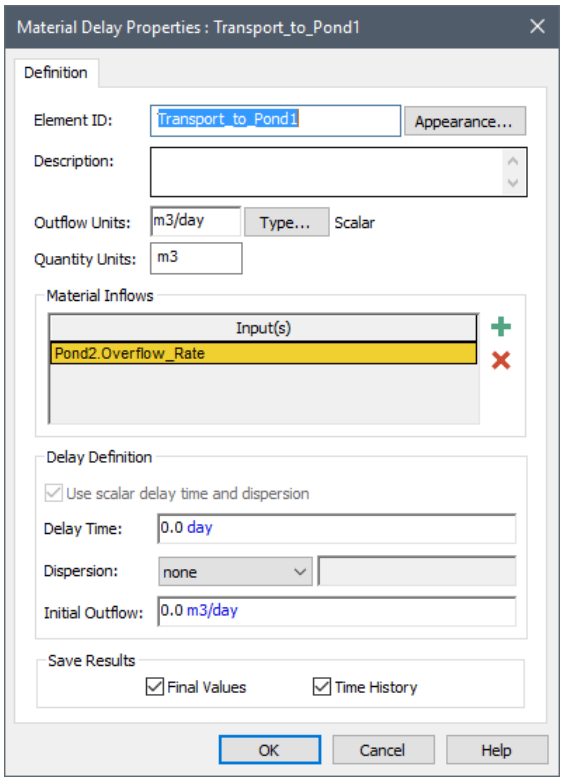
Read more: How a Reservoir Computes the Overflow Rate (page 248).

What we would like to do is route the overflow from Pond2 back into Pond1, hence creating a recirculating system: water is pumped from Pond1 into Pond2, and when Pond2 overflows, it is directed back into Pond1. Logically, there is nothing at all wrong with this system. However, if you try to do this (by routing the Overflow_Rate from Pond2 as an Addition for Pond1, the following error is displayed:

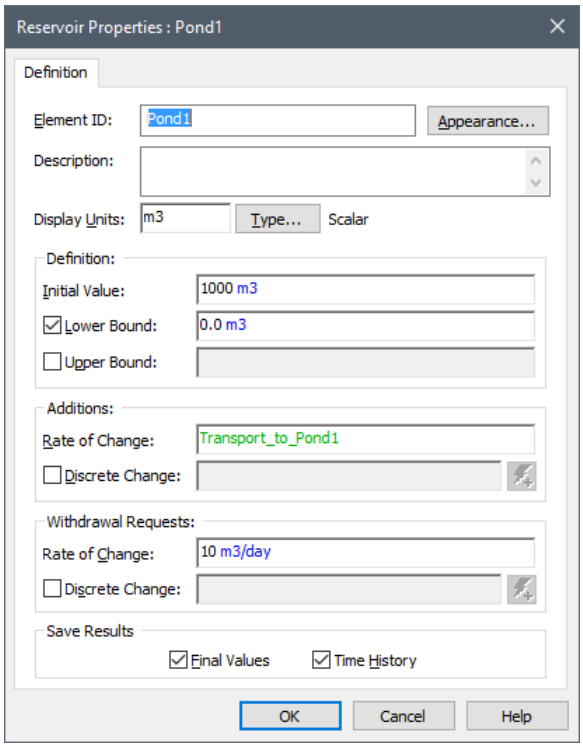


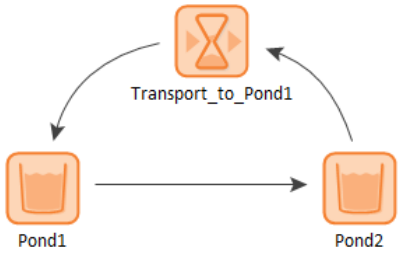
GoldSim is unable to create this link, because it would form a loop that contains no state variables. All loops in GoldSim must contain a state variable. (There are no state variables in the loop because neither the Withdrawal_Rate output nor the Overflow_Rate output is a state variable.)

Fortunately, we can address this by inserting a Material Delay element into this loop. In particular, we can define the Overflow_Rate from Pond2 as the input to a Material Delay:



We can then define the output for the Material Delay as the Addition to Pond1, thereby closing the loop:





This works because the output of a Material Delay is a state variable.

Read more: Understanding State Variables in GoldSim (page 356).

But what does this mean physically? It simply means that when water overflows from Pond2 it does not enter Pond1 immediately. There is a delay while it is transported there. In fact, we could also add a Material Delay between Pond1 and Pond2, as there is likely some kind of delay there also. What is the appropriate delay time? If we leave it at zero, GoldSim will use the timestep length as the delay time. That is, material cannot move through a Material Delay in less than a timestep. This would be appropriate if the actual travel time was quite short. (This introduces a slight error if the actual delay time is significantly less than a timestep. If this is important to represent, it would be necessary to shorten the timestep). If the travel time is greater than a timestep, the actual travel time should be entered.

Mathematics of Material Delays

In the absence of dispersion and assuming a constant Delay Time, the output of a Material Delay is simply computed as follows:

Outflow(t) = Inflow(t - Delay Time)

If the flow is dispersed (or the Delay time is variable), the solution involves a convolution integral of the form:

$$\text{Outflow}(t) = \int_0^t \text{Inflow}(\tau)\, f(t-\tau)\, d\tau$$

f(t) is the gamma probability distribution, which is equivalent to (and a generalization of) the Erlang distribution that is frequently used in simulation models. f(t) represents the probability density of the time of "release" from the delay of an input at time 0:

$$f(t) = \frac{t^{n-1} e^{-t/\beta}}{\beta^n \Gamma(n)}$$

where:

n is the Erlang value (specified by the user);

$\beta = D/n$;

D is the mean delay time; and

Γ is the gamma function (*not* the Gamma distribution).

The Erlang distribution is equivalent to the distribution of passage times through a cascaded series of n mixing cells, each of which has a mean residence time of D/n. The gamma distribution represents the time until the occurrence of n sequential Poisson-process events, where each event's random time is represented by an exponential distribution with mean D/n.

The gamma distribution is a generalized version of the Erlang distribution, and does not require n to be an integer. Note that for n=1, the distribution is exponential, and for increasing values of n it becomes less skewed, approaching normality for large n.

The standard deviation of the gamma probability distribution is equal to D/√n. The degree of dispersion for a Material Delay can be specified in terms of either n or the standard deviation.

Read more: Modeling Material Delays with Dispersion (page 347).

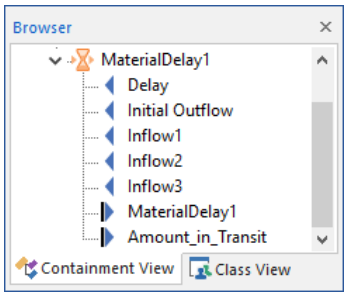
GoldSim actually solves the convolution integral by first carrying out a transformation of the time axis. This allows for accurate representation of variable Delay Times.

The Amount in Transit within a Material Delay is computed by taking the integral of the difference of the Inflow and the Outflow:

$$\text{Amount in Transit}(t) = \int_0^t \text{Inflow}(\tau) - \text{Outflow}(\tau)\, d\tau$$

Browser View of a Material Delay Element

As shown below, the browser view of a Material Delay element shows two outputs, and has at least three inputs (an Inflow, an Initial Outflow, and the length of the Delay:



Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

Additional inputs appear for each Inflow that is added to the element.

How GoldSim Carries Out its Calculations

When getting started with GoldSim and/or when building simple models it is not necessary to understand the details of how GoldSim actually carries out its calculations. Hence, if you are new to GoldSim, you probably don't need to be concerned with these details (and can skip the sections below).

However, to fully take advantage of all of the powerful features in GoldSim and use them in an appropriate manner, all users should eventually obtain a basic understanding of how GoldSim does these calculations. This knowledge not only provides you with a better understanding of the basic assumptions (and hence limitations) of GoldSim, but also allows you to design models that better represent the system you are trying to simulate.

Understanding State Variables in GoldSim

Within a GoldSim model (actually, any dynamic model), there are fundamentally two types of outputs:

1. Outputs whose current value only depends on the current value of their element's inputs ((i.e., they have no "memory"). These outputs themselves fall into one of two sub-categories:
   - Those that represent unchanging input data (or direct functions of input data) and are therefore static, in that they only need to be computed at the beginning of the simulation and do not need to be recalculated every timestep. Examples include the outputs of Data elements and Stochastics (which are not being resampled).
   - Those whose inputs change with time, and therefore need to be recalculated every timestep. Examples include the outputs of Expressions and Selectors whose inputs vary with time.
2. Outputs whose value is computed based on the historical value of the element's inputs (as opposed to only being a function of the current value of the element's inputs). These outputs can be thought of as having "memory" of what has happened before. The primary output of a Reservoir or a Pool is a classic example.

This second type of output is referred to as a ***state variable*** in GoldSim. State variables are typically the key system variables that you are interested in predicting. Together, the state variables define the predicted state of the system at any time in the future. Examples of state variables include the volume of water in a pond, the amount of money in an account, the status (on/off/failed) of a piece of equipment, and the number of times a certain event has occurred.

All state variables have, by definition, an initial value (e.g., for Integrators, Reservoirs and Pools, the initial value is explicitly specified). This allows the outputs to be computed when there are no historical input values available (e.g., at the start of simulation).

All state variables have "memory"; that is, their value at time t is a function of their value at time t - Δt. Furthermore, state variables can change during a simulation in two different ways:

- Some state variables are intrinsically a function of time. That is, every timestep, they may change because they are inherently defined with respect to time. Integrators, Reservoirs and Pools are examples of this. Since these elements fundamentally solve time integrals, whenever the simulation time changes, by definition they must be updated.
- Some state variables can be triggered by or respond to other elements in the model, and in turn, change their value. A Status element is a good example of this.

Some state variables may change due to just one of these mechanisms, while others may potentially change due to both. For example, Status elements can only change by the second mechanism; Reservoirs can change due to both.

Read more: The Causality Sequence and Element Updating (page 358).

Note that based on whether or not a particular state variable can change due to the second mechanism listed above, it falls into one of these two categories:

1. Its value at time t is completely determined by its value (and the inputs) at time t - Δt.
2. Its value at time t is determined by its value (and the inputs) at time t - Δt, but can also be further modified by its inputs at time t.

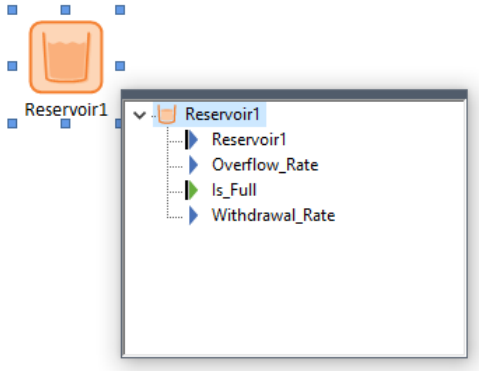
Most state variables fall into the second category.

The most common state variables are the primary outputs of stocks (Integrators, Reservoirs and Pools). A number of other elements, however, also have outputs which are state variables, and these are summarized in the table below.

Element	Output
Integrator	Current Value
Pool	Current Value (Quantity)
	Is_Full
Reservoir	Current Value
	Is_Full
Stochastic	Current Value
	Probability Density
	Cumulative Probability
Script	Result (primary output)
Extrema	Current Value
Status	Current Status
Decision	Last Decision
Milestone	Completion Status
	Date of Completion
	Elapsed Time of Completion
Timed Event Generator	Cumulative Number Emitted
Triggered Event Generator	Cumulative Number Emitted
Discrete Change	Cumulative Number Emitted
Information Delay	**Current Value**
Material Delay	**Current Value**
	Amount in Transit
Event Delay	Cumulative Number Emitted
	Number in Transit
	Number in Queue
	Mean Time for Emitted Events
	Current Service Time
Discrete Change Delay	Cumulative Number Emitted
	Number in Transit
	Number in Queue
Conditional Container	Activity Status
	Completion Status
Previous Value	**Previous value of input**
Time Series	**Current Value**
History Generator	**Current Value**

*Outputs listed in **bold** fall into category #1 above (i.e., they can never be impacted by inputs from the current timestep).*

The icons for state variables are indicated in browsers (e.g., output ports) by showing a vertical line to the left of the output triangle:



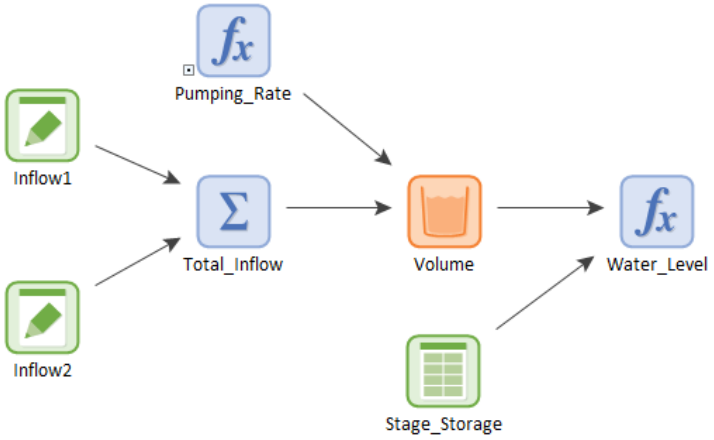
Reservoir1 (the primary output) and Is_Full are state variables.

Note: In addition to the elements listed above, a number of elements in GoldSim's extension modules also have outputs that are state variables.

The Causality Sequence and Element Updating

In order for GoldSim to determine how to carry out its calculations, it first must create the ***causality sequence*** for all of the elements. This represents the sequence in which the elements must be logically computed. For example, if A was a function of B, and B was a function of C, then C would be sequenced first, followed by B, and then followed by A. Although the sequence is obvious in this trivial example, in complex models the correct causality sequence may not be as obvious.

The internal logic within GoldSim for updating a model based on its causality sequence is very complex, and you don't generally need to be concerned with it. However, to better understand the basic concepts of the causality sequence and how GoldSim actually updates a model every timestep, let's consider another example that is a bit more complex:



In this model, we are computing the volume of water in a pond (represented by a Reservoir). The outflow (Withdrawal Request) from the pond (Pumping_Rate) is an Expression that is defined as a function of time. Inflow1, Inflow2, and therefore Total_Inflow are constant values. The Water_Level is a function of the Volume (the function being defined by a Lookup Table). So what does the causality sequence look like for this model?

We can actually view the causality sequence by pressing **F10**, which brings up the following dialog:

Read more: Viewing and Modifying the Causality Sequence (page 1041).

What should immediately catch your attention here is that four of the elements (Stage_Storage, Inflow1, Inflow2 and Total_Inflow) do not appear in the list.

This can be explained by pointing out that there are actually two different sequences: the *Static Sequence* and the *Function Sequence*. The Static Sequence consists of those elements that only need to be computed once (at the beginning of the simulation), since they cannot change with time. The Function Sequence consists of those elements that can change as a function of time.

By default, the dialog displays the Function Sequence. If we choose to view the Static Sequence (in the top right corner of the dialog), it looks like this:

These three elements cannot change with time, and only need to be computed once. Note, however, that the sequence indicates that Inflow1 and Inflow2 must logically be computed before Total_Inflow.

Note: The Lookup Table element Stage_Storage is a special case in that it does not appear in either list. This is because it actually does not compute an output itself and hence never really needs to be updated; it is used to define a static function (completely analogous to a built-in function such as sin or max) that is used by other elements (in this case, Water_Level). Hence, Lookup Tables do not appear in the causality sequence.

Returning to the Function Sequence, let's walk through how GoldSim actually carries out its calculations every timestep for this example. As noted above, at the beginning of the simulation, GoldSim first computes all of the static elements (i.e., those elements in the Static Sequence). After doing so, it does not have to compute these again for the rest of the simulation.

Every timestep, GoldSim carries then out its calculations in three steps:

1. It changes the system clock to the appropriate time (e.g., moves it forward a timestep).

2. It computes those elements that have state variable outputs that are intrinsic functions of time (e.g., Reservoirs). In the discussion below, this is referred to as the *intrinsic update* of the element.
3. It computes the elements in the Function Sequence.

So prior to evaluating the Function Sequence, every timestep, after changing the system clock, GoldSim first updates the state variable outputs for elements that are intrinsic functions of time. In this example, the only output that falls into this category is the primary output (the current value) of the Reservoir element named Volume. Note that to do this, GoldSim uses the Additions and Withdrawal Requests that were computed at the *previous* timestep. (This is because Additions and Withdrawal Requests are forward-looking; they represent the values over the *next* timestep).

It then computes the Function Sequence. First it updates the Pumping_Rate.

It then updates the Reservoir again. In this particular model, however, other than the intrinsic changes (represented by the Additions and Withdrawal Requests) there are no other elements that impact the primary output of the Reservoir, so it is not changed by the Function Sequence calculation. However, other outputs of the Reservoir that are not state variables (e.g., the Withdrawal_Rate) are updated at this time. Moreover, the inputs for the Reservoir (e.g., its Withdrawal Request input) are updated (e.g., due to a change in the Pumping_Rate) and "remembered" so that they can be used for the *next* intrinsic update the following timestep.

Finally, it computes the Water_Level (based on the current value of the Volume).

Note: Outputs that are intrinsic functions of time may actually be evaluated twice under some circumstances within the same timestep: first in step #2 (e.g., for the case of a Reservoir, to bring it up to the current time via its intrinsic behavior of time integration of additions and withdrawals), and then again in step #3 (e.g., in the case of a Reservoir, if an Upper Bound changes, forcing the output to a certain value).

Several additional points should be noted regarding the causality sequence:

- The three steps above are not only carried out during scheduled timesteps. They are also carried out during unscheduled timesteps that GoldSim automatically inserts to more accurately represent the system, and in some cases, may be carried out multiple times within the same timestep (e.g., within a looping Container).

  Read more: Understanding Timestepping in GoldSim (page 473).

- Looping systems obviously complicate the causality sequence. In some cases, GoldSim can handle these systems automatically. In other cases, you may need to take action in order to represent logic that is recursive.

  Read more: Evaluating Feedback Loops (page 361).

- For some complex looping systems (particularly those involving events that impact state variables), there may exist more than one way to sequence that system (and these may produce different results). In these cases, you can manually force a particular causality sequence to ensure that the model accurately represents your system.

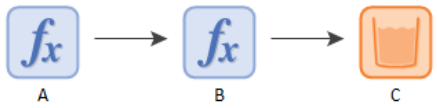
Read more: Invalid and Ambiguous Causality Sequences (page 364).

- When Discrete Changes are present in a Function Sequence, the Discrete Changes are propagated to any affected stock elements instantaneously when the Discrete Change is updated in the sequence (regardless of where the affected stocks are in the sequence).

  Read more: Discrete Change Elements (page 398).

Evaluating Feedback Loops

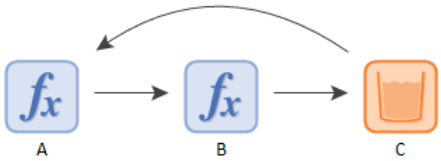
Simple models have a direct chain of *causality*: input data affect some elements, which affect other elements, and so on, until eventually the elements that calculate the desired results of the model are reached:



GoldSim automatically analyzes your entire model to identify "who affects who", and ensures that the "upstream" elements are calculated prior to the "downstream" elements. At each timestep the elements are updated in this causality-based sequence.

Read more: The Causality Sequence and Element Updating (page 358).

Most real-world models, however, contain elements whose output can, directly or indirectly, affect one of their own inputs. This creates a looping or circular system such as the one shown below:



These types of systems are referred to as ***feedback loops***. Feedback loops are present in one form or another in most real-world systems, and can be readily modeled in GoldSim. In the example above, A affects B which affects C, and then C "feeds back" to affect A and so on. That is, feedback loops represent a closed chain of cause and effect. Note that the terms "feedback" and "cause and effect" intentionally imply that the relationship between the variables is dynamic and the system changes over time (although systems with feedback loops can also reach a dynamic equilibrium).

GoldSim allows you to create looping systems like this. In order to do so, however, the loop must meet one requirement: it must contain at least one ***state variable***. State variables provide inertia or "memory" to a system, and always have an existing value prior to updating the model at a new time point. As a result, they allow a looping model to properly initialize itself and subsequently move from one timestep to the next.

Read more: Understanding State Variables in GoldSim (page 356).

In the simple looping example above, A references the primary output (a state variable) of C. Let's also assume that B represents the the Rate of Change (an addition) to C.

Every timestep, after changing the system clock, GoldSim first updates the state variable outputs that are intrinsic functions of time. In this example, the only element that falls into this category is the Reservoir named C. Its primary output is a state variable. So the primary output for C is first brought up to the current time (based on the value of B at the end of the previous timestep).

After doing this, GoldSim then updates the elements according to the causality sequence. If we were to view the causality sequence for the system above, it would look like this:

So first GoldSim computes A (based on the updated value of the primary output of C). Then it computes B. Finally, GoldSim updates C again.

Why is C updated twice (prior to evaluating the causality sequence and then again at the end of the causality sequence)? In this simple example, it is because C has multiple outputs, not all of which are state variables (e.g., the Withdrawal_Rate). These non-state variables need to be updated here at the end of the causality sequence. Moreover, during this update, C stores the new input for B for use the next time the clock is advanced.

Note: In some cases, GoldSim may not be able to create a valid sequence at all. This is the result of the system having circular (recursive) logic without a state variable involved. GoldSim can still represent such systems, but in order to do so, it is necessary for you to explicitly add a state variable to the system.

Read more: Invalid and Ambiguous Causality Sequences (page 364).

Feedback loops are discussed in further detail below.

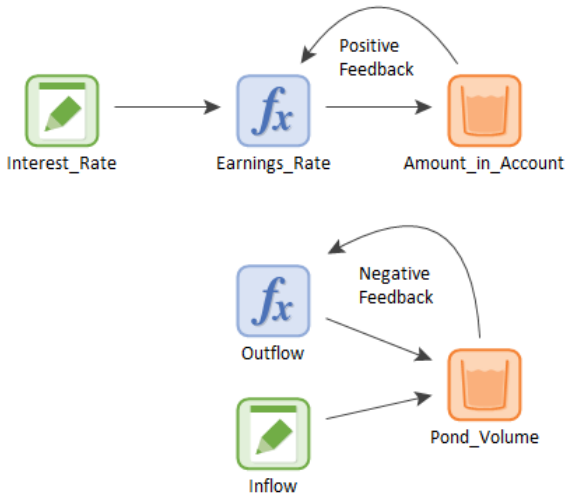
Types of Feedback Loops

Feedback loops are present in one form or another in most real-world systems. There are two basic kinds of feedback loops: positive feedback loops and negative feedback loops.

- **Positive feedback loops** are self-reinforcing. They generate growth and amplify changes. The more adult rabbits you have, the more baby rabbits that are produced; the more baby rabbits that are produced, the more adult rabbits you have, and so on until the world is full of rabbits (or this positive loop is counteracted by a negative feedback loop).
- **Negative feedback loops** are self-correcting. They drive systems toward equilibrium and balance. The more rabbits you have, the less food you have; the less food you have, the less rabbits you have.

The dynamics of most systems are driven by the interactions of many such loops.

The example below shows two simple feedback loops: the positive feedback loop associated with earning interest on a bank account; and the negative feedback loop associated with leakage from a pond. Note that both loops contain a dynamic element (in this case, a Reservoir):



This model (Feedback.gsm) can be found in the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Limitations on the Use of SubSystems in Feedback Loops

SubSystems are treated by other elements as if they were a single element (analogous to a complex Expression element). This has an important implication for systems that include feedback loops. In particular, if a SubSystem contains elements with ***state variable*** outputs, and these state variable outputs are referenced outside of the SubSystem, they will not be treated as state variables outside of the SubSystem.

Read more: Treating a Container as a SubSystem (page 140).

As a result, if you try to create a feedback loop by referencing a state variable contained within the SubSystem outside of the SubSystem, GoldSim will not be able to create the loop (and will provide an error message indicating that creating such a link would result in a recursive system).

In most cases, the most appropriate way to "close" such a loop is to reference the state variable from the SubSystem in a Material Delay element (whose primary output is a state variable) located outside of the SubSystem.

Read more: Using Material Delays to Close Feedback Loops and Model Recirculating Systems (page 350).

Finding Feedback Loops

When using the Function Of or Affects View for an element that is within a feedback loop, GoldSim will stop building a branch of the dependency tree as soon as an item is repeated (and it will mark this as a "loop").

Read more: Viewing Element Dependencies (page 114).

For example, if Reservoir1 is a function of X, X is a function of Y, and Y is a function of Reservoir1, the Function Of View for Reservoir1 would look like this:

When using the Find function (**Ctrl+F**) in a Function Of or Affects view, one of the options is to search in Labels. If this is selected, and you enter "loop", GoldSim will find the next loop in the list (since it will find the word "loop" in the label for the element).

Read more: Finding Elements (page 113).

Invalid and Ambiguous Causality Sequences

When creating complex models, determining the appropriate causality sequence can sometimes become difficult. In particular, two problems can sometimes occur:

- GoldSim may not be able to create a valid sequence at all. This is the result of the system having circular (recursive) logic without a state variable involved. If you tried to build such a model, GoldSim would be unable to create a valid causality sequence, and would display an error, warning you that the system is recursive. GoldSim can still represent such systems, but in order to do so, it is necessary for you to explicitly add a state variable to the system. Depending on the system, there are generally two ways to address this issue:
  - In some cases, the system does in fact represent a feedback loop, but due to the lack of a state variable, you are unable to "close" the loop. These systems can usually be addressed by adding a state variable in the form of a Material Delay.

    Read more: Using Material Delays to Close Feedback Loops and Model Recirculating Systems (page 350).

  - In other cases, the system does not represent a feedback loop, but instead represents a coupled process (that may not be dynamic at all). These systems can be solved by using Previous Value elements to close the recursive loop.

    Read more: Creating Recursive Loops Using Previous Value Elements (page 1033).

- In rare cases, GoldSim can sequence the system, but there may be more than one valid way to sequence the system, and these produce different results. This can occur, for example, if state variables that are impacted by an event (e.g., a discrete change) affect another element. Should the downstream element be updated before or after the state variable is modified? From the point of view of GoldSim, both sequences for the downstream element may be equally valid, but depending on the application, you may specifically require one instead of the other. In these cases, you can explicitly force a particular causality sequence to ensure that the model accurately represents your system.

  Read more: Addressing Ambiguous Causality Sequences (page 1045).

Chapter 5: Simulating Discrete Events

We are ready for any unforeseen event
that may or may not occur.

Dan Quayle

Chapter Overview

Most of the elements in GoldSim (e.g., Reservoirs, Expressions, Time Series elements) were designed primarily to be used to represent continuous variables and processes. In many systems, however, processes occur that are discrete as opposed to continuous. These discrete occurrences are referred to within GoldSim as *events*. GoldSim provides powerful capabilities for superimposing the occurrence and effects of discrete events onto continuously varying systems.

This allows for the realistic simulation of things such as financial transactions, accidents, system failures, storms, labor strikes, and lawsuits. Events such as these have important effects on the performance of many systems, and it is therefore important to represent them in a realistic manner.

This chapter describes the GoldSim elements that you can use to simulate the occurrence and consequences of discrete events.

In this Chapter

The following topics are discussed in this chapter:

- Basic Concepts of Discrete Event Modeling
- Understanding Event Triggering
- Generating Discrete Event Signals
- Responding to Events
- Generating Discrete Changes Using Time Series Elements
- How GoldSim Inserts Events into a Simulation
- Determining if an Event Has Occurred
- Controlling the Calculation Sequence of Events

Basic Concepts of Discrete Event Modeling

A discrete event is something that occurs instantaneously (as opposed to continuously or gradually) in time. It represents a "spike", a discontinuity, or a discrete change of state for the system.

The flow of water out of a hole in a bucket is a continuous process (as long as water remains in the bucket). Puncturing the bucket to create the hole is a discrete event. Stopping the flow from the bucket (by plugging the hole or by the bucket becoming empty) is also a discrete event. Similarly, through continuous compounding of interest, the money in a bank account continuously increases, but the account can also increase and decrease instantaneously due to discrete events (i.e., deposits and withdrawals).

Of course, "instantaneous" and "gradual" are relative terms. That is, whether something is treated as instantaneous or gradual is a function of the time scale of interest, and hence you must differentiate between the two based on the context of your model. Typically, the differentiation will be obvious. For example, if the time scale of interest is 10 years, something happening over the span of a day can be considered to be "instantaneous". If the time scale of interest is several days, however, something happening over the span of a day would in most cases need to be treated in a continuous manner.

GoldSim handles "instantaneous" changes to a model by providing a mechanism for a model to generate and respond to discrete events. This is accomplished by providing the ability to instantaneously trigger an element to take a particular action (e.g., instantaneously change its value) in response to an event. Hence, in GoldSim, an event is specifically defined as *an instantaneous occurrence that subsequently triggers a particular action*.

In GoldSim, an event can be generated in one of four ways:

- The event occurs when a specified condition (e.g., X > Y) becomes true or false;
- The event occurs when a specified output in the model changes;
- The event occurs at a specified calendar or elapsed time; or
- The event occurs based on a specified rate of occurrence, which can be treated as regular or random ("occur exactly once a week" or "occur, *on average*, once a week").

In addition, some elements can respond to an event generated via one of the mechanisms above, and generate a new event.

Note: Depending on how the event was generated, it may not fall exactly on a "scheduled update" (i.e., a timestep that was defined in the **Time** tab of the Simulation Settings dialog). That is, an event could actually occur between scheduled updates of the model. Such events can trigger an "unscheduled update" of the model.

Read more: Understanding Timestepping in GoldSim (page 473).

A variety of GoldSim elements can be triggered by an event, with each element responding to the event (taking a particular action) in a different manner. For example, the action taken by a Stochastic element when it is triggered by an

event is to resample itself. The action taken by a Status element when it is triggered by an event is to instantaneously change its value (from True to False or from False to True).

The manner in which events are specified to occur is discussed in detail in "Understanding Event Triggering" and "Generating Discrete Event Signals". The elements that can respond to events, and the manner in which they do so, are discussed in "Responding to Events".

Read more: Understanding Event Triggering (page 369); Generating Discrete Event Signals (page 379); Responding to Events (page 398).

Propagating Discrete Signals Between Elements

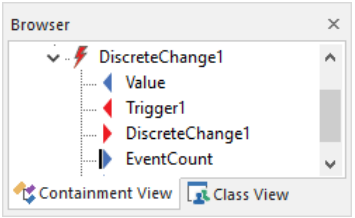
In some cases, an event will occur (e.g., X becoming greater than Y) which triggers a particular action in a single element (e.g., change the output of a Status element to True). In such a case, the event is internal to that element, and it does not directly impact other elements. In other cases, however, an event may impact multiple elements, or one element may respond to an event by triggering other elements to take a particular action. In these cases, it is necessary for discrete signals to propagate between elements.

If you think carefully about this, you will realize that this is very different from how information is typically passed between elements in GoldSim. In most situations, information is transferred between elements (via links) continuously in time. For example, if Expression element X is defined as being equal to A + B, the values of A and B are continuously sent to X (i.e., the information is "broadcast" through the link throughout the simulation). Conceptually, at any given time in the simulation, X is receiving a signal from A and B.

In order to propagate events (and their consequences) between elements in a model, however, it is necessary to send information between elements intermittently as a "spike" or discrete "packet" of information. To facilitate this, GoldSim allows certain elements to emit and receive (i.e., produce as outputs and/or accept as inputs) a ***discrete signal***. Discrete signals are a special category of outputs that emit information discretely, rather than continuously.

When you view an element that can emit or receive a discrete signal in the browser, the symbols for the inputs and outputs that represent discrete signals are identified as red triangles (as opposed to blue, green or gray for other output types).

Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).



In this example, the "Trigger1" input only accepts (receives) discrete signals. The output ""DiscreteChange1" produces (emits) discrete signals.

Within GoldSim, there are actually two types of discrete signals that can be passed from one element to another: discrete event signals and discrete change signals.

A ***discrete event signal*** is a discrete signal indicating that something (e.g., an earthquake, a monthly bank deposit, a traffic accident) has occurred. It does not describe the consequence of that occurrence; it simply emits a signal between elements indicating that an event has occurred.

A ***discrete change signal***, on the other hand, emits information regarding the response to an event. In particular, a discrete change signal contains two pieces of information: a value (e.g., 10 dollars) and an instruction (e.g., Add). A discrete change signal can only be generated in response to an event. It can only be received by a few select elements (e.g., Reservoirs, some Financial Module elements) which understand how to process it.

Only certain elements in GoldSim can emit (as outputs) or receive (as inputs) discrete signals. These elements and the manner in which they can interact with discrete signals are summarized in the tables below.

Elements that Emit and Receive Discrete Event Signals

Element	Emits Discrete Event Signals	Receives Discrete Event Signals
Timed Event	x	
Triggered Event	x	x
Event Delay	x	x
Decision	x	x
Random Choice	x	x
Previous Value	x	x
Stochastic		x
Status		x
Milestone		x
Discrete Change		x
Extrema		x
Interrupt		x

In addition to being triggered by discrete event signals, the elements indicated in the right-hand column can also be triggered by discrete change signals (which are treated as discrete event signals when entered into a field that accepts discrete event signals).

Read more: Understanding Event Triggering (page 369).

Note: An additional type of element, a conditional Container, can also emit and receive discrete event signals.

Read more: Using Conditional Containers (page 968).

Elements That Emit and Receive Discrete Change Signals

Element	Emits Discrete Change Signals	Receives Discrete Change Signals
Discrete Change	**x**	-
Discrete Change Delay	**x**	**x**
Integrator	-	**x**
Reservoir	**x**	**x**
Pool	**x**	**x**
Time Series	**x**	-
Splitter	**x**	**x**
Allocator	**x**	**x**
Previous Value	**x**	**x**

Note: Some elements in the various GoldSim extension modules can also emit and receive discrete signals. The elements listed above only include those found in the basic GoldSim framework.

The manner in which each of these elements can be used to simulate the occurrence and consequences of discrete events is discussed in detail in the sections below.

An example model which demonstrates the basic types of discrete event configurations (DiscreteEvents.gsm) can be found in the General Examples/Events folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu). The folder also includes more detailed examples that utilize discrete event logic.

Understanding Event Triggering

All discrete event modeling involves *triggering* of one form or another. When you trigger an element, you are telling it that a discrete event has occurred that you want the element to respond to. Therefore, before describing the details of the various elements associated with discrete event modeling, it is first necessary to understand the concept of triggering.

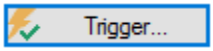
The following element types can be triggered in GoldSim:

- Triggered Event
- Event Delay
- Stochastic
- Status
- Milestone
- Decision
- Random Choice
- Discrete Change

- Extrema
- Conditional Containers

(Specialized elements within some of the GoldSim extension modules, such as the Reliability Module and the Financial Module, can also be triggered.)

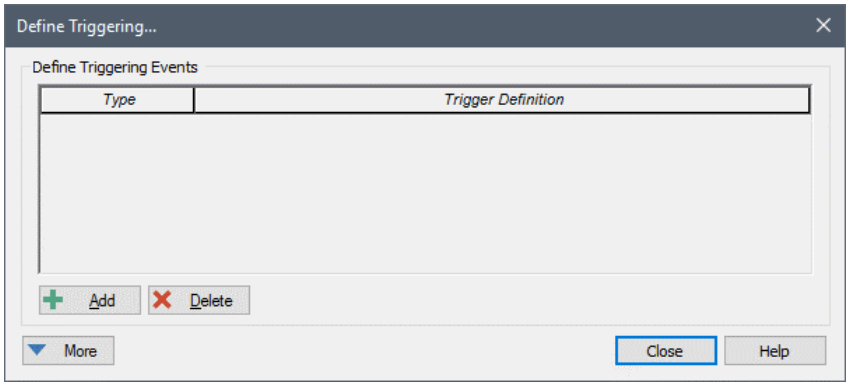
Each of these elements responds to a trigger in a different way. They are, however, all triggered in the same way. That is, these elements all share a common Triggering dialog, which controls how they are triggered. The Triggering dialog is accessed via a button in the dialog for each element:



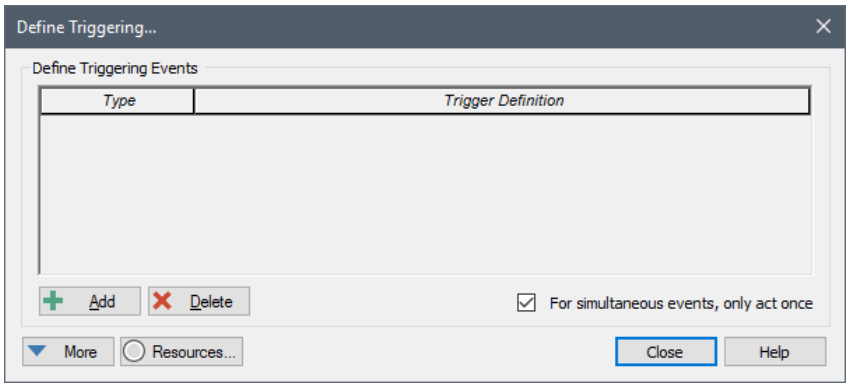
Note: Depending on the element, the label for the trigger button will not always be "Trigger…".

Note: Holding your cursor over the trigger button displays a tool-tip summarizing the current trigger settings.

The Triggering dialog for every element looks like this:



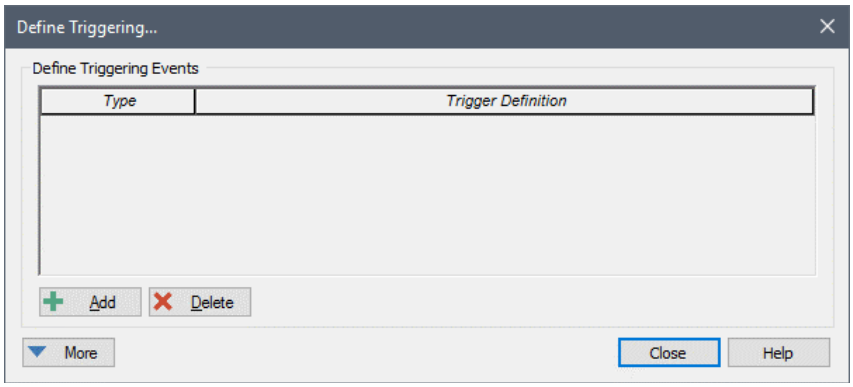
Note that for some elements, an additional button (for specifying **Resource** interactions) is available on the Trigger dialog:



The Triggering dialog is discussed in detail in the sections below.

Specifying Triggering Events

The top part of the Triggering dialog (which is the only portion visible when you first define a trigger) is where you define the triggering events (the discrete occurrences) that you want the element to respond to:



The **More** button provides access to advanced triggering options: specifying precedence conditions and required conditions.

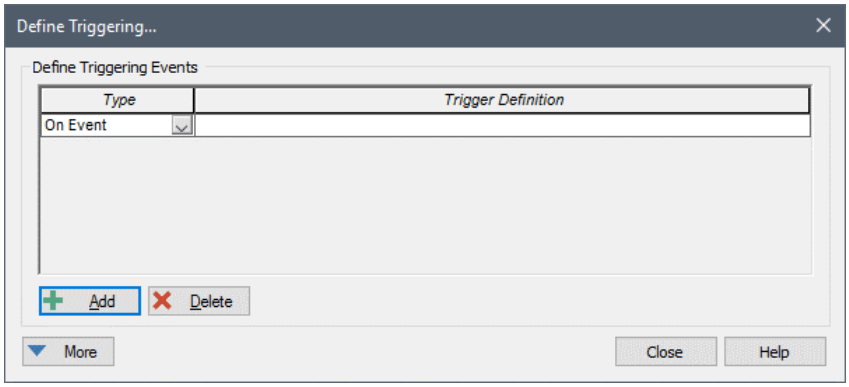
Read more: Specifying a Precedence Condition for a Trigger (page 375); Specifying a Required Condition for a Trigger (page 376).

By default, when you first create an element that can be triggered, no triggers will exist, and therefore the element will never be triggered.

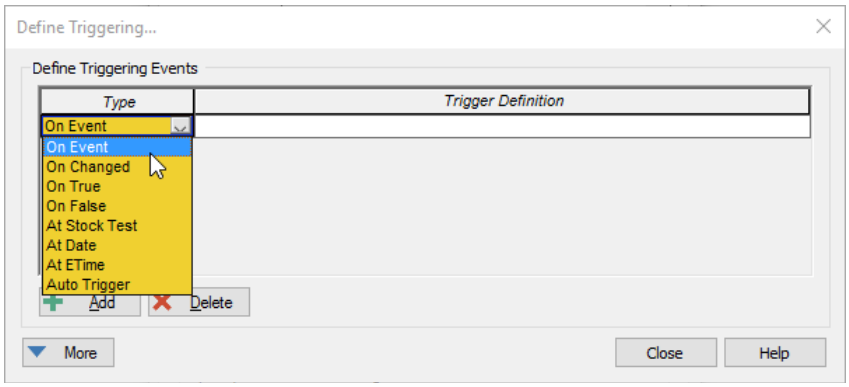
Note: There is one exception to this rule. The Deactivation trigger for conditional Containers has a default defined trigger.

Read more: Using Conditional Containers (page 968).

To define a trigger for the element, you simply press the **Add** button to add a row to the list of triggering events:



By default, the **Type** of event added will be "On Event". If you click on the small button in the **Type** column, a drop-list will be presented allowing you to edit the event type:



There are eight types of events that can be added:

On Event: The Trigger Definition must be a discrete event or discrete change signal from another element. The element is triggered whenever the signal is received.

On Changed: The Trigger Definition can be any continuous output (it cannot be an expression or a discrete signal). The element is triggered whenever the value of Trigger Definition changes.

On True: The Trigger Definition can be any condition output or conditional expression. The element is triggered whenever the Trigger Definition *becomes* True.

On False: The Trigger Definition can be any condition output or conditional expression. The element is triggered whenever the Trigger Definition *becomes* False.

At Stock Test: The Trigger Definition must be a conditional expression of of the form "A>B", "A>= B", "A<B", "A<=B", or "A=B" where A is the primary output of a Reservoir, a Pool or a Fund (from the Financial Module). The element is triggered whenever the Trigger Definition *becomes* True. As discussed below, this triggering event interrupts the clock and adds an unscheduled update.

Warning: The item A cannot be a Reservoir defined as an array, or a scalar item of a Reservoir defined as an array. The element itself which is being compared must be scalar.

At Date: The Trigger Definition must be a date or date and time, enclosed in quotations. (Alternatively, the date can also be expressed as the amount of time since 30 December 1899). The element is triggered whenever the simulated date reaches the specified date. As discussed below, this triggering event interrupts the clock and adds an unscheduled update.

Read more: Referencing Dates in Expressions (page 135).

At ETime: The Trigger Definition must be an elapsed time. The element is triggered whenever the simulated elapsed time reaches the specified elapsed time. As discussed below, this triggering event interrupts the clock and adds an unscheduled update.

Auto Trigger: An Auto Trigger requires no user-defined Trigger Definition and its behavior is defined by its context (i.e., the type of element). Auto Triggers can react to the activation or deactivation of their parent Container.

In some special cases (e.g., specialized Reliability elements), they can also be used to respond to other types of actions impacting a parent Container (e.g., preventive maintenance). Depending on the type of element, this option may not always be available.

Note: *At Stock Test*, *At Date* and *At ETime* triggers interrupt the clock and insert an unscheduled update when they occur (whereas *On True*, *On False* and *On Changed* triggers do not create an unscheduled update). To understand the implications of this, consider an example in which your scheduled updates were every 10 days. There are two different ways you could try to trigger an event when the value of Reservoir A became greater than the value B. You could create an *At Stock Test* trigger of A > B, or you could create an *On True* trigger of A > B. If we assume that A > B actually became true at 15 days, these two triggers would behave very differently. The *At Stock Test* trigger would catch this point exactly, and insert an unscheduled update at 15 days. In the absence of any other unscheduled updates, however, the *On True* trigger would not be evaluated and implemented until 20 days. Similarly, if you wished to trigger an event at a specific elapsed time (e.g., 17 days), you could try to do so in two different ways. You could trigger the event using an *At ETime* trigger of 17 days, or you could create an *On True* trigger with ETime >=17days. Again, these two triggers would behave very differently. The *At ETime* trigger would catch this point exactly, and insert an unscheduled update at 17 days. In the absence of any other unscheduled updates, however, the *On True* trigger would not be evaluated and implemented until 20 days.

Read more: Understanding Timestepping in GoldSim (page 473).

Warning: Care must be taken if you choose to disable insertion of unscheduled updates while using At Stock Test, At Date or At ETime triggers. These triggers are designed to interrupt the clock and insert a new update, and may not trigger at all if you disable unscheduled updates.

Read more: Controlling Unscheduled Updates (page 489).

You can add as many triggering events as desired (with different event types). The element is triggered when any one of the events occurs.

The following details should be noted regarding triggering:

- Unless you are using conditional Containers, you should generally never use an Auto Trigger. If you do, the element will automatically be triggered when its parent Container activates (which in the absence of conditional Containers, is at the beginning of the realization). In most cases, this is not how you will want elements to be triggered.

  Read more: Using Conditional Containers (page 968).

- On Event triggers can have multiple triggering signals. These are specified by separating the discrete event or discrete change signals with semicolons. If an On Event trigger has multiple triggering signals, the event is triggered after all of the event signals have occurred. For

example, if two triggering signals are specified, one which occurs at 10 days, and a second at 20 days, the event will be triggered at 20 days.

- On Changed, On True and On False events are triggered whenever the element determines that the argument to the event has changed, become true, or become false, respectively. If the element is in a conditional Container, it does not evaluate these arguments while it is inactive, and therefore some On Changed, On True and On False events that occur while the Container is inactive can be "delayed" until the element activates (rather than ignored). For example, if an On True trigger is defined as "Etime > 15 days", and the element is inactive until 20 days, the event will actually be triggered at 20 days (since, from the element's viewpoint, this is first time that it is able to determine that the condition has become true).

  Read more: Using Conditional Containers (page 968).

- Unless the Trigger Definition has a well-defined initial value (e.g., such as a Reservoir), On Changed triggers cannot fire at the beginning of a simulation (ETime = 0).

- You should never reference an item of an array within an On Changed, On True or On False trigger (e.g., On Changed vector1[A]). If you do, the trigger will fire if *any* item of the vector changes (or becomes true or false). If you need to do this, create a scalar Expression with the appropriate definition and use that in the trigger.

- On True events are triggered when the condition switches from False to True. Conversely, On False events are triggered when the condition switches from True to False. The one exception to this rule is the behavior of these triggers at Etime = 0. In particular, an On True trigger that is true at Etime = 0 (e.g., "Etime >= 0 days") or an On False trigger that is False at Etime = 0 (e.g., "Etime != 0 days") will fire at Etime = 0.

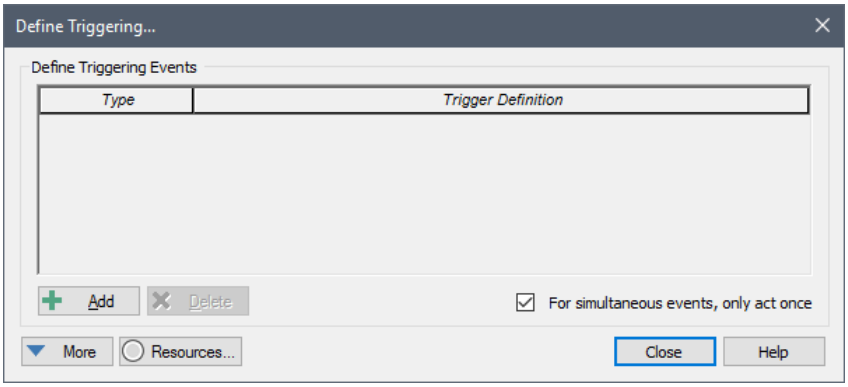
- You should generally not use equality conditions which reference Time or Etime as a trigger (e.g., an On True triggering event with "Etime = 10 day"). This is because the expression is only evaluated every timestep (and not between timesteps), such that if a timestep does not fall exactly on the time referenced in the condition, the condition will never be True. In such a case, it is always better to use expressions such as "Etime >= 10 day".

- If the argument to the On Changed trigger is a Run Property that conceptually cycles (e.g., Hour), and your timestep is such that the actual value remains unchanged (e.g., Changed(Hour), with a 1 day timestep), GoldSim will still consider that the argument has changed after such a timestep (since the fact that it remains unchanged is simply an artifact of timestepping).

  Read more: Understanding and Referencing Run Properties (page 505).

- Several elements have a checkbox on the Trigger dialog labeled **For simultaneous events, act once**. If this box is checked and multiple events occur at the same time, the element will be triggered only once. If the box is cleared, the element will be triggered once for each event. In cases where the triggering of an element multiple times by simultaneous events would not make any difference (e.g., Stochastics),

this checkbox is not available in the Triggering dialog, and the simultaneous events only trigger the element once.



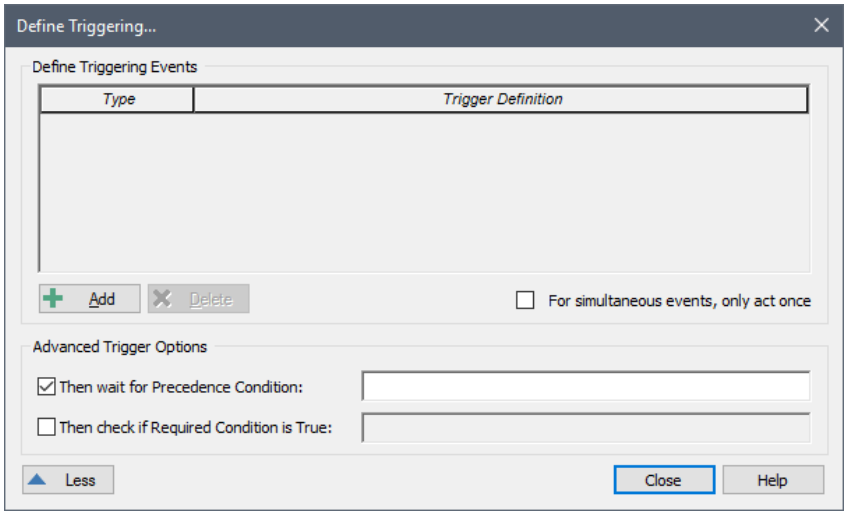
The example model Triggers.gsm in the General Examples/Events folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains examples of the various types of triggers.

Specifying a Precedence Condition for a Trigger

In some cases, it may be convenient to "hold" or delay the triggering of an element until a particular precedence requirement is met. If the triggering event occurs after the precedence requirement is met, the element is immediately triggered. If the triggering event occurs before the precedence requirement is met, the element is triggered as soon as the precedence requirement is met.

To facilitate these kind of triggers, GoldSim allows you to specify a Precedence Condition for a triggering event.

You add a Precedence Condition by pressing the **More** button on the Trigger dialog to expand it, and then selecting the **Then wait for Precedence Condition** checkbox. When you do so, the Precedence Condition field becomes available. The field accepts any condition output or conditional expression.

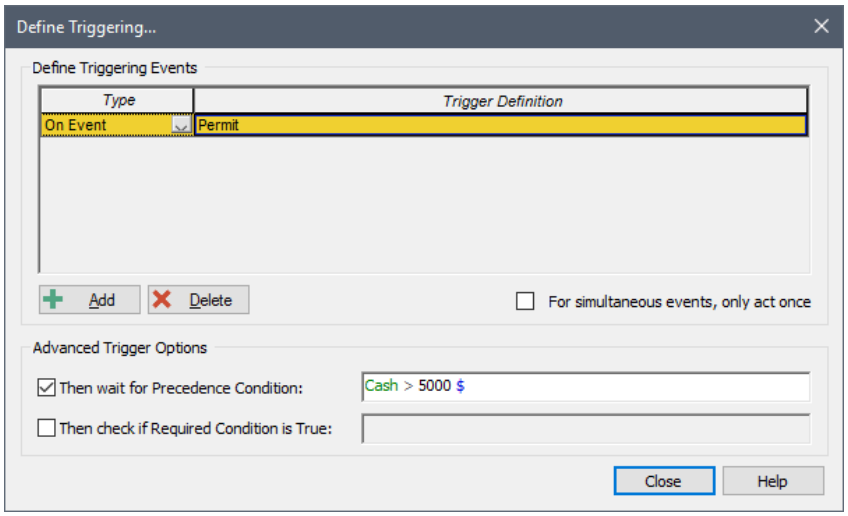


The triggering of the element is "held" until the specified Precedence Condition is met (the Condition becomes True), and then the element is triggered. Hence, unless the Precedence Condition is met at the time that the triggering event occurs, the element will be triggered (if it is triggered at all) after the actual triggering event has occurred.

For example, suppose that you were simulating a project, and you wanted to trigger a particular task to start. Before you can start the task, however, you must

first ensure that 1) you received the necessary permission (e.g., a building permit); and 2) you had sufficient money to carry out the task.

To simulate this, you could model the permit process as a triggering event (i.e., obtaining a permit is a triggering event), while the Precedence Condition could be modeled as a simple condition related to the amount of money available. Your Triggering dialog might look like this:



Note: If you define multiple triggering events that occur at different times, and you have specified a Precedence Condition, it is possible that both events could occur (at different times), and then upon the Condition becoming true, both would be simultaneously released. In such a case, if **For simultaneous events, act once** is checked, only one event would be released.

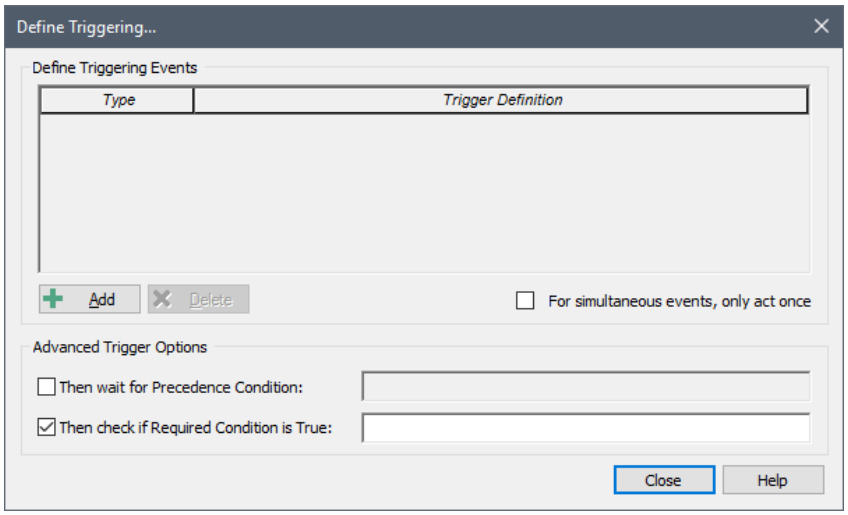
Note: As a general rule, you should not specify both a Precedence Condtiona and a Required Condition. If you do specify both a Precedence Condition and a Required Condition, events are evaluated as follows: If the Precedence Conditions is True when the triggering event occurs, the Required Condition is evaluated immediately. If the Precedence Condition is False when the triggering event occurs, the Required Condition is not evaluated until the Precedence Condition become True.

Specifying a Required Condition for a Trigger

In some cases, you may not want to trigger an element unless a particular required condition is met at the time that the triggering event occurs.

To facilitate these kind of triggers, GoldSim allows you to specify a Required Condition for a triggering event.

You add a Required Condition by pressing the **More** button on the Trigger dialog to expand it, and then selecting the **Then check if Required Condition is True** checkbox. When you do so, the Required Condition field becomes available. The field accepts any condition output or conditional expression.

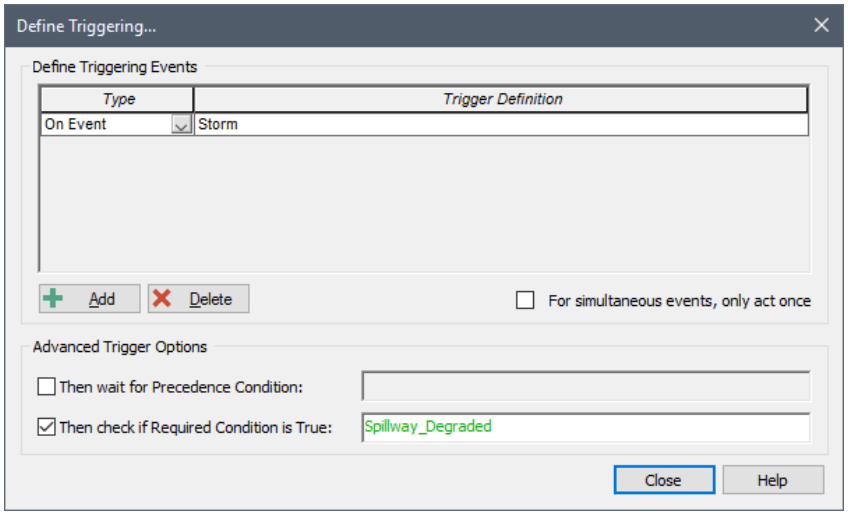


If the condition is True when the triggering event occurs, the element is triggered; otherwise it is not triggered (i.e., the triggering event is ignored).

For example, suppose that you were simulating the performance of a dam, and you defined an event (e.g., a storm) which resulted in the failure of the dam. The dam only failed, however, if at the time the storm occurred, the dam's spillway was degraded to a certain extent.

To simulate this, you could model the storm as a triggering event, monitor the spillway condition elsewhere in the model, and enter this as the Required Condition that must be met in order for the element to be triggered.

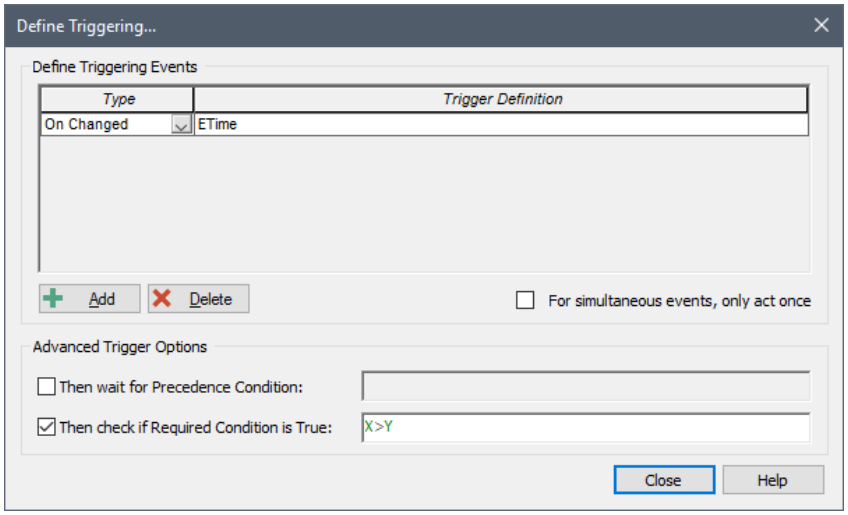
Your Triggering dialog might look like this.



Note: Triggered events are not "held" until the Required Condition is met (as they are for Precedence Conditions). If the condition is not True when the triggering event occurs, the triggering event is ignored (i.e., discarded).

Note: As a general rule, you should not specify both a Precedence Condtiona and a Required Condition. If you do specify both a Precedence Condition and a Required Condition, events are evaluated as follows: If the Precedence Conditions is True when the triggering event occurs, the Required Condition is evaluated immediately. If the Precedence Condition is False when the triggering event occurs, the Required Condition is not evaluated until the Precedence Condition become True.

Required Conditions can be used to simulate the equivalent of an If True triggering event (i.e., to trigger something when it *is* true rather than when it *becomes* true). To do so, simply use an On Changed trigger with ETime as the argument, and a Required Condition that is the actual If True condition:

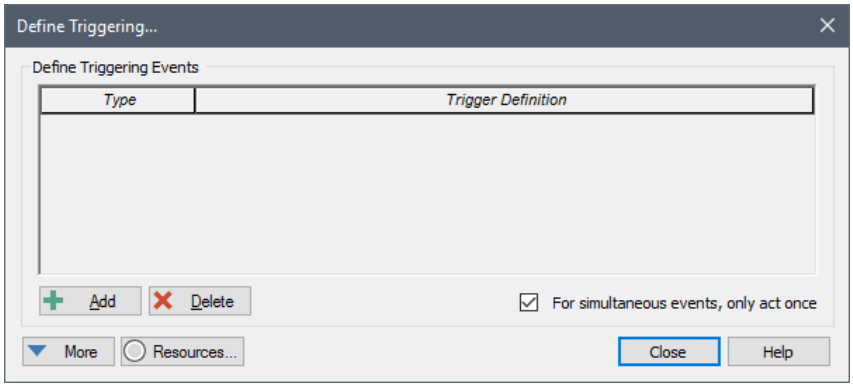


Specifying a Resource Interaction for a Trigger

A ***Resource*** is something that has a limited supply (e.g., spare parts, fuel, skilled personnel, money) and is required in order for elements of the modeled system to carry out certain actions.

Read more: Using Resources (page 906).

Only certain kinds of elements in GoldSim can interact with Resources. Some of these elements can interact with Resources through their Trigger dialog. In these cases, a **Resources** button is added to the dialog:



This button allows you to define Resource Requirements for the trigger. These represent special conditions that must be met in order for the trigger to be

pulled. If they are not met, the trigger is held (similar to a precedence condition) until the Resource Requirements are met.

Note: Holding your cursor over the **Resources…** button displays a tool-tip summarizing the current Resource Requirements.

Resources are an advanced feature, and by default, an element has no Resource Requirements.

Generating Discrete Event Signals

There are five elements that can generate discrete event signals:

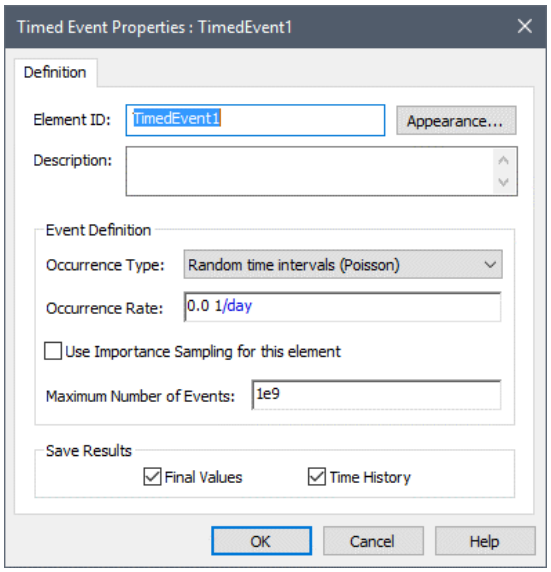
- Timed Events;
- Triggered Events;
- Decisions;
- Random Choices; and
- Event Delays.

These elements are described below.

Timed Event Elements

Timed Event elements produce discrete event signals based on a specified rate of occurrence.

The dialog for a Timed Event looks like this:



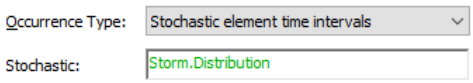
The first item that must be specified for a Timed Event is the **Type**.

The **Type** list box contains five choices:

Regular time intervals. The event occurs exactly according to the specified **Rate**. Hence, if the rate was 0.5 day^{-1}, the event would occur exactly every two days, starting at two days. The **Rate** must have dimensions of inverse time. If desired, you can specify the rate as a function of time such that it changes during the simulation.

Random time intervals (Poisson). The event is simulated as a Poisson process, such that the *expected* number of occurrences over some time period T is equal to the product of the **Rate** and T. The mathematics of a Poisson process are discussed in more detail in Appendix B. The **Rate** must have dimensions of inverse time. If desired, you can specify the rate as a function of time such that it changes during the simulation.

Stochastic element time intervals. For this event, a **Stochastic** element must be specified (rather than a Rate). The Stochastic element that is specified represents the distribution of the time intervals between events. As such, it must have dimensions of time.The Distribution output of the Stochastic must be referenced:



Note: if the Stochastic is time-dependent, GoldSim uses the distribution from the *previous* timestep to compute the occurrence of the next event.

Defined cumulative event count. This event requires as input a cumulative **Count**. This represents the cumulative number of events to be emitted. It is generally entered as an expression or a link from another element (e.g., a Time Series). It must increase monotonically (it cannot decrease with time). If the Count increases by more than one at any given time, the element will release multiple events simultaneously.

Remaining time to event. This event requires as input a **Remaining time**. This represents the time until the next event. This event type is designed to provide a straightforward way to insert events at specific times in the middle of a scheduled timestep. Every time the model is updated (e.g., every timestep), GoldSim recomputes Remaining time and reschedules the event. That is, this event is reset every timestep. Hence, for the event to occur, at some point the Remaining time value should be less than the scheduled timestep length (If the Remaining time was defined as a constant value that was greater than the timestep length, the event would never occur.) As an example, you could use this type of event to accurately represent when a vehicle reached a particular destination by defining the Remaining time as Distance_Remaining/Velocity.

Importance sampling of events is frequently necessary to evaluate the consequences of low-probability, high-consequence events (i.e., events that occur with a very low frequency, but have a significant impact on the system). Because the models for such systems are often complex (and hence need significant computer time to simulate), it can be difficult to use the conventional Monte Carlo approach to evaluate these low-probability, high-consequence events, as this may require excessive numbers of realizations.

To facilitate these type of analyses, GoldSim allows you to utilize an ***importance sampling*** algorithm to modify the conventional Monte Carlo approach so that the high-consequence, low-probability events are sampled with an enhanced frequency. That is, importance sampling serves to increase the rate of occurrence of the event. During the analysis of the results that are generated, the biasing effects of the importance sampling are reversed. The result is high-resolution development of the high-consequence, low-probability "tails" of the consequences (resulting from low-probability events), without paying a high computational price.

Importance sampling for Timed Events is specified by selecting the checkbox for **Use Importance Sampling for this element**. The algorithm that is used is discussed in detail in Appendix B.

Five points regarding importance sampling of events should be noted:

- Importance sampling can only be applied if the Occurrence Type is "Random time intervals (Poisson)" or "Stochastic element time intervals".
- Importance sampling is only applied to the first occurrence of the event. The increased sampling frequency is not applied to subsequent occurrences within the same realization.
- Importance sampling of events should only be used for events that are *rare*. As used here, "rare" indicates an event that would not adequately be represented without enhanced sampling. As a general rule of thumb, an event will be adequately sampled if the product of the number of realizations and the expected number of events over the course of a single realization is at least 10 (this would indicate that the event would be expected to occur at least 10 times if that many realizations were executed). For example, if the rate of occurrence of an event was once every thousand years, and the simulation was run for 10 years, one could expect 0.01 events per realization. If 100 realizations were run, the total expected number of events (over all realizations) would therefore be 1. This is a rare event and importance sampling should be applied (or more realizations should be run).
- There is a limit to the effectiveness of importance sampling for extremely rare events, such that in some cases, it may become necessary to increase the number of realizations in order to effectively represent the event. In particular, the degree of biasing for low probability events that GoldSim can provide is (*at most*) equal to the number of realizations. For example, if the rate of occurrence of an event was once every 100,000 hours, and the simulation was run for 10 hours, one could expect 1e-4 events per realization. If 100 realizations were run, the total expected number of events (over all realizations) would therefore be 0.01. This is a rare event and importance sampling should be applied. However, importance sampling could only increase the total number of events (over all realizations) by a factor of 100 (the number of realizations) to 1 (which would still provide inadequate representation). If 1000 realizations were run, the total expected number of events (over all realizations) without importance sampling would be 0.1, but importance sampling would improve it by a factor of 1000.
- You should use importance sampling sparingly (i.e., only for those elements that really need it). This is because, as stated above, the degree of biasing for low probability failures that GoldSim can provide is *at most* equal to the number of realizations, and the actual biasing provided decreases with the number of elements for which importance sampling is applied.

The importance sampling algorithm is discussed in detail in Appendix B.

With the exception of the Defined cumulative event count event type, you can specify a **Maximum Number of Events** to limit the total number of events that are generated.

Timed Event elements have the ability to influence when a model is updated. Typically, a model is updated at every "scheduled" timestep. That is, all the elements are computed at every timestep. A Timed Event, however, can force a model to be updated between "scheduled" timesteps.

For example, suppose that you have specified a 10 day timestep. If a Timed Event occurred at, say 23 days, GoldSim would insert an update (an "internal" event) between timesteps (i.e., at 23 days) in order to more accurately represent the event.

Read more: Understanding Timestepping in GoldSim (page 473).

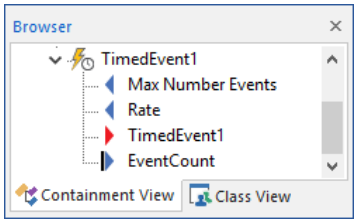
Note: Timed Event elements with a Defined cumulative event count do not influence when the model is updated.

Note: Timed Events are designed to interrupt the clock and insert a new update. If you choose to disable unscheduled updates, the events will be deferred to the next scheduled update.

Read more: Controlling Unscheduled Updates (page 489).

Timed Events have up to two inputs (a Rate, a Stochastic, a Count, or a Remaining time, along with the Maximum Number of Events).

Timed Events have two outputs: 1) the discrete event signal itself (the primary output); and 2) the EventCount (i.e., the cumulative number of events which have been emitted during the realization).



The discrete event signal output itself cannot be saved or viewed as a result.

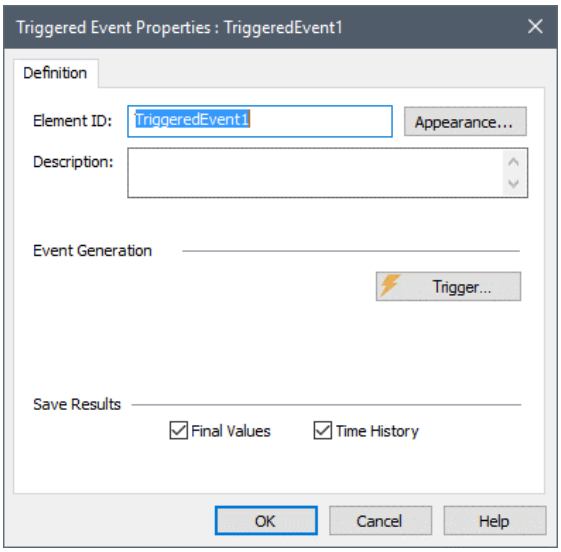
Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

The example model TimedTriggered.gsm in the General Examples/Events folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains an example of the use of Timed Event elements.

Triggered Event Elements

Triggered Event elements produce discrete event signals based on a specified trigger. You would use a Triggered Event if you needed to trigger a number of other elements (e.g., Discrete Change elements or Stochastics) with a single event

The dialog for a Triggered Event is quite simple, containing only the Trigger button:



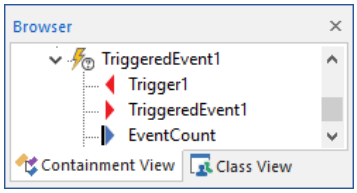
The **Trigger…** button in the Triggered Event dialog provides access to a standard Trigger dialog.

Read more: Understanding Event Triggering (page 369).

The inputs to a Triggered Event are the trigger(s) and any associated Precedence or Required Conditions.

Triggered Events have two outputs: 1) the discrete event signal itself (the primary output); and 2) the EventCount (i.e., the cumulative number of events that have been emitted during the realization).

These outputs can be seen in the browser view of the element:



The discrete event signal output itself cannot be saved or viewed as a result.

Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

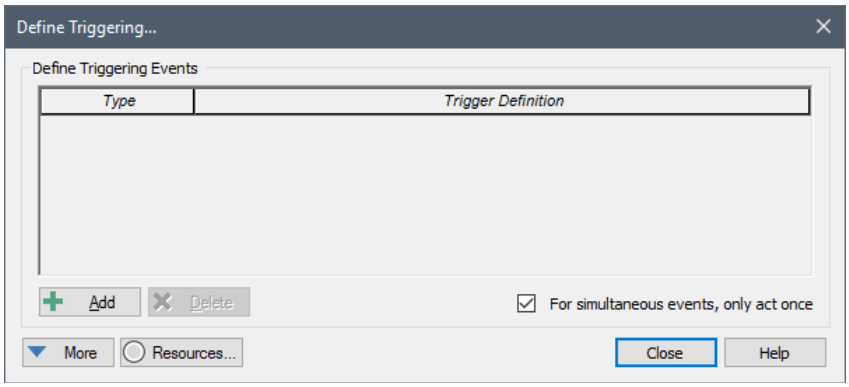
The example model TimedTriggered.gsm in the General Examples/Events folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains an example of the use of Triggered Event elements.

Specifying Resources for a Triggered Event

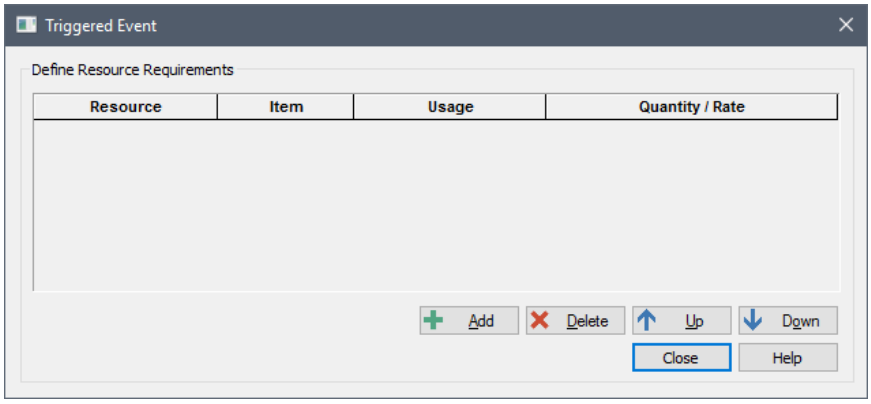
Triggered Events can have specified Resource Requirements.

Read more: Using Resources (page 906).

The Trigger dialog for a Triggered Event includes a **Resources…** button:



To define a Resource Requirement for a Triggered Event, press the **Resources…** button in the Trigger dialog for the element. The following dialog will be displayed:



You can add a Resource Requirement by pressing the **Add** button.

Read more: Interacting with Resources (page 916).

A Triggered Event interacts with the specified Resource Stores when triggered, and can only have two types of interactions (specified in the **Usage** column):

- **Spend (discrete):** A discrete quantity of the Resource is required in order to pull the trigger. If triggered with a Spend Requirement and the requested Resource quantity is not available, the trigger is held (it waits) until the Resource becomes available. If the Resource becomes available at a later time in the simulation, this creates a delay; if the Resource never becomes available, the trigger is never pulled.
- **Deposit (discrete):** A discrete quantity of the Resource is created and deposited with the Store when the element is triggered.

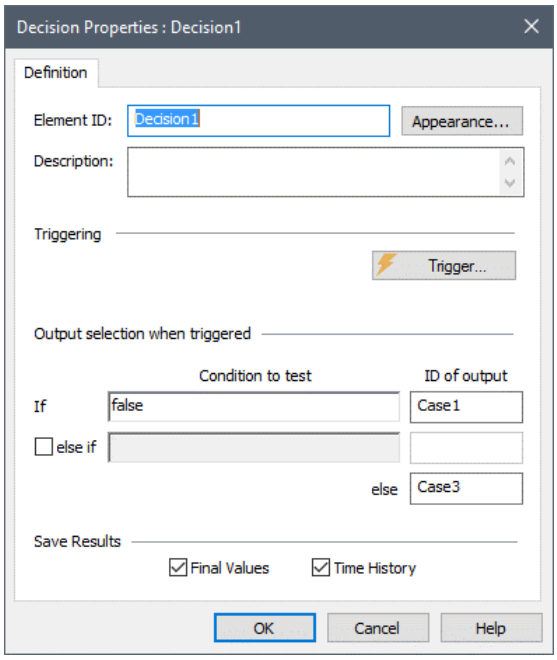
Resources are an advanced feature, and you should read the sections below before attempting to use them.

Decision Elements

Decision elements allow you to better represent decision or branching logic in your model.

Decision elements have either two or three outputs which represent discrete event signals. When the element is triggered, it emits a discrete event signal from one (and only one) of its outputs, depending on a set of user-specified conditions.

The dialog for a Decision element looks like this:



You first specify when the Decision is to be triggered via the **Trigger…** button. The **Trigger…** button in the Decision dialog provides access to a standard Trigger dialog.

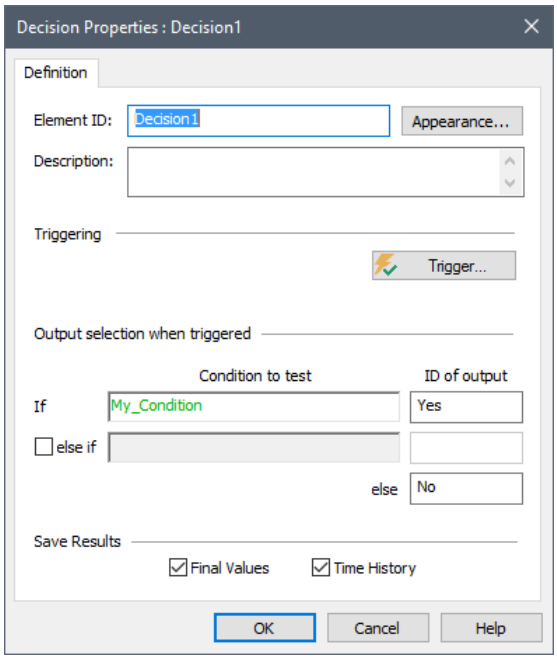
Read more: Understanding Event Triggering (page 369).

When the element is triggered, it evaluates the **Condition to test** field to determine which output will emit a discrete event signal. By default, there are two discrete event signal outputs, which are named Case1 and Case3. The **Condition to test** field accepts any condition output or conditional expression.

The **ID of output** can be modified by the user to any string. (Note, however, that the same rules which apply for element names apply for these IDs.)

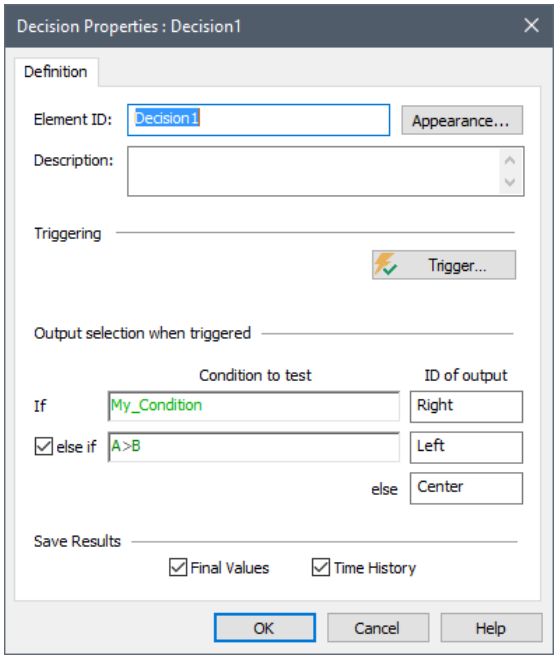
Read more: Editing an Element's Name, Description and Appearance (page 79).

To understand how a Decision element works, consider the following example:



In this case, whenever the element is triggered, GoldSim evaluates the output "My_Condition" (which must be a condition). If this condition is True, a discrete event signal is emitted from the Yes output of the element (in this case, named Decision1.Yes). Otherwise, a discrete event signal is emitted from the No output of the element (in this case, named Decision1.No).

You can add a second condition (and a third output) by clicking the checkbox to the left of the "else if" on the dialog.



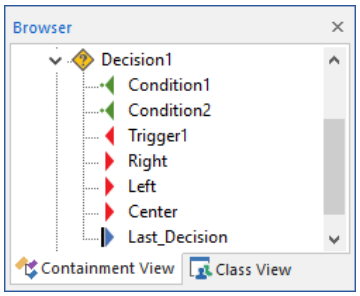
In this case, whenever the element is triggered, if My_Condition is True, a discrete event signal is emitted from the "Right" output of the element (in this case, named Decision1.Right). If My_Condition is False, but A > B, then a discrete event signal is emitted from the "Left" output of the element (in this

case, named Decision1.Left). If neither of these conditions is True (i.e., My_Condtion is False and A<= B), a discrete event signal is emitted from the "Center" output of the element (in this case, named Decision1.Center).

In addition to the two (or three) discrete event signal outputs associated with a Decision element (which you provide a name for), an additional output is produced called Last_Decision. This is a value which takes on one of four values: 0, 1, 2, or 3. Prior to the Decision being triggered, it takes on a value of 0. After a Decision element is triggered, it records which of the three discrete event signal outputs emitted the signal. These are always 1, 2 or 3. Note that even if there are only two outputs, the last event signal output (the "else") is referred to as output 3.

Note: A Decision element could be triggered multiple times within a single update (e.g., a timestep), in which case it would output multiple events. Note, however, that these events would all be sent to the same output (since the **Condition to test** fields are only evaluated once each update).

The inputs to a Decision are the trigger(s) and any associated Precedence or Required Conditions, as well as the test conditions. Decisions have up to three discrete event signal outputs, along with the Last_Decision output.



The discrete event signal outputs themselves cannot be saved or viewed as a result.

Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

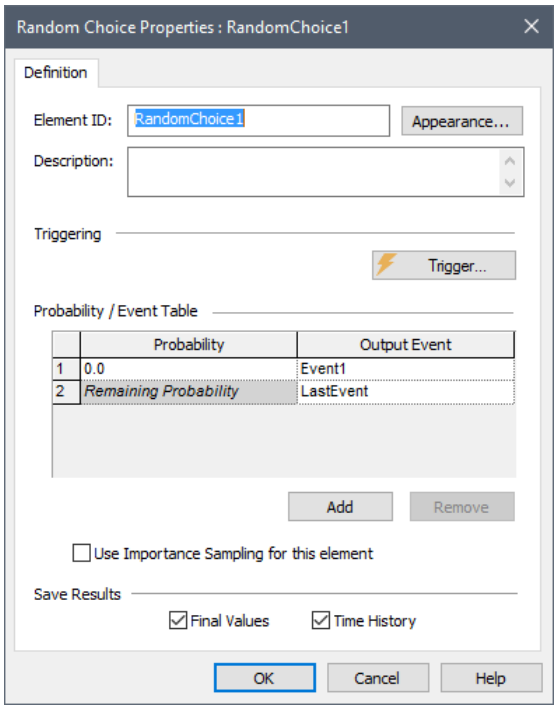
The example model Decision.gsm in the General Examples/Events folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains an example of the use of Decision elements.

Random Choice Elements

Random Choice elements allow you to represent event trees (processes consisting of specified random event sequences).

Random Choice elements have an unlimited number of specified outputs which represent discrete event signals. When the element is triggered, it emits a discrete event signal from one (and only one) of its outputs, depending on a set of user-specified probabilities.

The dialog for a Random Choice element looks like this:



You first specify when the Random Choice is to be triggered via the **Trigger…** button. The **Trigger…** button in the Decision dialog provides access to a standard Trigger dialog.

Read more: Understanding Event Triggering (page 369).

You must then define a set of Probability/Event pairs. That is, you specify the name of an **Output Event** (a discrete event signal output) and a corresponding **Probability**.

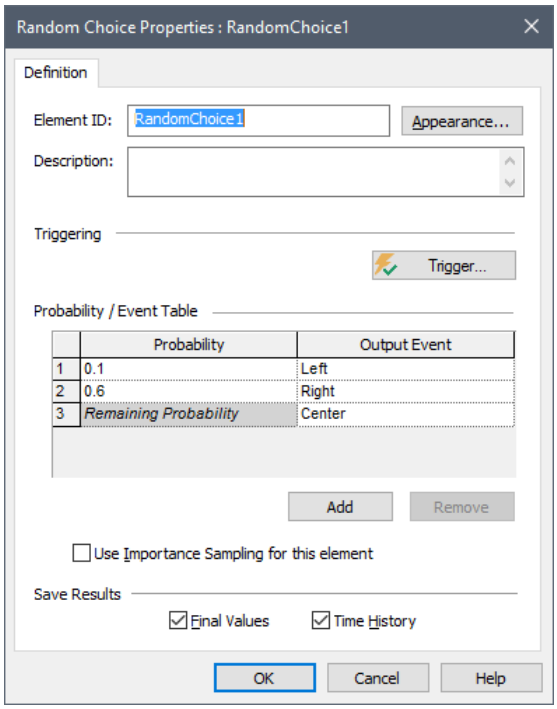
By default, there are two Output Events, which are named Event1 and LastEvent. The **Output Event** name can be modified by the user to any string. (Note, however, that the same rules which apply for element names apply for these IDs.)

Read more: Editing an Element's Name, Description and Appearance (page 79).

You can define the **Probability** for all of the Events, except the last. The probability of the last event is always equal to 1 – (the sum of the other probabilities). The **Probability** can be specified as a number, links or expression, and can change with time. At all times, however, the specified values must sum to a value less than or equal to 1 (otherwise, a fatal error will be displayed when you run the simulation).

When the element is triggered, it randomly selects one of the **Output Events** based on the specified discrete probabilities, and emits a discrete event signal from that output.

To understand how a Random Choice element works, consider the following example:



In this case, whenever the element is triggered, GoldSim evaluates the Probabilities, and randomly selects an Output Event based on these Probabilities. In this particular case, there is a 10% chance that it will emit a discrete event signal from the Left output of the element (in this case, named RandomChoice1.Left), a 60% chance that it will emit a discrete event signal from the Right output of the element (in this case, named RandomChoice1.Right), and a 30% chance (1 – 0.1 – 0.6) that it will emit a discrete event signal from the Center output of the element (in this case, named RandomChoice1.Center).

In addition to the discrete event signal outputs associated with a Random Choice element (which you provide a name for), an additional output is produced called Last_Choice. This is a value which takes on an integer value of between 0 and n, where n is the number of Output Events defined. Prior to the Random Choice being triggered, it takes on a value of 0. After the Random Choice is triggered, it records which of the discrete event signal outputs emitted the signal (e.g., if the third event in the list was emitted, Last_Choice would be 3).

Note: A Random Choice element could be triggered multiple times within a single update (e.g., a timestep), in which case it would output multiple events. For each event, it would internally resample the Output Event.

Importance sampling is frequently necessary to evaluate the consequences of low-probability, high-consequence events (i.e., events that occur with a very low frequency, but have a significant impact on the system). Because the models for such systems are often complex (and hence need significant computer time to simulate), it can be difficult to use the conventional Monte Carlo approach to evaluate these low-probability, high-consequence events, as this may require excessive numbers of realizations.

To facilitate these type of analyses, GoldSim allows you to utilize an ***importance sampling*** algorithm to modify the conventional Monte Carlo approach so that the high-consequence, low-probability events are sampled with an enhanced frequency. That is, importance sampling serves to increase the rate of occurrence of the event. During the analysis of the results that are generated, the biasing effects of the importance sampling are reversed. The result is high-resolution development of the high-consequence, low-probability "tails" of the consequences (resulting from low-probability events), without paying a high computational price.

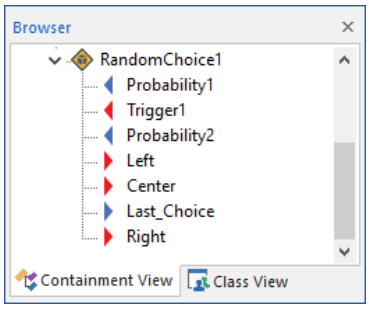
Importance sampling for Random Choice elements is specified by selecting the checkbox for **Use Importance Sampling for this element**. The algorithm that is used is discussed in detail in Appendix B. For Random Choice elements, when importance sampling is applied, the alternatives are sorted by their probabilities, and the importance sampling serves to artificially bias (increase) the likelihood of the low probability alternatives (such that the least probable choice has the greatest magnification).

Three points regarding importance sampling for Random Choice elements should be noted:

- Importance sampling is only applied to the element the first time it is triggered. The increased sampling frequency for low probability alternatives is not applied to subsequent times the element is triggered in the realization.
- Importance sampling of Random Choice alternatives should only be used if at least one of the alternatives is *rare*. As used here, "rare" indicates that an alternative would not adequately be represented without enhanced sampling. As a general rule of thumb, an alternative will be adequately sampled if the product of the number of realizations and the probability of occurrence is at least 10 (this would indicate that the alternative would be expected to be selected at least 10 times if that many realizations were executed). For example, if the probability of an alternative was 0.01 and 100 realizations were run, the total expected number of times the alternative would be selected (over all realizations) would therefore be 1. This is a rare alternative and importance sampling should be applied (or more realizations should be run).
- There is a limit to the effectiveness of importance sampling for extremely rare alternatives, such that in some cases, it may become necessary to increase the number of realizations in order to effectively represent the alternative. In particular, the degree of biasing for low probability alternatives that GoldSim can provide is (*at most*) equal to the number of realizations. For example, if probability of an alternative was 1e-4, and 100 realizations were run, the total expected number of times that alternative would be selected (over all realizations) would therefore be 0.01. This is a rare alternative and importance sampling should be applied. However, importance sampling could only increase the total number of occurrences (over all realizations) by a factor of 100 (the number of realizations) to 1 (which would still provide inadequate representation). If 1000 realizations were run, the total expected number of occurrences (over all realizations) without importance sampling would be 0.1, but importance sampling would improve it by a factor of 1000. As stated above, the degree of biasing for low probability alternatives that GoldSim can provide is *at most* equal to the number of realizations. The actual degree of biasing provided decreases with the number of elements for which importance

sampling is applied (and the algorithm is discussed in detail in Appendix B.

The inputs to a Random Choice are the trigger(s) and any associated Precedence or Required Conditions, as well as the Probabilities. Random Choice elements have at least two discrete event signal outputs, along with the Last_Choice output.



The discrete event signal outputs themselves cannot be saved or viewed as a result.

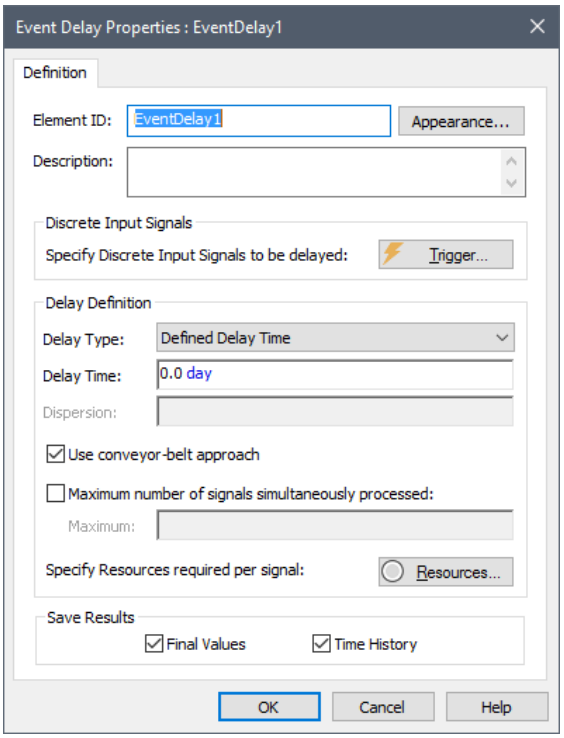
Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

The example model RandomChoice.gsm in the General Examples/Events folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains an example of the use of Random Choice elements.

Event Delay Elements

Event Delay elements provide a mechanism for delaying a discrete event signal. Once an Event Delay receives a discrete event signal, it holds it for a specified time period, and then emits it.

The dialog for an Event Delay looks like this:



You first specify when the element is to be triggered via the **Trigger…** button in the Event Delay dialog. The **Trigger…** button provides access to a standard Trigger dialog.

Read more: Understanding Event Triggering (page 369).

Each time the element is triggered, it waits for a specified time, and then emits a discrete event signal.

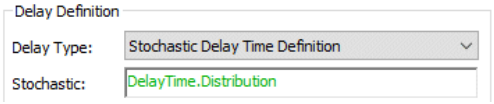
The delay time is computed based on a specified **Delay Type**. There are four types:

- Defined Delay Time.
- Defined Delay Time + Erlang Dispersion
- Defined Delay Time + Std. Deviation
- Stochastic Delay Time Definition

The last three options allow the delay time to have a specified dispersion. That is, they allow you to simulate variability in when a signal is emitted once the element is triggered. This is equivalent to saying that there is a distribution of actual delay times around some mean, and whenever the element is triggered, the delay time for that event is sampled from a distribution.

The first three options require a specified **Delay Time** (or a **Mean Time** if dispersion is specified). The **Delay Time**, and **Mean Time** must have dimensions of time and generally should be positive.

The fourth option requires a **Stochastic** that represents a distribution of Delay Times. The Stochastic element that is specified represents the distribution of the delay time. As such, it must have dimensions of time. The Distribution output of the Stochastic must be referenced:



Note: If the specified delay time is equal to zero, the event is emitted immediately (i.e., on the same update) without any delay. A negative delay time will result in a fatal error.

Note: The **Use conveyer-belt approach** box only impacts the behavior of the Delay if the delay time changes with time.

Read more: Event Delays with Time-Variable Delay Times (page 395).

You can optionally specify that an Event Delay requires one or more **Resources** in order to process the signal.

Read more: Specifying Resources for an Event Delay (page 396).

Event Delay elements have the ability to influence when a model is updated. Typically, a model is updated at every "scheduled" timestep. That is, all the elements are computed at every timestep. However, an Event Delay can force a model to be updated between "scheduled" timesteps.

For example, suppose that you have specified a 10 day timestep. If an Event Delay receives a signal at 20 days, and has a 3 day delay time, GoldSim will insert an update (an "internal" event) between timesteps (i.e., at 23 days) in order to more accurately represent the event.

Read more: Understanding Timestepping in GoldSim (page 473).

Warning: Event Delays are designed to interrupt the clock and insert a new update when the event is released. If you choose to disable unscheduled updates, the event in the Delay will be deferred to the next scheduled update (and hence the actual Delay Time will be longer than specified).

Read more: Controlling Unscheduled Updates (page 489).

Event Delays have at least five, and as many as six outputs:

1. the discrete event signal itself (the primary output);
2. the cumulative number of discrete signals emitted (released) by the Delay (EventCount);
3. the number of discrete signals currently in transit within the Delay (Num_in_Transit);
4. the number of discrete signals currently in the queue (Num_in_Queue), which is only present if a capacity or a Resource Requirement is specified;
5. the mean time that emitted signals have spent in the delay (Mean_Time); and

6. the current service time (Current_Service_Time). This represents the expected time it will take a new item (event) to transit the system. If there is no queue (no capacity or Resource requirements specified), or if no events have transited the system, then the current service time is simply reported as -1 (indicating no data). If there is a queue and at least one event has transited the system, the current service time is approximated as the time it took *the most recent item* to transit the system.

Note that the discrete event signal output itself cannot be saved or viewed as a result.

The example model EventDelay.gsm in the General Examples/Events folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains an example of the use of Event Delay elements.

Modeling Event Delays without Dispersion

The simplest (and most common) use of an Event Delay element is to represent the delay of a non-dispersed signal. To simulate such a system, the **Delay Type** should be set to "Defined Delay Time". In this case, after being triggered, the element "holds" the signal for a time period equal to the specified **Delay Time**, and after this delay, emits a discrete event signal.

Modeling Event Delays with Dispersion

In some cases, there may be some variability in when a signal is emitted once the element is triggered. This is equivalent to saying that there is a distribution of actual delay times around some mean, and whenever the element is triggered, the delay time for that event is sampled from a distribution.

If we conceptualize the Delay as a conveyer belt for the signal, another way to view event dispersion is that as the signal moves along the belt, it slips randomly forward or backward on the belt, with the amount of movement proportional to the degree of dispersion.

You can specify such dispersion in the delay time in three different ways:

- By specifying the dispersion in terms of an Erlang dispersion factor;
- By specifying the dispersion in terms of a standard deviation; or
- By specifying a custom distribution of delay times (by referencing a Stochastic element).

If "Defined Delay Time + Erlang Dispersion" is selected, you must enter an **Erlang n-value**, which is a dimensionless value greater than or equal to 1. As n increases, the degree of dispersion decreases. As n goes to infinity, the dispersion goes to zero. The maximum amount of dispersion allowed is represented by n = 1.

If "Defined Delay Time + Std. Deviation" is selected, you must enter a **Std. Deviation**, which is a value with dimensions of time. The value must be greater than or equal to zero and less than or equal to the **Mean Time**. As the **Std. Deviation** decreases, the degree of dispersion decreases. When the **Std. Deviation** goes to zero, the dispersion goes to zero. The maximum amount of dispersion allowed is represented by **Std. Deviation** = **Delay Time**.

The Erlang n and the Std. Deviation are related by the following equation:

$$n = \left(\frac{\text{Delay Time}}{\text{Std. Deviation}} \right)^2$$

If the signal is dispersed, for every event, the Delay Time for that event is sampled from the following distribution:

$$f(t) = \frac{t^{n-1} e^{-t/\beta}}{\beta^n \Gamma(n)}$$

where:

n is the Erlang value (specified by the user);

$\beta = D/n$;

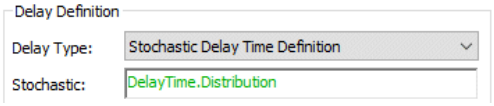
D is the mean delay time; and

Γ is the gamma function (*not* the Gamma distribution).

f(t) is the gamma probability distribution, which is equivalent to (and a generalization of) the Erlang distribution that is frequently used in simulation models.

The gamma distribution represents the time until the occurrence of n sequential Poisson-process events. Each event's random time is represented by an exponential distribution with mean D/n. The gamma distribution does not require n to be an integer. Note that for n=1, the distribution is exponential, and for increasing values of n it becomes less skewed, approaching normality for large n.

The "Stochastic Delay Time Definition" option provides a way to specify a custom distribution for the delay time (rather than the gamma used for the Erlang and Std. Deviation options). If this option is selected, you must specify a **Stochastic** element. The Stochastic element that is specified represents the distribution of the delay time. As such, it must have dimensions of time. The Distribution output of the Stochastic must be referenced:



Note: When dispersion is specified for a Delay, each event which triggers the element is "assigned" an actual delay time by sampling from the distribution presented above. As a result, when Event Delays are dispersed, the events will not necessarily be "released" in the order that they were received.

Event Delays with Time-Variable Delay Times

In some cases, the delay time for your Event Delay may be specified to change as a function of time. You would do this by directly specifying the **Delay Time** or **Mean Time** as varying as a function of time.

Whenever the **Delay Time** or **Mean Time** are specified to vary with time in a simulation, you have two options as to how GoldSim can represent this.

If the **Use conveyer-belt approach** box is checked, GoldSim will treat the delay as if it is a conveyer belt. In particular, if the **Delay Time** or **Mean Time** is specified to become shorter (or longer) during the simulation (e.g., by defining it as a function of time), it can be imagined that the speed at which the belt moves has simply been increased (or decreased), and all events that are in the Delay at the time of the change start to move faster (or slower) by a common factor (the ratio of the old **Delay** or **Mean Time** to the new one).

For example, if the Event Delay was triggered at 10 days while the **Delay Time** was equal to 1000 days, and again at 15 days at which time the **Delay Time** was equal to 1 day, both signals would effectively be emitted at 16 days. That is, at

the time that the **Delay Time** decreased, the first event would not have traversed a significant distance along the conveyer, and therefore it would be emitted from the conveyer just slightly in front of the second event.

If the **Use conveyer-belt approach** box is cleared, each event is assigned an effective delay time when it enters the Delay. Once an event enters the Delay, its delay time is not impacted at all if the **Delay Time** or **Mean Time** is subsequently specified to become shorter (or longer) during the simulation. Referring to the example above, if the **Use conveyer-belt approach** box was cleared, then the first event would be emitted at 1010 days, while the second event would be emitted at 16 days.

Note: When using the "Stochastic Delay Time Definition" option, the Delay can never act as a conveyer (the **Use conveyer-belt approach** box is cleared and grayed out). Every event is assigned an actual delay time by sampling from the Stochastic. If the Stochastic is modified during a simulation, it does not affect events that have already been assigned a delay time.

Specifying Capacities and Modeling Queues for an Event Delay

By checking the **Maximum number of signals simultaneously processed** checkbox within the Event Delay dialog, you can specify a capacity for the Delay in the input field directly below the checkbox.

For example, if you specify this value as 3, the element can only have three signals in transit at any given time. Any other signals that it receives are placed in a *queue*. Signals in the queue must wait for one of the signals in transit to be emitted before they can begin to traverse the delay. GoldSim keeps track of the number of signals in transit (Num_in_Transit), the number of signals in the queue (Num_in_Queue), the mean time that all emitted signals spent in the Delay (Mean_Time), and the time it will take any newly arriving items to transit the system (Current_Service_Time). These latter two outputs account for both the time spent in the queue and the time spent in transit.

These features allow you to model things such as lines at the grocery store, calls at a call center, traffic on a road, and a wide variety of other real-world queues.

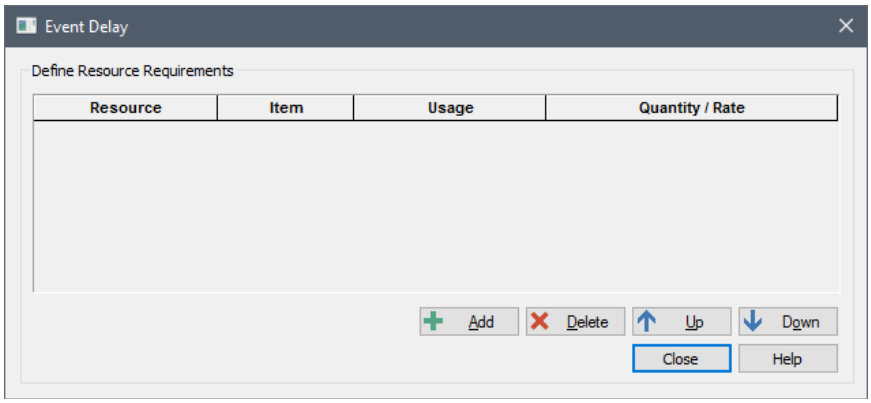
Note: The specified capacity can be a number, a link or an expression. It must be dimensionless and non-negative. GoldSim automatically truncates the value to an integer.

Specifying Resources for an Event Delay

Event Delays can have specified Resource Requirements.

Read more: Using Resources (page 906).

To define a Resource Requirement for an Event Delay, press the **Resources…** button on the main dialog for the element. The following dialog will be displayed:



You can add a Resource Requirement by pressing the **Add** button.

Read more: Interacting with Resources (page 916).

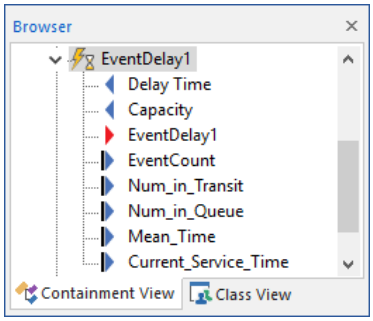
An Event Delay interacts with the specified Resource Stores when a Signal arrives in the Delay (via the Trigger dialog), and can only have three types of interactions (specified in the **Usage** column):

- **Spend (discrete):** A discrete quantity of the Resource is required in order to begin to process the Signal. If the requested Resource quantity is not available, the Signal is added to the element's queue, where it waits for the Resource to become available.
- **Borrow (discrete):** A discrete quantity of the Resource is required in order to begin to process the Signal. If the requested Resource quantity is not available, the Signal is added to the element's queue, where it waits for the Resource to become available. Once the Signal leaves the Delay, the borrowed quantity is returned to the Resource Store.
- **Deposit (discrete):** A discrete quantity of the Resource is created and deposited with the Store when the element begins to process the Signal.

Resources are an advanced feature, and you should read the sections below before attempting to use them.

Browser View of an Event Delay Element

The browser view of an Event Delay includes all of its inputs (e.g., the Delay Time, Dispersion, and Trigger) and up to six outputs:



The discrete event signal output itself cannot be saved or viewed as a result.

Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

Responding to Events

Elements such as Timed Events and Decisions can emit (and in some cases, receive) discrete change signals. Ultimately, however, discrete event modeling must involve discretely impacting an element in some manner in response to the occurrence of the event. There are five elements that, when triggered, respond to an event:

- Discrete Changes;
- Statuses;
- Milestones;
- Stochastics; and
- Interrupts.

The manner in which these elements respond to events is described below.

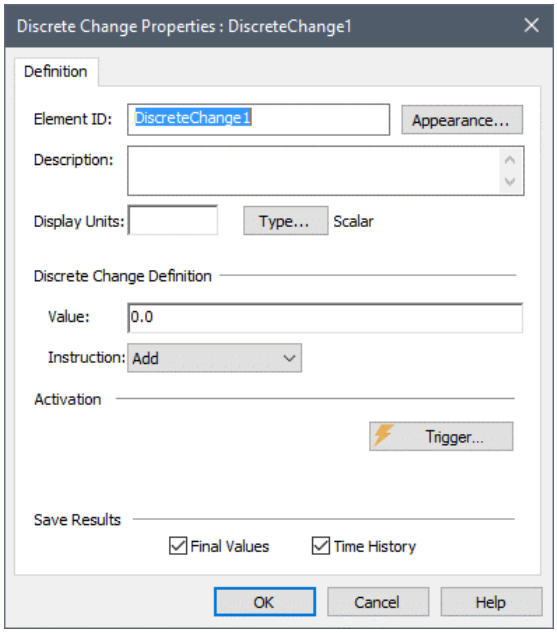
Discrete Change Elements

The Discrete Change element is triggered by an event, and responds by emitting a discrete change signal. The triggering event can be a discrete event signal or another type of event (e.g., a condition, such as X becoming greater than Y).

The discrete change signal output by the element can only be used by a number of elements. In particular, it can be delayed by a Discrete Change Delay element; and it can instantaneously impact the value of an Integrator, a Reservoir or a Pool. It can also act as an input to some elements in GoldSim's specialized modules (e.g., the Financial Module).

Read more: Propagating Discrete Signals Between Elements (page 367).

The dialog for a Discrete Change element looks like this:



You first specify when the element is to be triggered via the **Trigger…** button in the Discrete Change dialog. The **Trigger…** button provides access to a standard Trigger dialog.

Read more: Understanding Event Triggering (page 369).

Once the element is triggered, it emits a discrete change signal. A discrete change signal contains information regarding the response to an event and consisting of two pieces of information: a *Value* (e.g., 10 dollars) and an *Instruction* (e.g., Add).

The **Value** can be a number (e.g., 10 m3) or a link. The required order (scalar, vector or matrix) of the Value is specified in a dialog accessed via the **Type…** button. The required dimensions of the Value are specified in the **Display Units** field. By default, the Value is a dimensionless scalar.

The **Instruction** drop-list contains three choices: "Add", "Replace" and “Push”. This instructs the element(s) receiving the discrete change signal (e.g., an Integrator, a Reservoir or a Pool) how to act upon the value being received.

While Add and Replace have obvious implications for how they are handled by the receiving element (and are the most commonly used), a Push instruction is more complex (and used less often), and is intended specifically to facilitate modeling of aging chains.

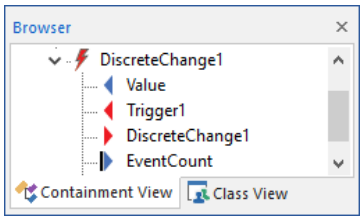
Read more: Modeling Aging Chains (page 876).

Note: A discrete change signal can be used as an argument to an On Event triggering event (in the same manner that a discrete event signal can).

Read more: Specifying Triggering Events (page 370).

Discrete Change elements have two outputs: 1) the discrete change signal itself (the primary output); and 2) the EventCount (i.e., the cumulative number of discrete change signals that the element has emitted during the realization.

These outputs can be seen in the browser view of the element:



The discrete change signal output itself cannot be saved or viewed as a result.

Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

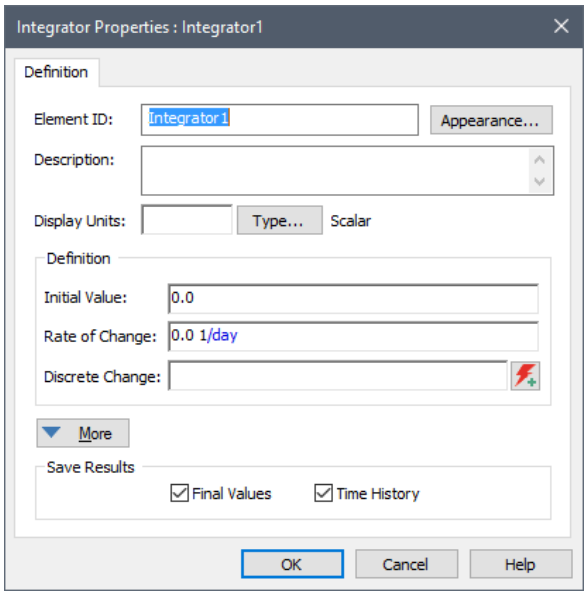
The example model DiscreteChange.gsm in the General Examples/Events folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains an example of the use of Discrete Change elements.

Modeling Discrete Changes to an Integrator

Integrator elements can be instantaneously impacted by a discrete change signal.

Read more: Integrator Elements (page 233).

The Integrator dialog has a special input field for accepting a discrete change signal:



*Discrete changes to the Integrator are entered In the **Discrete Change** field, or by clicking the **Multiple Discrete Signals** button.*

The **Discrete Change** input only accepts discrete change signals. The dimensions and order of the discrete change signals must be the same as those of the Integrator.

When an Integrator receives a discrete change signal with an Add instruction, it instantaneously adds the value of the signal to the Current Value of the Integrator. When an Integrator receives a discrete change signal with a Replace instruction, it instantaneously replaces the Current Value of the Integrator with the value of the signal.

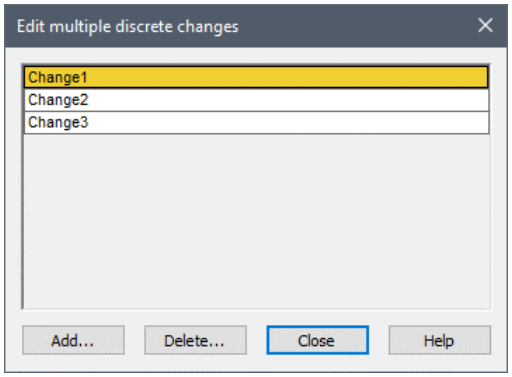
An Integrator can also accept a discrete change signal with a Push instruction, which facilitates the modeling of aging chains.

Read more: Modeling Aging Chains (page 876).

An Integrator can accept multiple discrete changes. This is indicated in the input field by separating the individual discrete change signals by semi-colons (e.g., Change1; Change2; Change3).

Multiple Discrete Signals button

You can also specify the multiple discrete changes using the Multiple Discrete Signals button, which displays a table listing the multiple discrete change signals:



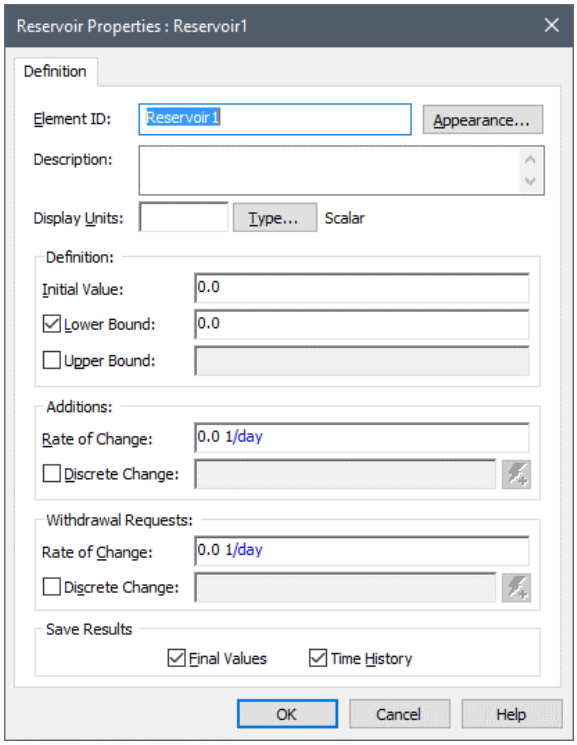
A simple (and fun) application of Discrete Change elements, simulating a bouncing ball (Bounce.gsm), is included in the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Modeling Discrete Changes to a Reservoir

Reservoir elements can be instantaneously impacted by a discrete change signal. Moreover, a Reservoir can also produce (emit) discrete change signals.

Read more: Reservoir Elements (page 240).

The Reservoir dialog has special input fields for accepting a discrete change signal:



*Discrete changes to the Reservoir are entered in the **Discrete Change** fields (**Additions** or **Withdrawal Requests**).*

If the checkbox to the left of **Discrete Change** under **Additions** in the Reservoir dialog is checked, then:

- the input field is activated; and
- if the Reservoir has an Upper Bound, a new output called Discrete_Overflow is created on the element.

The **Discrete Change** input under **Additions** accepts discrete change signals which have a positive value Add instruction. It also accepts discrete change signals which have a Replace instruction. The dimensions and order of the discrete change signal must be the same as those of the Reservoir.

When a Reservoir receives a Discrete Change Addition with an Add instruction, it instantaneously adds the value of the signal to the Value of the Reservoir. When a Reservoir receives a Discrete Change Addition with a Replace instruction, it instantaneously replaces the Value of the Reservoir with the value of the signal.

If the Reservoir has an **Upper Bound** and this is exceeded by the Discrete Change Addition, the Value is fixed at the **Upper Bound**, and the Reservoir produces (emits) a discrete change signal (Discrete_Overflow) which represents the amount of the Discrete Change Addition which "overflowed" the Reservoir.

Read more: Defining Upper and Lower Bounds for a Reservoir (page 246).

Note: If you have specified an **Upper** or **Lower Bound**, and choose to Replace the current value of a Reservoir, the replacement value must be within the bounds (or GoldSim will display a fatal error message).

If the checkbox to the left of **Discrete Change** under **Withdrawal Requests** is checked, then

- the input field is activated; and
- a new output called Discrete_Withdrawals is created on the element.

The **Discrete Change** input under **Withdrawal Requests** only accepts discrete change signals which have a positive value and an Add instruction. The dimensions and order of the discrete change signal must be the same as those of the Reservoir.

When a Reservoir receives a Discrete Change Withdrawal Request, it instantaneously subtracts the value of the signal from Value of the Reservoir. In addition, a discrete change signal (Discrete_Withdrawals) which echoes the Discrete Change Withdrawal Request that was removed from the Reservoir is automatically emitted.

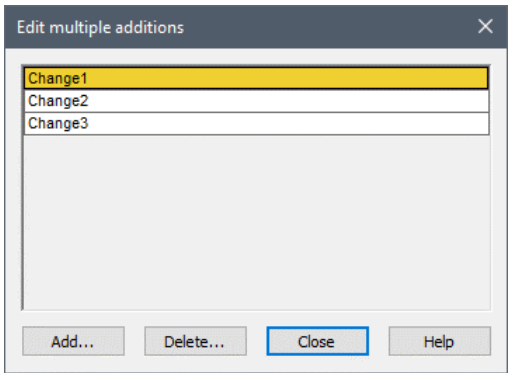
If the Reservoir has a **Lower Bound** and the Discrete Change Withdrawal Request forces the Reservoir to go below this value, the Value is fixed at the **Lower Bound**, and the Reservoir produces (emits) a discrete change signal (Discrete_Withdrawals) which represents the actual Discrete Change Withdrawal that was removed from the Reservoir (i.e., the difference between the Value prior to the withdrawal and the **Lower Bound**).

Read more: Defining Upper and Lower Bounds for a Reservoir (page 246).

A Reservoir can accept multiple Discrete Changes (both **Additions** and **Withdrawal Requests**). This is indicated in the input field by separating the individual discrete change signals by semi-colons (e.g., Change1; Change2; Change3).

Multiple Discrete Signals button

You can also specify the multiple discrete changes using the Multiple Discrete Signals button, which displays a table listing the multiple discrete change signals:

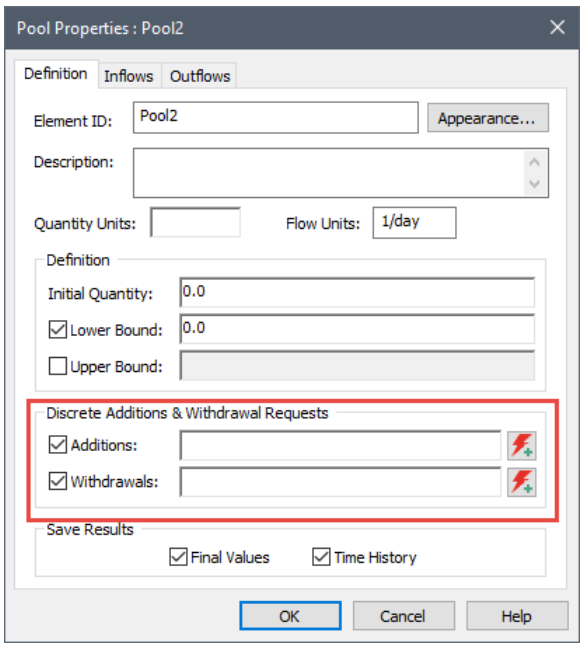


Modeling Discrete Changes to a Pool

Pool elements can be instantaneously impacted by a discrete change signal. Moreover, a Pool can also produce (emit) discrete change signals.

Read more: Pool Elements (page 258).

The Definition tab of the Pool dialog has special input fields for accepting a discrete change signal:



*Discrete changes to the Pool are entered in the Discrete Change fields (**Additions** or **Withdrawals**).*

If the checkbox to the left of **Additions** in the Pool dialog is checked, then:

- the input field is activated; and
- if the Pool has an Upper Bound, a new output called Discrete_Overflow is created on the element.

The **Additions** input accepts discrete change signals which have a positive value Add instruction. It also accepts discrete change signals which have a Replace instruction. The dimensions of the discrete change signal must be the same as those of the **Quantity Units**.

When a Pool receives a Discrete Change Addition with an Add instruction, it instantaneously adds the value of the signal to the Quantity of the Pool. When a

Pool receives a Discrete Change Addition with a Replace instruction, it instantaneously replaces the Quantity of the Pool with the value of the signal.

If the Pool has an **Upper Bound** and this is exceeded by the Discrete Change Addition, the Quantity is fixed at the **Upper Bound**, and the Pool produces (emits) a discrete change signal (Discrete_Overflow) which represents the amount of the Discrete Change Addition which "overflowed" the Pool.

Read more: Defining Upper and Lower Bounds for a Pool (page 264).

Note: If you have specified an **Upper** or **Lower Bound**, and choose to Replace the current value of a Pool, the replacement value must be within the bounds (or GoldSim will display a fatal error message).

If the checkbox to the left of **Withdrawals** is checked, then

- the input field is activated; and
- a new output called Discrete_Withdrawals is created on the element.

The **Withdrawals** input only accepts discrete change signals which have a positive value and an Add instruction. The dimensions of the discrete change signal must be the same as those of the **Quantity Units**.

When a Pool receives a Discrete Change Withdrawal, it instantaneously subtracts the value of the signal from Quantity of the Pool. In addition, a discrete change signal (Discrete_Withdrawals) which echoes the Discrete Change Withdrawal Request that was removed from the Reservoir is automatically emitted.

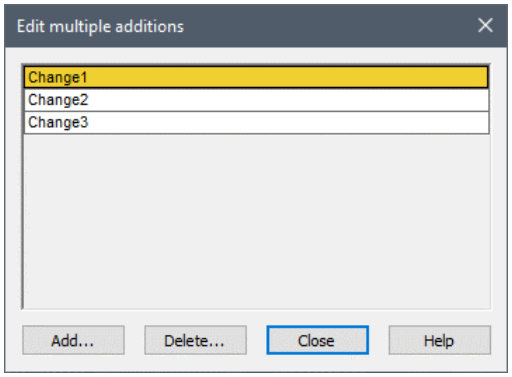
If the Pool has a **Lower Bound** and the Discrete Change Withdrawal forces the Pool to go below this value, the Quantity is fixed at the **Lower Bound**, and the Pool produces (emits) a discrete change signal (Discrete_Withdrawals) which represents the actual Discrete Change Withdrawal that was removed from the Pool (i.e., the difference between the Quantity prior to the withdrawal and the **Lower Bound**).

Read more: Defining Upper and Lower Bounds for a Pool (page 264).

A Pool can accept multiple Discrete Changes (both **Additions** and **Withdrawals**). This is indicated in the input field by separating the individual discrete change signals by semi-colons (e.g., Change1; Change2; Change3).

Multiple Discrete Signals button

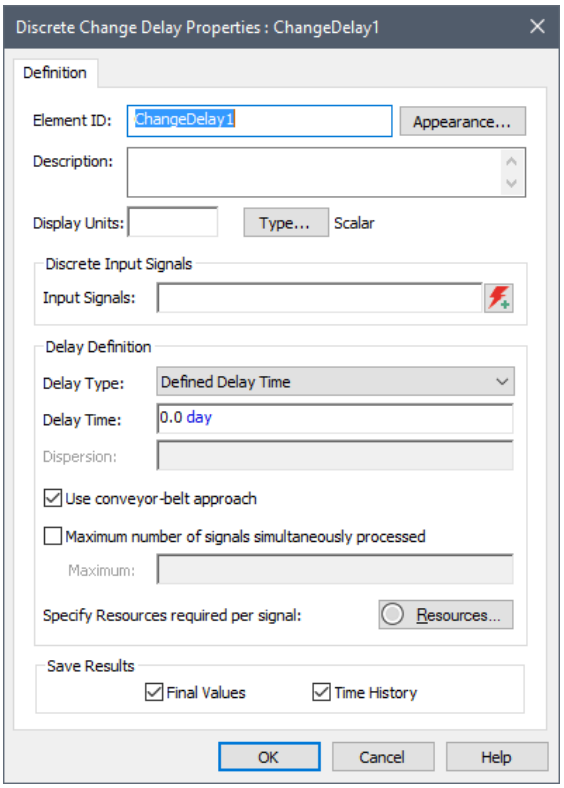
You can also specify the multiple discrete changes using the Multiple Discrete Signals button, which displays a table listing the multiple discrete change signals:



Delaying a Discrete Change Signal

Discrete Change Delay elements provide a mechanism for delaying a discrete change signal. Once a Discrete Change Delay receives a discrete change signal, it holds it for a specified time period, and then emits it.

The dialog for a Discrete Change Delay looks like this:

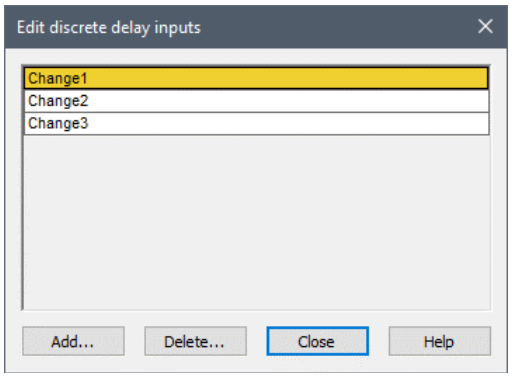


Within the Discrete Change Delay dialog, you must first specify which discrete change signal(s) you wish to delay. The **Discrete Input Signals** field accepts *only* discrete change signals. The discrete change signal inputs to a Discrete Change Delay must all have the same attributes (order and dimensions) as the output. The required order (scalar, vector or matrix) of the output signal is specified in a dialog accessed via the **Type…** button. The required dimensions of the signal are specified in the **Display Units** field. By default, the signal is a dimensionless scalar.

A Discrete Change Delay can accept multiple discrete change signals. This is indicated in the input field by separating the individual discrete change signals by semi-colons (e.g., Change1; Change2; Change3).

Multiple Discrete Signals button

You can also specify the multiple discrete changes using the Multiple Discrete Signals button, which displays a table listing the multiple discrete change signals:



After defining the signal(s) to be delayed, you then define the delay itself. The delay time is computed based on a specified **Delay Type**. There are three types:

- Defined Delay Time.
- Defined Delay Time + Erlang Dispersion
- Defined Delay Time + Std. Deviation

The last two options allow the delay time to have a specified dispersion. That is, they allow you to simulate variability in when a signal is emitted once the element is triggered. This is equivalent to saying that there is a distribution of actual delay times around some mean, and whenever the element is triggered, the delay time for that event is sampled from a distribution.

All three options require a specified **Delay Time** (or a **Mean Time** if dispersion is specified). The **Delay Time** and the **Mean Time** must have dimensions of time and generally should be positive.

Note: If the specified delay time is equal to zero, the signal is emitted immediately (i.e., on the same update) without any delay. A negative delay time will result in a fatal error.

Note: The **Use conveyer-belt approach** box only impacts the behavior of the Delay if the delay time changes with time.

Read more: Discrete Change Delays with Time-Variable Delay Times (page 409).

You can optionally specify that a Discrete Change Delay requires one or more **Resources** in order to process the signal.

Read more: Specifying Resources for a Discrete Change Delay (page 410).

Discrete Change Delay elements have the ability to influence when a model is updated. Typically, a model is updated at every "scheduled" timestep. That is, all the elements are computed at every timestep. However, an Event Delay can force a model to be updated between "scheduled" timesteps.

For example, suppose that you have specified a 10 day timestep. If a Discrete Change Delay receives a signal at 20 days, and has a 3 day delay time, GoldSim will insert an update (an "internal" event) between timesteps (i.e., at 23 days) in order to more accurately represent the event.

Read more: Understanding Timestepping in GoldSim (page 473).

Warning: Discrete Change Delays are designed to interrupt the clock and insert a new update when the discrete change is released. If you choose to disable unscheduled updates, the discrete change in the Delay will be deferred to the next scheduled update (and hence the actual Delay Time will be longer than specified).

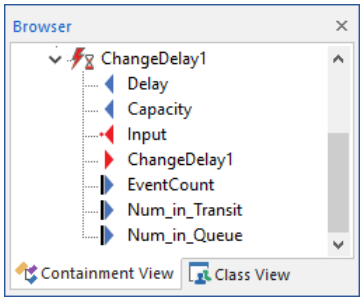
Read more: Controlling Unscheduled Updates (page 489).

Discrete Change Delays have at least three, and as many as four outputs:

1. the discrete change signal itself (the primary output);
2. the cumulative number of discrete change signals emitted (released) by the Delay (EventCount);
3. the number of discrete change signals currently in transit within the Delay (Num_in_Transit);
4. the number of discrete change signals currently in the queue (Num_in_Queue), which is only present if a capacity or a Resource Requirement is specified;

Note that the discrete change signal output itself cannot be saved or viewed as a result.

The browser view of the Discrete Change Delay element looks like this:



Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

The example model DiscreteChange.gsm in the General Examples/Events folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains examples of the use of Discrete Change Delay elements.

Modeling Discrete Change Delays without Dispersion

The simplest (and most common) use of a Discrete Change Delay element is to represent the delay of a non-dispersed signal.

To simulate such a system, the **Delay Type** should be set to "Defined Delay Time". In this case, after being triggered, the element "holds" the signal for a time period equal to the specified **Delay Time**, and after this delay, emits a discrete change signal.

Modeling Discrete Change Delays with Dispersion

In some cases, when you are delaying a discrete change signal in a Discrete Change Delay element, there may be some variability in delay times for signals. This is equivalent to saying that there is a distribution of actual delay times

around some mean, and whenever the element receives a signal, the delay time for that signal is sampled from a distribution.

If we conceptualize the Delay as a conveyer belt for the signal, another way to view signal dispersion is that as the signal moves along the belt, it slips randomly forward or backward on the belt, with the amount of movement proportional to the degree of dispersion.

You can specify such dispersion in the delay time in two different ways:

- By specifying the dispersion in terms of an Erlang dispersion factor; or
- By specifying the dispersion in terms of a standard deviation.

If "Defined Delay Time + Erlang Dispersion" is selected, you must enter an **Erlang n-value**, which is a dimensionless value greater than or equal to 1. As n increases, the degree of dispersion decreases. As n goes to infinity, the dispersion goes to zero. The maximum amount of dispersion allowed is represented by n = 1, which corresponds to an exponential distribution of delay times.

If "Defined Delay Time + Std. Deviation" is selected, you must enter a **Std. Deviation**, which is a value with dimensions of time. The value must be greater than or equal to zero and less than or equal to the **Mean Time**. As the **Std. Deviation** decreases, the degree of dispersion decreases. When the **Std. Deviation** goes to zero, the dispersion goes to zero. The maximum amount of dispersion allowed is represented by **Std. Deviation** = **Delay Time**.

The Erlang n and the Std. Deviation are related by the following equation:

$$n = \left(\frac{\text{Delay Time}}{\text{Std. Deviation}} \right)^2$$

If the signal is dispersed, for every signal received, the Delay Time for that signal is sampled from the following distribution:

$$f(t) = \frac{t^{n-1} e^{-t/\beta}}{\beta^n \Gamma(n)}$$

where:

n is the Erlang value (specified by the user);

$\beta = D/n$;

D is the mean delay time; and

Γ is the gamma function (*not* the Gamma distribution).

f(t) is the gamma probability distribution, which is equivalent to (and a generalization of) the Erlang distribution that is frequently used in simulation models.

The gamma distribution represents the time until the occurrence of n sequential Poisson-process events. Each event's random time is represented by an exponential distribution with mean D/n. The gamma distribution does not require n to be an integer. Note that for n=1, the distribution is exponential, and for increasing values of n it becomes less skewed, approaching normality for large n.

Note: When dispersion is specified for a delay time, each signal received by the element is "assigned" an actual delay time by sampling from the distribution presented above. As a result, when signals in a Discrete Change Delay are dispersed, the signals will not necessarily be "released" in the order that they were received.

Discrete Change Delays with Time-Variable Delay Times

In some cases, the delay time for your Discrete Change Delay may be specified to change as a function of time. You would do this by directly specifying the **Delay Time** or **Mean Time** as varying as a function of time.

Whenever the **Delay Time** or **Mean Time** are specified to vary with time in a simulation, you have two options as to how GoldSim can represent this.

If the **Use conveyer-belt approach** box is checked, GoldSim will treat the delay as if it is a conveyer belt. In particular, if the **Delay Time** or **Mean Time** is specified to become shorter (or longer) during the simulation (e.g., by defining it as a function of time), it can be imagined that the speed at which the belt moves has simply been increased (or decreased), and all items that are in the Delay at the time of the change start to move faster (or slower) by a common factor (the ratio of the old **Delay** or **Mean Time** to the new one).

For example, if the Discrete Change Delay was triggered at 10 days while the **Delay Time** was equal to 1000 days, and again at 15 days at which time the **Delay Time** was equal to 1 day, both signals would effectively be emitted at 16 days. That is, at the time that the **Delay Time** decreased, the first item would not have traversed a significant distance along the conveyer, and therefore it would be emitted from the conveyer just slightly in front of the second item.

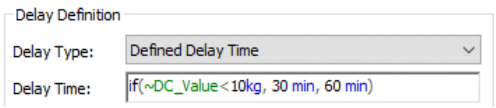
If the **Use conveyer-belt approach** box is cleared, each item is assigned an effective delay time when it enters the Delay. Once an item enters the Delay, its delay time is not impacted at all if the **Delay Time** or **Mean Time** is subsequently specified to become shorter (or longer) during the simulation. Referring to the example above, if the **Use conveyer-belt approach** box was cleared, then the first item would be emitted at 1010 days, while the second item would be emitted at 16 days.

Note: The **Use conveyor-belt approach** option is not available if you have referenced the discrete change signal Value directly when specifying the delay time.

Referencing the Discrete Change Value to Determine the Delay Time

In some cases, the delay time for a Discrete Change Delay may be a function of the Value that is associated with the Discrete Change signal being processed. For example, perhaps the Discrete Change Delay represented a manufacturing or treatment process, the Value of the signal represented the size of the item to be processed, and the processing time was a function of the size.

This can be simulated by referencing "~DC_Value", which is a locally available property within the Discrete Change Delay dialog:



Read more: Understanding Locally Available Properties (page 874).

In this example, if the Value of the incoming signal is less than 10kg, it takes 30 minutes to process; otherwise it takes 60 minutes.

Note: The ~DC_Value property is not available if the **Use conveyor-belt approach** option is selected. This is because when using the conveyor-belt approach, *all* signals in the delay are impacted when the Delay Time changes, and in almost all cases, it would therefore not make sense to adjust the Delay Time based on the attribute of one particular signal.

Read more: Discrete Change Delays with Time-Variable Delay Times (page 409).

Note that the "~DC_Value" locally available property can be referenced in any field in the Discrete Change Delay element, including those associated with specifying Resource requirements.

Read more: Specifying Resources for a Discrete Change Delay (page 410).

The ability to reference the discrete change signal Value within a Discrete Change Delay, coupled with the ability to reference the discrete change signal Value within a Splitter, enables a wide range of discrete event processes to be simulated within GoldSim.

Read more: Using Splitter Elements to Route Discrete Changes Based on Their Value (page 411).

Specifying Capacities and Modeling Queues for a Discrete Change Delay

By checking the **Maximum number of signals simultaneously processed** checkbox within the Discrete Change Delay dialog, you can specify a capacity for the Delay in the input field directly below the checkbox.

For example, if you specify this value as 3, the element can only have three signals in transit at any given time. Any other signals that it receives are placed in a queue. Signals in the queue must wait for one of the signals in transit to be emitted before they can begin to traverse the delay. GoldSim keeps track of the number of signals in transit (Num_in_Transit) and the number of signals in the queue (Num_in_Queue).

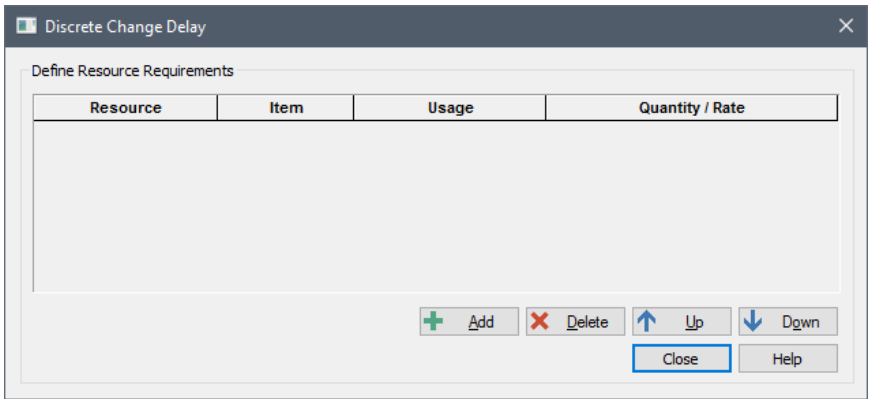
Note: The specified capacity can be a number, a link or an expression. It must be dimensionless and non-negative. GoldSim automatically truncates the value to an integer.

Specifying Resources for a Discrete Change Delay

Discrete Change Delays can have specified Resource Requirements.

Read more: Using Resources (page 906).

To define one or more Resource Requirements for a Discrete Change Delay, press the **Resources…** button on the main dialog for the element. The following dialog will be displayed:



You can add a Resource Requirement by pressing the **Add** button.

Read more: Interacting with Resources (page 916).

A Discrete Change Delay interacts with the specified Resource Stores when a discrete change signal arrives in the Delay, and can only have three types of interactions (specified in the **Usage** column):

- **Spend (discrete):** A discrete quantity of the Resource is required in order to begin to process the Signal. If the requested Resource quantity is not available, the Signal is added to the element's queue, where it waits for the Resource to become available.
- **Borrow (discrete):** A discrete quantity of the Resource is required in order to begin to process the Signal. If the requested Resource quantity is not available, the Signal is added to the element's queue, where it waits for the Resource to become available. Once the Signal leaves the Delay, the borrowed quantity is returned to the Resource Store.
- **Deposit (discrete):** A discrete quantity of the Resource is created and deposited with the Store when the element begins to process the Signal.

Note: The Quantity/Rate field can reference the locally available property ~DC_Value (the Value that is associated with the Discrete Change signal being processed). This allows you to define a Resource Requirement that is a function of this value.

Read more: Referencing the Discrete Change Value to Determine the Delay Time (page 409).

Resources are an advanced feature, and you should read the sections below before attempting to use them.

Using Splitter Elements to Route Discrete Changes Based on Their Value

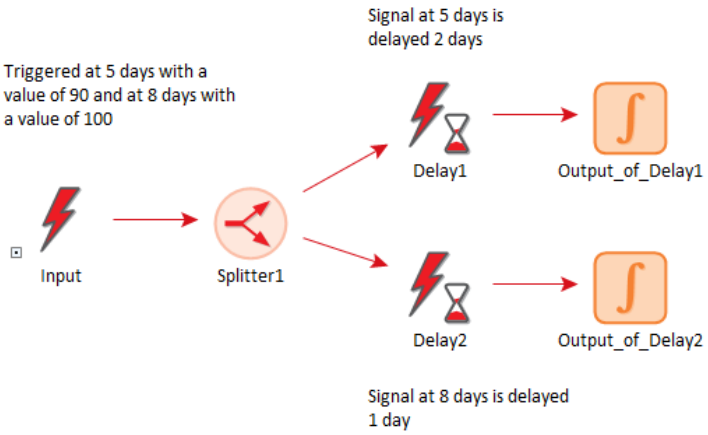
In some situations, you may want to route a discrete change signal based on the Value it is carrying. For example, based on the Value associated with the discrete change signal, you may want to route the item to different processing streams.

This can be accomplished by using a Splitter to route the discrete change signal based on its Value. This is possible because 1) a Splitter can accept (and route) discrete change signals; and 2) the specified fraction (or amount) for a Splitter output can reference the value of the signal using the ~Amount local property.

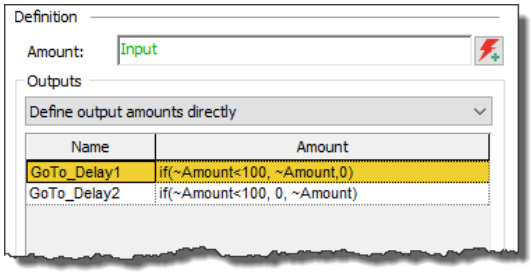
Read more: Splitter Elements (page 288).

To illustrate this, it is instructive to consider a simple example. This example can be found in the file Splitter.gsm in the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

In this example, a discrete change signal with an "Add" instruction is generated. If the value is less than 100, we want to send it to one set of processes; if it is greater than 100, we want to send it to a different set of processes. The Splitter is used to route it in the appropriate direction:



The Splitter accomplishes this by referencing "~Amount", which is a locally available property within the Splitter dialog:



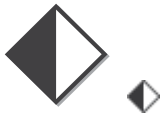
Read more: Understanding Locally Available Properties (page 874).

This technique works because a Splitter does not propagate a discrete change signal with a value of zero and an "Add" instruction ("Replace" and "Push" instructions with zero values would be propagated). Hence, given the logic specified above, only one signal is propagated whenever a discrete change signal is received by the Splitter.

Note: If you only wanted to adjust the delay time for a single process, you could do so without using the Splitter at all by defining a single Discrete Change Delay and referencing the ~DC_Value. The example above is simply meant to illustrate how you could split a signal into one of several processing directions (which might each have many subsequent processing steps).

Read more: Referencing the Discrete Change Value to Determine the Delay Time (page 409).

Status Elements



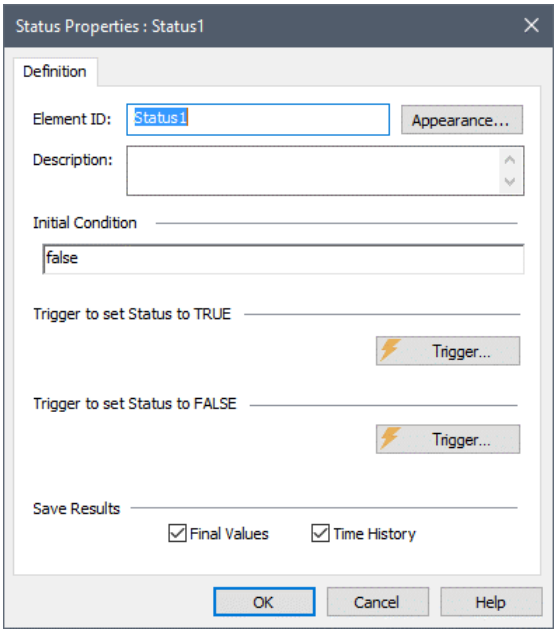
Status elements allow you to monitor the status of something that is changed instantaneously (i.e., is triggered) by events. The single output of a Status element is a condition (True or False). The element has an initial condition (True or False) and two triggers: one that sets the Status to True, and another that sets the Status to False.

You would use a Status element to track the status or state of processes or objects in your model. For example, if you were modeling a material handling facility, you could use a Status element to signify whether or not a particular storage area could accept any more material (i.e., is it full?). You might then reference the output of the Status element in a Selector element or a Decision element to determine the flow of material in your model.

One of the most powerful uses of a Status element is to represent a deadband when modeling an active feedback control system.

Read more: Simulating a Deadband Using a Status Element (page 415).

The dialog for a Status element looks like this:



Within the Status dialog, you should first specify the **Initial Condition** for the element (True or False). This can be entered as a condition (e.g., False) or a conditional expression. By default, it is False.

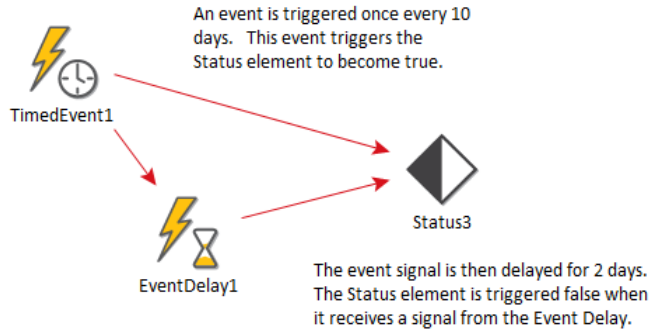
Note: The **Initial Condition** cannot be a function of Time.

You must then specify the triggering event(s) which cause the element to be set to True and False. These are both defined via **Trigger…** buttons, which provide access to standard Trigger dialogs.

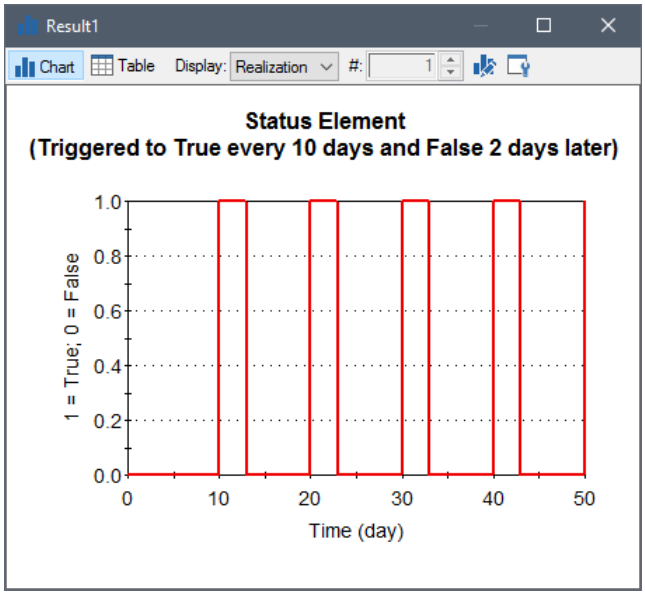
Read more: Understanding Event Triggering (page 369).

Note: You don't have to specify both the True and the False trigger. However, if you do not specify the trigger that represents the opposite of the **Initial Condition**, GoldSim will issue a warning when you close the dialog.

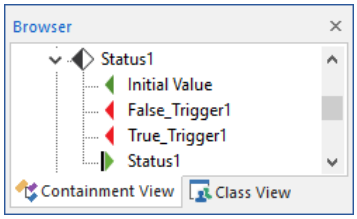
To understand how a Status element works, consider the following simple example. Assume that a Status element defaults to False. A triggering event is defined which sets the Status to True whenever an event occurs (regularly, every 10 days). This event also triggers an Event Delay (which has a delay of 2 days). The output of the Event Delay then sets the Status to False (2 days after it was set to True). The structure of this model looks like this:



The output of this simulation would look like this (note that in a chart, 1 corresponds to True, and 0 corresponds to False):



The browser view of a Status element looks like this:



Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

The example model StatusMilestone.gsm in the General Examples/Events folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains an example of the use of Status elements.

Simulating a Deadband Using a Status Element

In many engineered (and some social and organizational) systems, there is active feedback control designed directly into the system to make it behave in a specified manner. That is, the system includes a ***feedback loop***that is used to control behavior.

Read more: Evaluating Feedback Loops (page 361).

A thermostat is the classic example of this (the heating and/or cooling rate is adjusted based on the current temperature). Another example might be a pond (the pumping rate to and from the pond is adjusted based on the water level).

The goal of a feedback control system is generally to control the value of a ***state variable***in the system (typically represented by a Reservoir or a Pool in GoldSim) by actively adjusting additions and withdrawals to that variable so that it is maintained at or around a target value (e.g., the set temperature value on a thermostat).

Read more: Understanding State Variables in GoldSim (page 356).

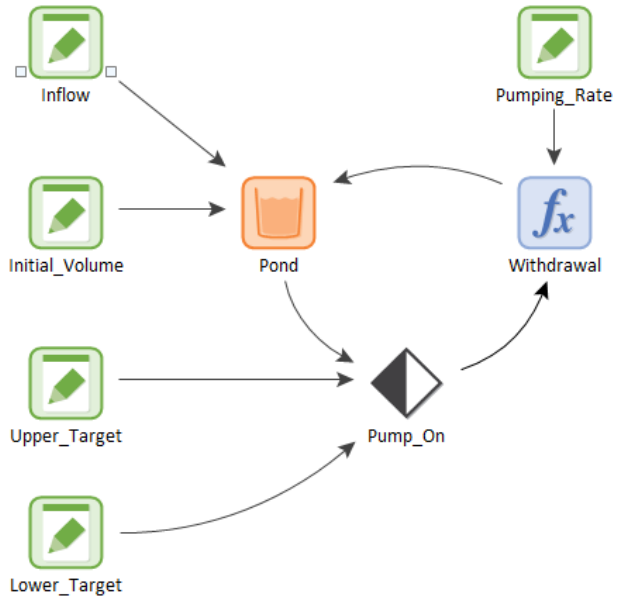
In the case of the thermostat, the state variable is the amount of heat in the house (quantified via the temperature) and the additions are withdrawals are associated with turning on/off the heat or air conditioning. For a pond, the state variable is the amount of water in the pond (which could be quantified via the water level) and the additions are withdrawals are associated with turning on/off pumps that remove (or perhaps add) water.

If you are going to model such systems, you need to understand how to properly represent these controlling feedback loops in a realistic way. In particular, it is quite common for novice (and even some experienced) modelers to represent such systems in such a way that the model behaves quite poorly (e.g., oscillates unrealistically).

Read more: Avoiding Oscillatory Behavior When Using Reservoirs (page 254); Avoiding Oscillatory Behavior When Using Pools (page 276).

One of the best ways to avoid the potential for unrealistic oscillatory behavior (and to realistically represent how the system would be managed in the actual system) is use what is referred to as a "deadband" or a target range within which the system is controlled. This is actually how a thermostat typically works (e.g., "turn the heat on when the temperature is 68 degrees and turn it off when it reaches 70 degrees"). You could implement this in GoldSim using a Status element.

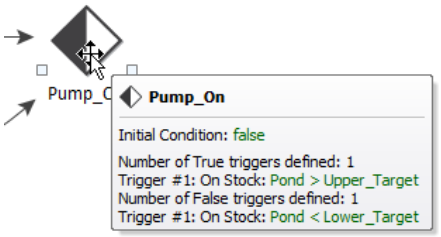
To illustrate this, let's consider the example pictured below (you can find this example in Reservoir.gsm in the General Examples/Stocks folder of your GoldSim directory, accessed by selecting **File | Open Example...** from the main menu):



Note: A similar example using a Pool instead of a Reservoir can be found in Pool.gsm in the General Examples/Stocks folder of your GoldSim directory, accessed by selecting **File | Open Example...** from the main menu.

In this simple model, water flows into a pond at a constant rate (100 m^3/day), and we wish to actively control the volume of water in the pond, maintaining the volume between a lower target or 290 m^3 and and upper target of 310 m^3 (the "deadband"). We do this by turning a pump (that removes water from the pond) on and off in a specified manner. The pump, when on, pumps at a rate of 200 m^3/day.

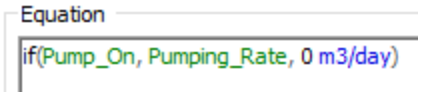
The Status element is used to determine if the pump is on or off. Its triggers are defined as follows:



Note: The triggers are defined as "On Stock" triggers, which force an unscheduled update at the point the condition is met, resulting in more accurate behavior. Using "On True" triggers would be less accurate (as unscheduled updates would not be created, and the trigger would not be pulled until the next scheduled update).

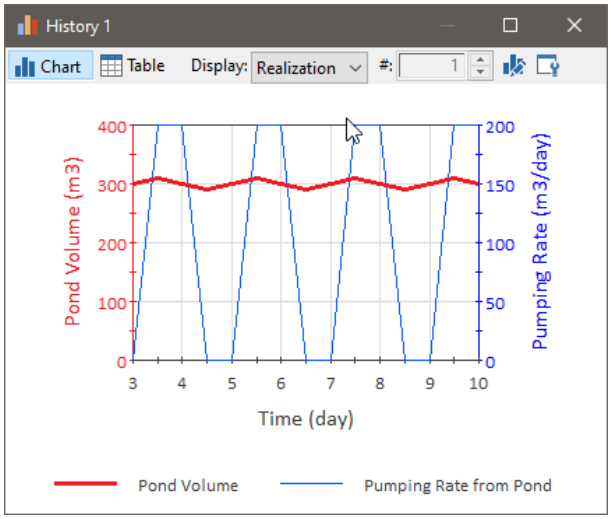
Read more: Specifying Triggering Events (page 370).

The Withdrawal from the pond is then defined as follows:



That is, when the pond volume is greater than the upper target volume, the pump is turned on. When it is below the lower target volume, it is turned off. Note that the Pumping_Rate is larger than the Inflow, so when the pump is turned on, the volume in the pond is reduced. The essentially creates a feedback loop between the pond volume and the withdrawal – it is an active feedback control system that is analogous to those common in many engineered systems.

The pond volume behaves as follows, slowly moving between the two targets:



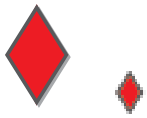
Milestone Elements

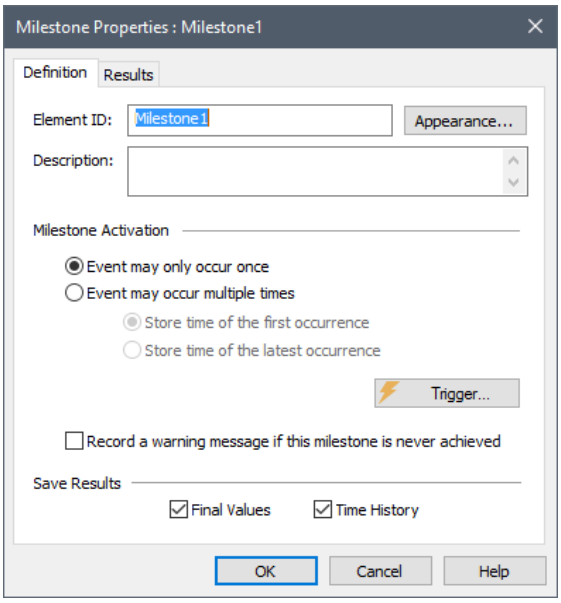
Milestone elements record the time that an event occurs. The Milestone element has three outputs: the Date (calendar time) that the triggering event occurred, the ETime (elapsed time) in the simulation that the triggering event occurred, and a Completion_Status (which is False prior to the element being triggered, and True afterward).

Read more: Setting the Basic Time Options (page 471).

You would use a Milestone element to record the time when a particular event occurred or condition was achieved. You could also use the Completion_Status of the Milestone to trigger other events (e.g., when Milestone X is reached, trigger event Y).

The dialog for a Milestone element looks like this:





The key inputs in the Milestone dialog are the triggering event(s) which cause the Milestone to be set.. This is defined via a **Trigger…** button, which provides access to a standard Trigger dialog

Read more: Understanding Event Triggering (page 369).

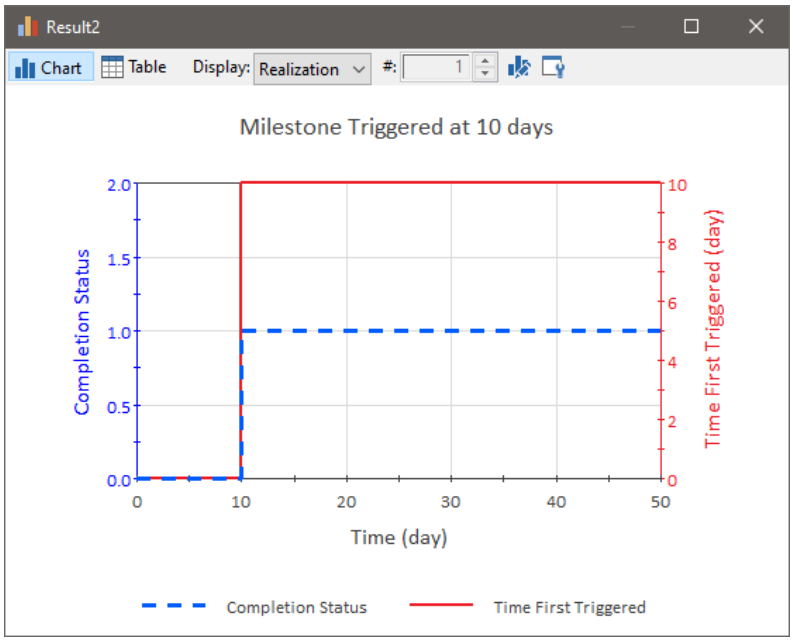
A Milestone also has several radio buttons and checkboxes.

If **Event may only occur once** is selected, then the Milestone records the time that it was first triggered. If it is triggered multiple times, a warning message is written to the Run Log.

If **Event may occur multiple times** is selected, then you must also select whether the Milestone is to **Store time of the first occurrence**, or **Store time of the last occurrence**. In the former case, the Milestone records the time that it was first triggered and ignores any other events. In the latter case, the Milestone records the time that it was last triggered.

If **Record a warning message if this milestone is never achieved** is checked, a warning message is written to the Run Log if the Milestone is never triggered.

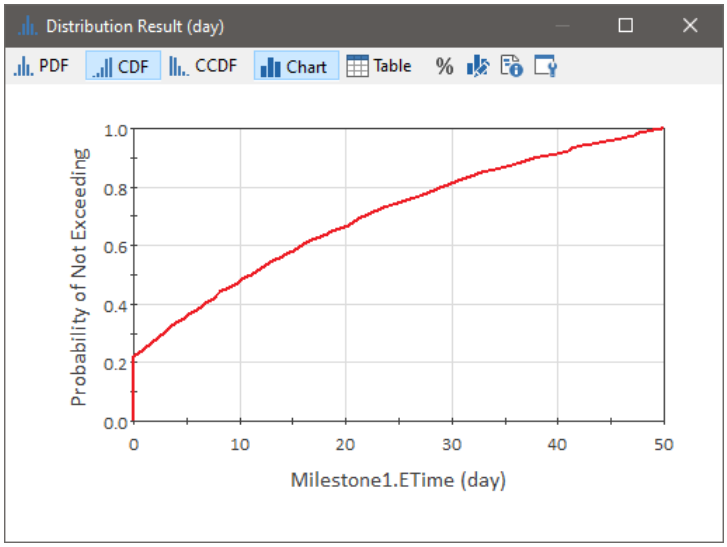
To better understand how a Milestone element works, consider the following simple example. Assume that a Milestone element is triggered by an event that occurs every ten days, the Milestone is defined such that **Event may occur multiple times** is selected, and the Milestone is set to **Store time of the first occurrence**. The output of the Etime output of the Milestone in this case would look like this (note that in a chart, 1 corresponds to True, and 0 corresponds to False):



The Milestone records when it was first triggered (at 10 days), and sets its Completion Status to True (1).

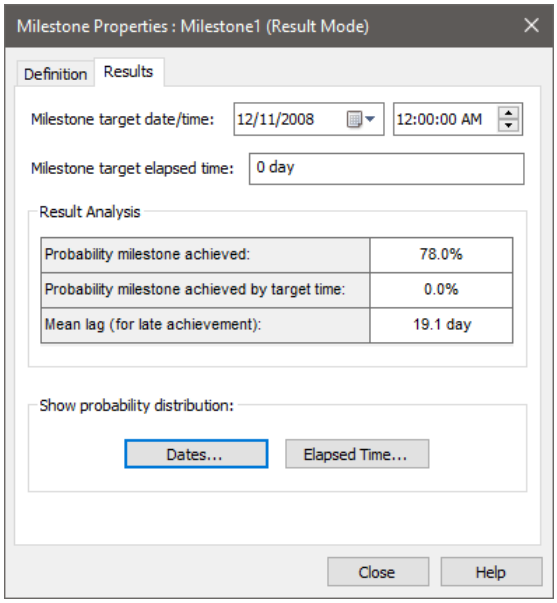
Note that the initial value of the Etime output for a Milestone (i.e., its value prior to being triggered) is zero (0). Similarly, the initial value of the Date output for a Milestone (i.e., its value prior to being triggered) is the Start Date/time. This can be misleading, because if the Milestone is never achieved during a realization, the result will actually indicate that it was achieved at the beginning of the realization (Etime = 0). Such a result is particularly confusing when viewing probabilistic results.

To illustrate this, consider the following probabilistic result (accessed by selecting the ETime output and viewing the **Distribution Result…**:

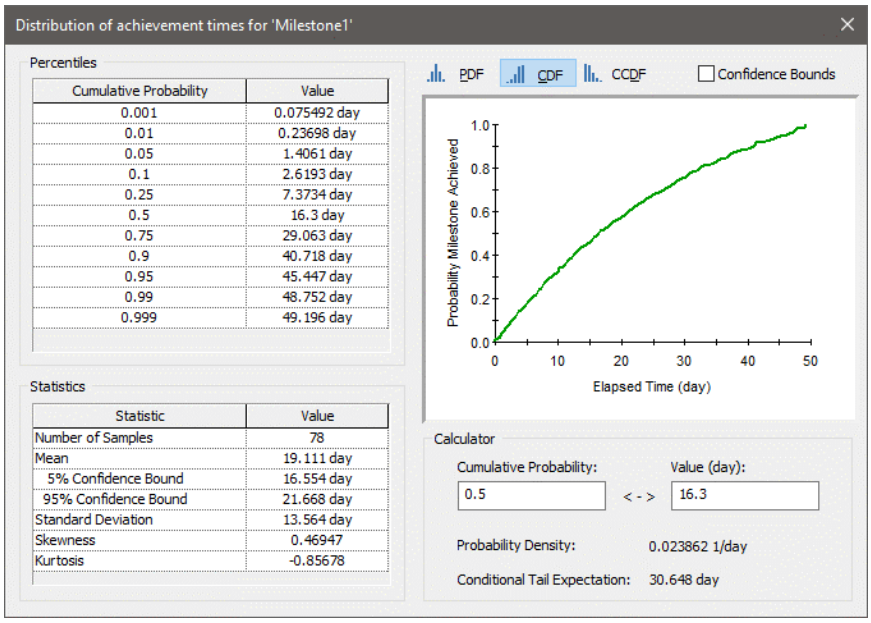


This plot indicates that just over 20% of the time, the Milestone was achieved immediately. In reality, just over 20% of the time, it was not achieved at all, but because the initial value for the time achieved was 0, the result indicates otherwise.

To get around this problem (and provide additional Milestone results), the Milestone element contains a **Results** tab:



At the bottom of the page are two buttons (**Dates…** and **Elapsed Time…**). Pressing these buttons displays the probability distribution of when the Milestone was achieved (in terms of calendar time or elapsed time, respectively) *considering only those realizations in which it was achieved*. Here is the **Elapsed Time…** result corresponding to the one shown previously:



As can be seen, the distribution no longer shows the (misleading) jump at ETime = 0; it only includes those realizations during which the Milestone was achieved.

Note: The **Dates…** and **Elapsed Time…** buttons are grayed out when the model is in Scenario Mode. That is, you cannot view these results when running and comparing scenarios.

Read more: Creating, Running and Comparing Scenarios (page 525).

The upper portion of the Milestone's **Results** tab shows additional results of interest. Two of these results are defined with respect to a defined *target time* that you define (in terms of either Elapsed Time or Date). The target time defaults to the beginning of the simulation.

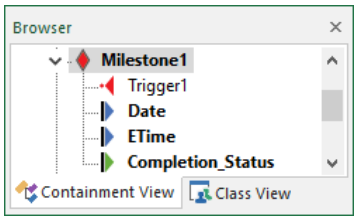
The results displayed directly below the target time are then defined as follows:

Probability milestone achieved: This is the probability that the Milestone is achieved during the simulation. Hence, this represents the fraction of realizations that are included in the **Elapsed Time…** or **Date…** plots accessed via the buttons at the bottom of the page.

Probability milestone achieved by target time: This is the probability that the Milestone is achieved by the specified target time.

Mean lag (for late achievement): For those realizations in which the Milestone is achieved after the target time (but before the end of the simulation), this is the mean time after the target time that the Milestone was achieved.

The browser view of a Milestone looks like this:



Note: Element inputs and outputs are only shown in the browser if you choose to **Show Element Subitems** (accessed via the browser context menu by right-clicking in the browser).

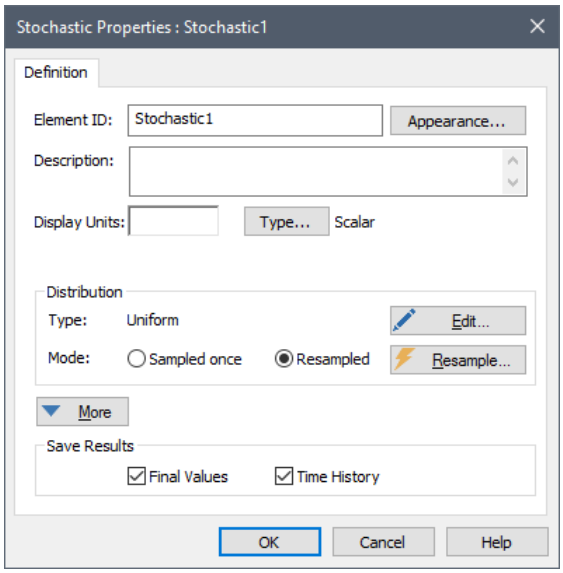
The example model StatusMilestone.gsm in the General Examples/Events folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains an example of the use of Milestone elements.

Triggering a Stochastic

By default, Stochastic elements are sampled once per realization (when their parent Container is first activated, which is typically at the beginning of the realization).

Stochastics can also be triggered to resample themselves by events. This may be useful, for example, if you wanted to resample a parameter representing the value of a discrete change (e.g., the magnitude of a storm) every time a particular event occurred, or if you wished to generate stochastic time histories (e.g., a precipitation record) by sampling a Stochastic on a regular basis (e.g., every day).

The **Resample…** button in the Stochastic dialog provides access to a standard Trigger dialog for controlling when a Stochastic is sampled:



Read more: Understanding Event Triggering (page 369).

By default, **Sampled once** is selected and this button is grayed out. This implies that the element will be sampled only at the beginning of the simulation.

If you select the **Resampled** radio button, the **Resample...** button becomes available, and you can define one or more triggers.

Note: If the Stochastic is not contained within a conditional Container, or if it is contained in a conditional Container *but is static* (i.e., no triggers are defined and is not otherwise a function of time), it will automatically be sampled at the start of the realization (and never again). If it is contained in a conditional Container and *is not static* (i.e., has at least one trigger defined or is otherwise a function of time), it is automatically sampled when its parent Container activates, and is assigned a value of zero prior to activation of the Container

Read more: Using Conditional Containers (page 968).

Note: One common requirement in models which represent a time-variable or stochastic process is to resample a Stochastic on a regular basis (e.g., every day or every month). You can do this in an easy way by utilizing the various Run Properties. For example, defining an On Changed trigger as “Day” would force the Stochastic to be triggered every day.

Note: If Stochastic X is correlated to Stochastic Y, you cannot specify that X is to be resampled (a Stochastic that is correlated can not be explicitly resampled). However, if Stochastic Y is resampled, then Stochastic X will also automatically be resampled (although this is not explicitly indicated in the dialog for X).

Read more: Understanding and Referencing Run Properties (page 505); Correlating Stochastic Elements (page 183).

Interrupting a Simulation

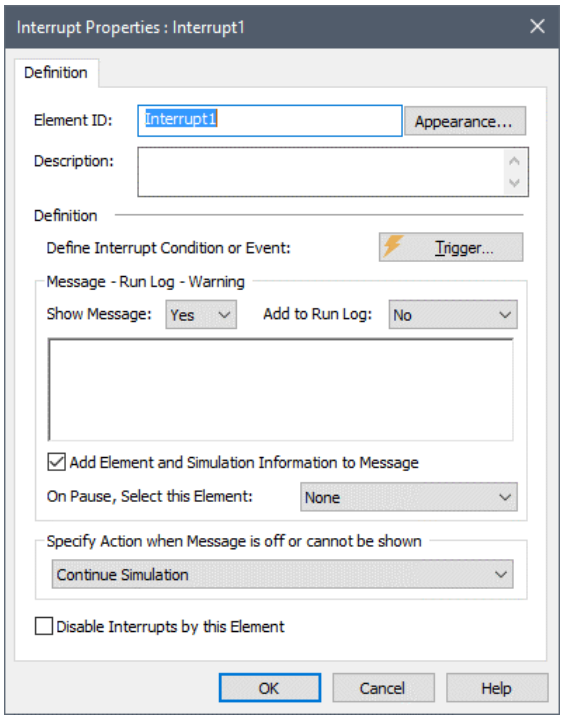
The Interrupt element is triggered by an event, and responds by interrupting the simulation. The triggering event can be a discrete event signal or another type of event (e.g., a condition, such as X becoming greater than Y).

When the simulation is interrupted, you can display a user-defined message dialog with options for continuing or pausing (and subsequently aborting) the simulation and/or you can specify that the message is written to the run log. You also specify how to treat the interrupted realization if the simulation is resumed (e.g., continue realization, or keep current realization results and move to the next).

The Interrupt element has a number of potential uses:

- **To alert you to error conditions that indicate a logical problem in a model**. For example, if a certain variable should not go below 0 (if it does, it indicates a logic error in the model), you could use an Interrupt element to check for this condition. This could be used, for example, to test for material balance in a model that was simulating movement of material (e.g., water).
- **To help you debug a model that is crashing or showing unusual behavior**. For example, if a model crashes (or starts behaving unusually) when certain conditions are met or at a particular time in a simulation, you could use an Interrupt element to pause the simulation at that point so that you can browse the model and/or save the results up to that point in time.
- **To terminate (skip to the end) of a simulation when a certain set of conditions are met**. For example, if you were carrying out a Monte Carlo simulation of a project, the project may actually complete at a different time each realization. When the project completes, you could use an Interrupt element to skip to the end of the realization.
- **To display status information to a user**. In some cases, you may simply want to display status information to a user who is running GoldSim interactively (e.g., using the GoldSim Player). The message could, for example, prompt the user to pause the model, adjust some of the input parameters in a Dashboard, and then continue the simulation.

The dialog for an Interrupt element looks like this:



The sections below describe the use of the Interrupt element in detail.

The example file Interrupt.gsm in the General Examples/Events folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) includes a simple example on the use of Interrupt elements.

Specifying When the Simulation is to be Interrupted

The key inputs to an Interrupt element are the interrupt triggers: the events and/or conditions that cause the simulation to be interrupted.

These are defined via the **Trigger…** button, which provides access to a standard Trigger dialog

Read more: Understanding Event Triggering (page 369).

The simulation will be interrupted whenever the trigger event occurs. Like all triggers in GoldSim, the Interrupt trigger can consist of multiple events and conditions.

In some cases, you may want to disable (turn off) an Interrupt element. When an Interrupt is disabled, it does not interrupt the simulation. You can disable the element by checking the box labeled **Disable Interrupts by this Element** at the bottom of the page.

When you do so, you will notice that the symbol for the element in the graphics pane (and browser) changes (to indicate that it is currently disabled):

Interrupt Enabled

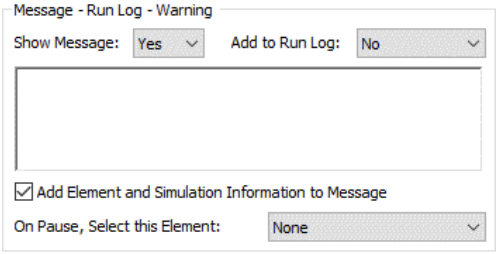
Interrupt Disabled

Note: During a simulation, whenever a simulation is interrupted, you also have the opportunity to disable the Interrupt (i.e., ignore any Interrupts) for the remainder of the simulation.

Read more: Controlling the Message Dialog for an Interrupt (page 425).

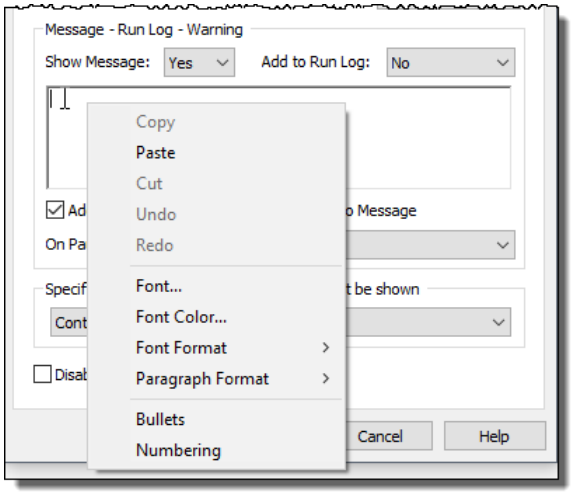
Controlling the Message Dialog for an Interrupt

The middle part of the Interrupt element is used to control the message dialog and the run log when a simulation is interrupted:



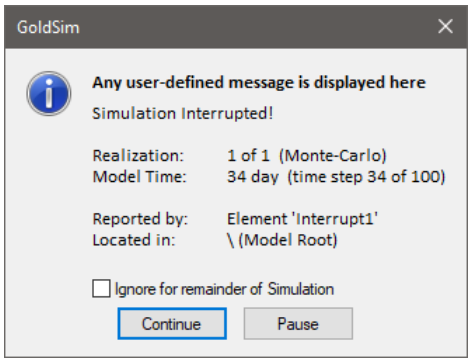
When defining an Interrupt, you can specify whether or not a message is displayed by selecting whether to **Show Message**. The default is Yes.

If you choose to show a message, you enter the message in the large input field directly below the **Show Message** field. The message field accepts formatted text (in Rich Text Format). Hence, you can cut and paste formatted text from another application into this box. You can also use the context menu for the input field to add formatting:



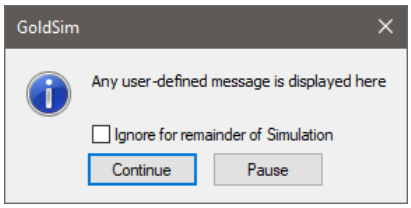
You can also specify whether or not additional information is included in the message dialog when the simulation is interrupted via the **Add Element and Simulation Information to Message** checkbox.

If this box is checked (the default), the message will look like this:



In addition to displaying the user-defined message, basic information about the simulation and element that caused the interruption is reported.

If the **Add Element and Simulation Information to Message** checkbox is cleared, the message will look like this:



Note: If you have added special formatting to the message, this will be ignored if the **Add Element and Simulation Information to Message** box is checked. That is, the formatting only appears in the message box if the extra simulation information is *not* written to the dialog.

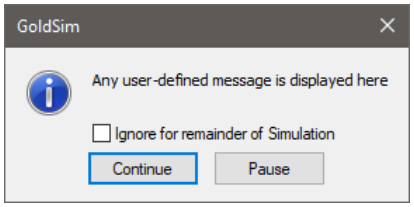
Whenever a message dialog is displayed, you have the choice to **Ignore for remainder of simulation**. If you check this box and then continue (by either pressing the **Continue** button, or by pressing the **Pause** button and subsequently resuming the simulation using the Run Control toolbar), the Interrupt element that triggered the message will be ignored for the remainder of the simulation.

Note: If the message is also written to the run log, and is specified to be written as a Warning, the message dialog box displays a Warning symbol in the upper left-hand corner. Otherwise, it displays an Information symbol.

Read more: Writing the Interrupt Message to the Run Log (page 428).

Continuing, Pausing and Aborting a Simulation After an Interrupt

When a simulation is interrupted and a message dialog is displayed, two buttons are provided on the dialog: **Continue** and **Pause**:



Pressing the **Continue** button simply closes the dialog and continues the simulation. The simulation continues to the end (or until the next Interrupt occurs).

Note: If you check the **Ignore for remainder of simulation** box and then press the **Continue** button, the Interrupt element that triggered the message will be ignored (disabled) for the remainder of the simulation.

Pressing the **Pause** button closes the dialog and pauses the simulation. When a simulation is paused, this will be indicated in the status bar at the bottom of the GoldSim window:

The Run Control toolbar can then be used to control the simulation:

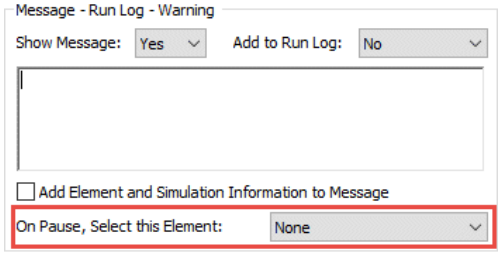
The options (from left to right) consist of aborting the simulation, resuming the simulation (which is equivalent to pressing the **Continue** button in the Interrupt message dialog), stepping one timestep at a time, or stepping one realization at a time.

Read more: Pausing and Stepping through a Simulation (page 522).

Once a model is paused, you can browse it and explore results in largely the same manner you would if you were in Result Mode.

While a model is paused, you may decide you want to ignore future interrupts before resuming the simulation. You can do this by navigating to the Interrupt element, right-clicking on it, and selecting **Ignore Interrupts** from the context menu before resuming the simulation.

You can control what part of the model is displayed in the graphics pane when you press the **Pause** button in the message dialog using the **On Pause, Select this Element** field in the Interrupt properties dialog:



The drop list contains two options: "None" (the default), and "This Interrupt Element". If "None" is selected, when you press the Pause button in a message dialog, the model view does not change from the view when the simulation was started. If "This Interrupt Element" is selected, when you press the Pause button in a message dialog, GoldSim displays the Container in which the Interrupt element resides.

If you choose to Abort the simulation, GoldSim will give you a choice of keeping results or discarding results (and returning to Edit Mode). If you are running multiple realizations and have paused after the first realization, a checkbox will be provided to give you the option of excluding the current (partially complete) realization, or including it. If you choose to include it, GoldSim will skip to the end of the realization (i.e., skip all further calculations for the realization, keeping the values of all elements constant at their last computed value).

Note: If you have aborted in the *first* realization and choose to save results, GoldSim will automatically skip to the end of the realization (i.e., skip all further calculations for the realization, keeping the values of all elements constant at their last computed value).

Read more: Aborting a Simulation (page 523).

Warning: When a simulation is interrupted, in almost all cases it will be interrupted in the middle of an update. That is, GoldSim elements are, by necessity, computed in a specific order (referred to as the causality sequence). When an Interrupt is triggered, it will be done in the middle of this sequence. That means that some of the elements will have been updated for the current timestep, and others will not have been updated yet. Hence, it may be necessary to view the causality sequence when browsing a model to fully understand the current values that are displayed.

Read more: The Causality Sequence and Element Updating (page 358).

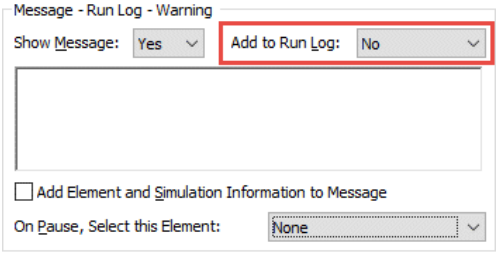
Warning: If you abort a simulation and include the results from the last (partially complete) realization, you should be careful with how you interpret the results. In particular, because the last realization was not complete, it may be inappropriate to combine it with or compare it to other (full) realizations.

Writing the Interrupt Message to the Run Log

In some cases, in addition to (or instead of) displaying a message when an interrupt occurs, you may want to also write a message to the run log.

Read more: The Run Log (page 569).

This is controlled by the **Add to Run Log** field in the Interrupt property dialog:



The drop list contains three options:

- "No". This is the default. The message is not written to the run log.
- "As Message". The message is written to the run log.
- "As Warning". The message is written to the run log as a Warning. As a result, a dialog is displayed at the end of the simulation indicating that the simulation triggered a warning.

Note: If you choose to both display a message and write to the run log, the **Add to Run Log** field has a small impact on the message dialog displayed when a simulation is interrupted. In particular, if the message is written to the run log as a warning, the message dialog box displays a Warning symbol in the upper left-hand corner of the message dialog. Otherwise, it displays an Information symbol.

Processing an Interrupt When the Message is Off or Cannot be Displayed

In some cases, you may choose not to show a message when an Interrupt is triggered. As discussed below, this is useful, for example, if you are using the Interrupt to terminate a realization and skip to the end when a certain condition occurs (e.g., a project completes). In other cases, it may not be possible to display the message (e.g., when simulating scenarios, or when carrying out a distributed processing simulation, a sensitivity analysis, or an optimization).

You must specify how you want GoldSim to handle the Interrupt when the message is turned off or cannot be displayed. This is done via the **Specify Action When Message is off or cannot be shown** field at the bottom of the Interrupt property dialog.

The drop list contains five options:

- "Continue Simulation". This is the default. The simulation continues.
- "Skip remainder of current Realization and Continue". GoldSim skips to the end of the realization (i.e., it skips all further calculations for the realization, keeping the values of all elements constant at their last compute value), and continues on to the next realization.

Note: This option is what you should select if you are using the Interrupt to terminate a realization and skip to the end when a certain condition occurs (e.g., a project completes).

- "Skip remainder of current Realization and Abort". GoldSim skips to the end of the realization (i.e., it skips all further calculations for the realization, keeping the values of all elements constant at their last compute value), and then aborts (keeping results for all realizations up to that point, including the partially completed realization).
- "Discard current Realization and Abort". GoldSim discards the current (partially completed) realization, and then aborts (keeping results for all realizations up to that point, excluding the partially completed realization).
- "Abort and Return to Edit Mode". The simulation is aborted and the model is returned to Edit Mode.

Warning: When running distributed processing, scenarios, sensitivity analysis or an optimization, Interrupt messages are never displayed. Moreover, unless the **Specify Action When Message is off or cannot be shown** field is set to "Continue" or "Skip remainder of current Realization and Continue", the Interrupt will result in a fatal error.

Note: Even if the message is turned off (or cannot be displayed), you can still specify that the message is to be added to the run log. Note, however, that a run log is not produced for sensitivity analyses and optimizations.

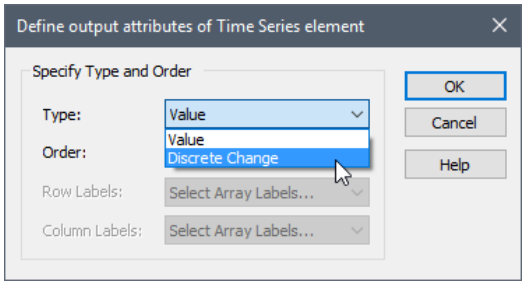
Read more: Writing the Interrupt Message to the Run Log (page 428).

Generating Discrete Changes Using Time Series Elements

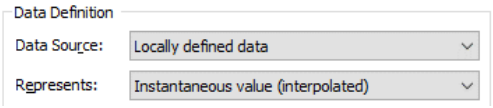
Time Series elements can be used to generate a series of discrete changes.

Read more: Using Time Series Elements (page 192).

In order to do so, you must specify that the data that you are entering represent a series of discrete changes. To change the data type, press the **Type…** button from the Time Series dialog, and the following dialog will be displayed:

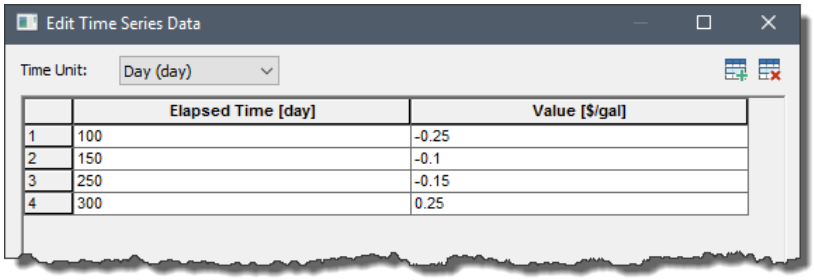


Select "Discrete Change" as the Type. After doing so and closing the dialog, the main dialog for the Time Series will indicate that the Time Series now **Represents** a "Discrete Change (Instantaneous)":



Under these circumstances, the output produced by the Time Series element is actually a discrete change signal. You specify the value for each signal, as well as the time that the signal is to be emitted.

For example, assume that the data series for a Time Series was defined as follows:



In this case, four discrete change signals would be emitted by the element. Discrete change signals emitted by a Time Series element always carry an "Add" instruction.

Time Series elements that generate discrete change signals have the ability to influence when a model is updated. Typically, a model is updated at every "scheduled" timestep. That is, all the elements are computed at every timestep. However, a Time Series element can force a model to be updated between "scheduled" timesteps. For example, suppose that you have specified a 10 day timestep. If a Time Series element has a discrete change that was specified to occur at, say 23 days, GoldSim would insert an update (an unscheduled update) between timesteps (i.e., at 23 days) in order to more accurately represent the event.

Read more: Understanding Timestepping in GoldSim (page 473).

Warning: Time Series elements are designed to interrupt the clock and insert a new update when the discrete change is released. If you choose to disable unscheduled updates, a discrete change that falls between scheduled updates will be deferred to the next scheduled update. If multiple discrete changes occur between scheduled updates, they will be summed and released at he next scheduled update.

Read more: Controlling Unscheduled Updates (page 489).

The example model BasicTimeSeries.gsm in the General Examples/TimeSeries folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains an example of the use of Time Series elements to generate discrete change signals.

How GoldSim Inserts Events into a Simulation

When a discrete event is generated in GoldSim by certain types of elements (e.g., a Timed Event, an Event Delay, or a Discrete Change Delay), the events may not fall exactly on a "scheduled" timestep (i.e., a timestep that was defined in the **Time** tab of the Simulation Settings dialog). That is, the events may actually occur between scheduled timesteps.

These events trigger an "unscheduled update" of the model. Unscheduled updates are timesteps that are dynamically inserted by GoldSim during the simulation in order to more accurately simulate the system. That is, they are not specified directly prior to running the model. GoldSim inserts them automatically (and, generally, without you needing to be aware of it).

For example, if you had specified a one day timestep, and a Timed Event occurs at 33.65 days (i.e., between the scheduled one-day updates), GoldSim would insert an unscheduled update at 33.65 days.

Read more: Understanding Timestepping in GoldSim (page 473).

By default, scheduled updates are always dynamically inserted by GoldSim. However, in some (rare) cases, you may want to prevent unscheduled updates from being inserted. For example, if your model included a specialized algorithm that was designed based on the assumption that the timestep was constant, inserting unscheduled updates could invalidate the algorithm. To support such situations, GoldSim allows you to disable unscheduled updates.

Warning: Because unscheduled updates are intended to more accurately represent a complex dynamic system, disabling this feature should be done with caution, and is generally not recommended.

Read more: Controlling Unscheduled Updates (page 489).

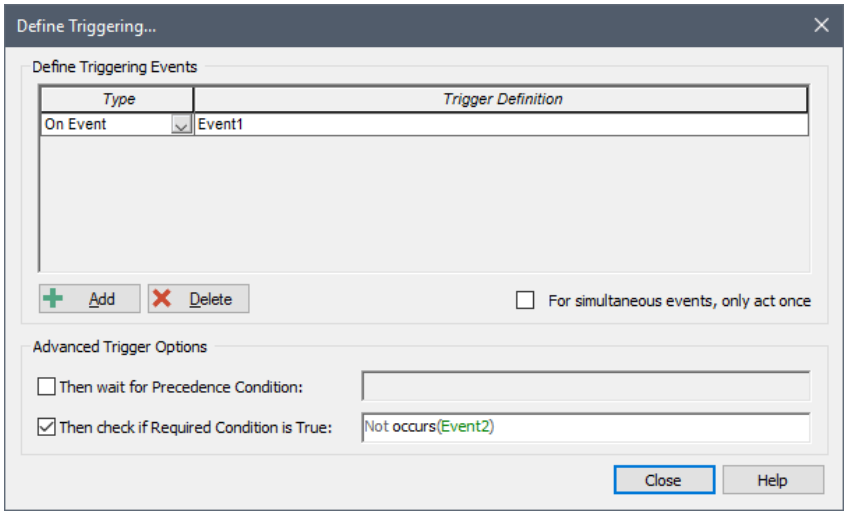
Determining if an Event Has Occurred

GoldSim provides a special function that can be useful in discrete event modeling: the "Occurs" function. The Occurs function accepts a single argument which must be a discrete event signal.

The Occurs function returns a condition (True or False). If the argument (the discrete event signal) has occurred during the current update, the value is True, otherwise it is False.

This can be useful in situations where you need to reference whether or not two events have occurred simultaneously. For example, suppose that there are two events in your simulation (Event1 and Event2), and you want to trigger a response if and only if Event1 occurs and Event2 does not (i.e., you do not want to trigger the response if both events occur simultaneously). A good way to do this is to use the Occurs function in the Required Condition field for each element.

The Trigger dialog that captures this behavior would look like this:



Note: If you try to plot an Expression defined using the occurs operator, the Expression will always show False (unless the event occurs exactly at a scheduled update point), since by default, GoldSim only records results at the scheduled plot points, and not at the unscheduled timesteps inserted by events (which are the only points at which the Expression would be evaluate to True). Note, however, that GoldSim provides an option to include unscheduled updates in time history displays (under a specified set of conditions) in the Advanced Time settings..

Read more: Understanding Timestepping in GoldSim (page 473); Including Unscheduled Updates in Time History Results (page 496).

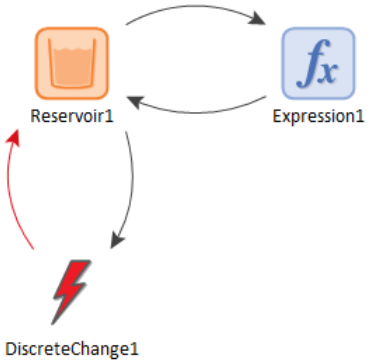
Controlling the Calculation Sequence of Events

When you build a model, GoldSim automatically *sequences* the elements in the order that they must be computed. For example if A was a function of B, and B was a function of C, C would be sequenced first, followed by B, followed by A. This is referred to as the causality sequence. In this simple example, the sequence is obvious, but for complex models with looping logic the causality sequence may not be readily apparent.

In most cases, you do not need to be concerned with how GoldSim sequences the elements. However, in some cases (particularly when simulating systems that include discrete changes and looping logic), expert users may need to understand or manipulate the causality sequence. (The causality sequence can be viewed by selecting **Model|Causality Sequence** from the main menu.)

Read more: The Causality Sequence and Element Updating (page 358).

Problems arise when simulating looping systems and/or systems with discrete changes because in these cases the appropriate order of the calculations can be ambiguous. A simple example is shown below:



For this model, in what order should the elements be calculated?

For these situations, GoldSim provides some special tools to force the sequencing to occur in a particular order.

Read more: Addressing Ambiguous Causality Sequences (page 1045).

Chapter 6: Customizing the Interface

As You Like It.

William Shakespeare

Chapter Overview

GoldSim allows you to customize the user interface in a variety of ways in order to best match the way that you use the program. For example, you can modify and create custom toolbars, change the appearance of the graphics pane, and modify the appearance of elements and links. You can also create your own custom units. This chapter describes how you can control and customize these user interface components.

In this Chapter

The following topics are discussed in this chapter:

- Customizing Toolbars
- Using and Managing the Color Palette
- Customizing the Appearance of the Graphics Pane
- Editing the Appearance of Elements
- Viewing and Creating Units

Customizing Toolbars

GoldSim has a number of toolbars that you can use to carry out common functions. The available toolbars are as follows:

- **Standard toolbar**: provides buttons for common actions (e.g., save a file, search, copy, paste, access simulation settings, access Help).

- **Run Control toolbar**: provides buttons for running your model.

- **Element toolbar**: provides buttons for adding elements to your model.

- **Advanced toolbar**: provides buttons for carrying out advanced options (e.g., distributed processing, running scenarios, running sensitivity analyses).

- **Drawing Tools toolbar**: provides buttons for adding graphical objects to your models.

- **Graphical Tools toolbar**: provides buttons for grouping, aligning, rotating, spacing, resizing and layering objects.

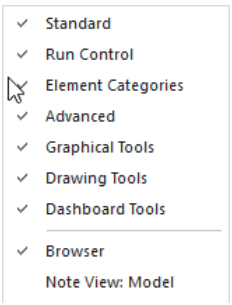
- **Dashboard Tools toolbar**: provides buttons for adding Dashboard controls.

You can turn these toolbars off and on, edit existing toolbars, create new (custom) toolbars, and move them around the screen.

Activating and Deactivating Toolbars

When you open GoldSim for the first time, all the toolbars are visible. Most of the toolbars are originally docked at the top of the screen, and two of the toolbars (Drawing Tools and Dashboard Tools) are originally docked (vertically) to the right of the graphics pane.

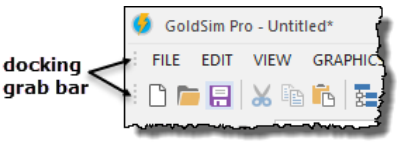
All toolbars can be hidden (deactivated). To activate or deactivate a toolbar, right-click anywhere within a toolbar (or the main menu). The following context menu is displayed:



Activated toolbars have a check mark next to them. To activate or deactivate one of the toolbars, click on it.

Moving and Docking Toolbars and the Menu Bar

The toolbars (and any menu bars) are originally docked. You can undock them and move them to another location on the screen (e.g., the bottom, or to the right of the graphics pane) by grabbing the **docking grab bar** at the left (or top) of the toolbar/menu bar and dragging it to the desired location:



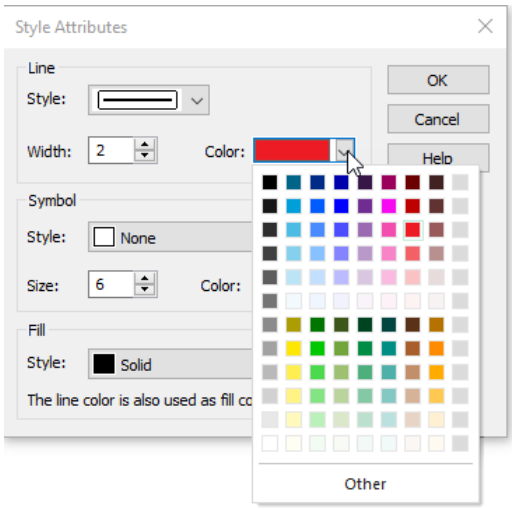
If you drag it to the edge of the window it will dock itself at that edge (otherwise, it will float). Note, however, that you cannot dock a toolbar on the left side if the window. That is, you can only dock at the top, the the right, and at the bottom (above the status bar).

You can also undock a toolbar or menu bar (and turn it into a floating window) by double-clicking on the docking grab bar.

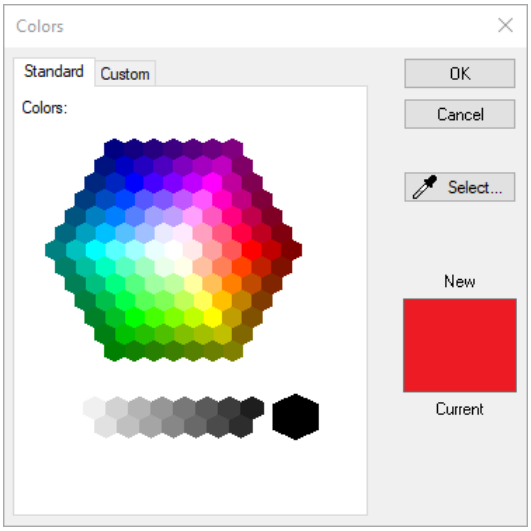
Using and Managing the Color Palette

There are numerous places in the GoldSim user interface where you can specify colors for different objects (e.g., backgrounds, text, chart lines). GoldSim selects default colors for all items, so it is not necessary for you to edit these. However, in many cases, you may want to, so GoldSim provides a number of tools for selecting and customizing the colors you use in your model. This includes saving custom colors to your registry so they can be used for all of your models, as well as exporting your custom colors so the same color scheme can be shared and used on other computers.

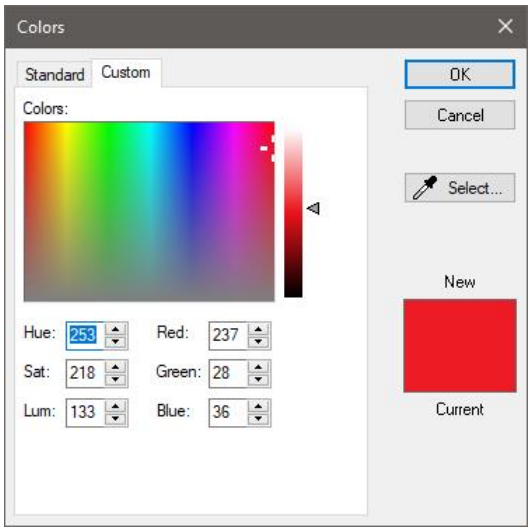
Any object that has a color that you can customize will have a dialog option (a drop-box) labeled **Color** (or some more specific description, such as **Background Color**). Selecting this drop-box will display a dialog of colors from which you can select:



This list represents a palette that is commonly used in modern displays. If you wish to select a color that is not provided in the list, you can define a custom color by selecting **Other**. This will display the following dialog:



You can pick a custom color by selecting a color in the hexagon and pressing **OK**. Alternatively, you can select the **Custom** tab on this dialog, which will display the following:



In this dialog, you can move to vertical slider on the right, select a specific color directly in the display, or manually select the **Red/Green/Blue** and/or **Hue/Sat/Lum**.

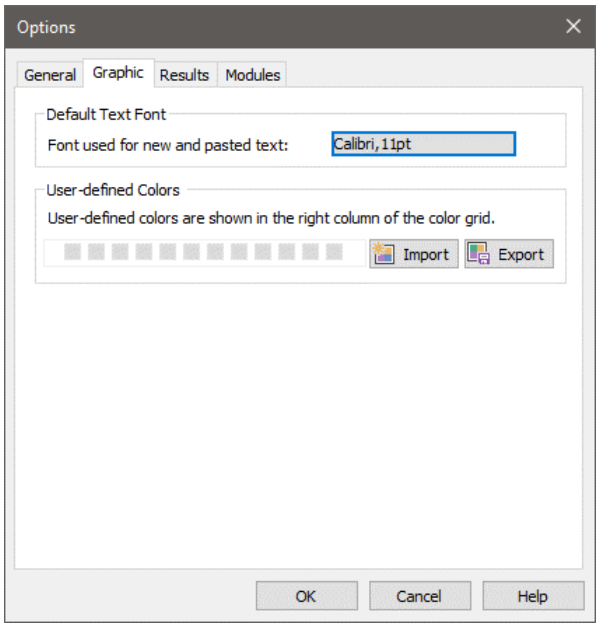
In both tabs of the dialog, you can also press the **Select…** button (the "eye-dropper") in order to select any color from outside of the GoldSim application (i.e., anywhere on your screen).

Although the steps outlined above allow you to define and apply a custom color to an object in GoldSim, doing so in this way does not save the color to the palette. That is, if you wanted to use the same custom color elsewhere, you would need to go through the same process outlined above. To assist you in reusing custom colors that you define (both within the current model as well as in other models) GoldSim provides a mechanism for you to save, export and import your custom colors. This is discussed in detail below.

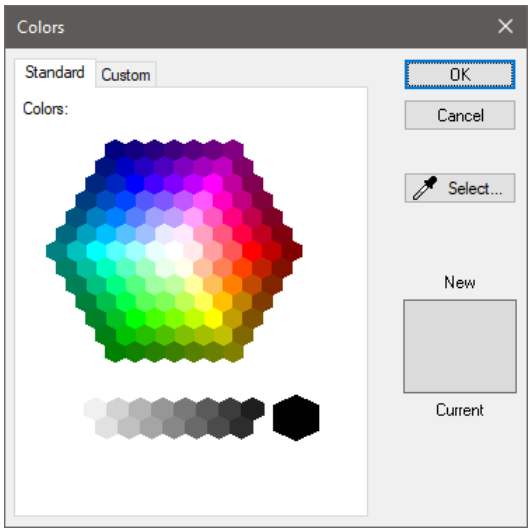
Saving, Exporting and Importing Custom Colors

There are numerous places in the GoldSim user interface where you can specify colors for different objects (e.g., backgrounds, text, chart lines). Within those dialogs, GoldSim allows you to select and customize those colors. However, once you do so, the custom color you selected is saved for that object, but is not available for use elsewhere. That is, if you wanted to use the same custom color for another object, you would need to go through the process to recreate that color. To assist you in reusing custom colors that you define (both within the current model as well as in other models) GoldSim provides a mechanism for you to save, export and import your custom colors.

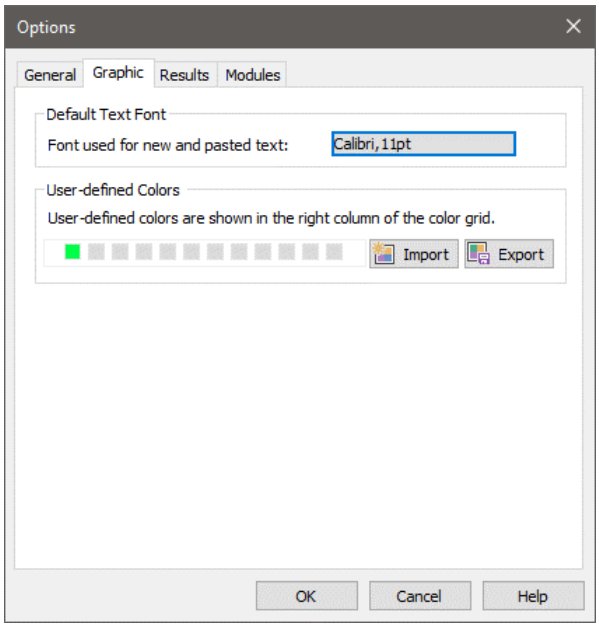
You can do so by creating and saving your custom colors via the Options dialog. In particular, you can do so by selecting **Model|Options…** from the main menu and selecting the the **Graphic** tab:



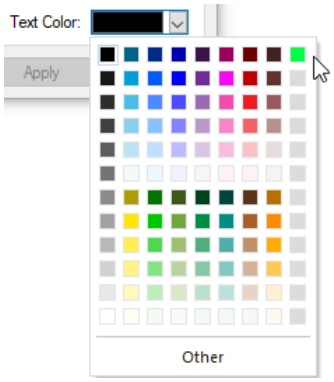
You can add a custom color by clicking on one of the empty (gray) color blocks in the **User-defined Colors** section. This will bring up a standard dialog (described in the previous section) for defining a custom color:



Once you define a custom color, you will notice that it appears as one of the color blocks:



More importantly, it also appears in any location in the interface where you can select a color:



Custom colors are displayed in the far-right column of the color selection dialog.

Note that the custom colors are saved to your registry. As a result, they are available to any other model you edit on your computer.

In addition, you can export your custom colors so that they can be imported for use on another computer. To export your custom colors, press the **Export** button in the **Graphic** tab of the Options dialog. You will be prompted for a file name (it will be saved as an .XML file). After transferring the .XML file to another computer, you can import the colors by pressing the **Import** button in the **Graphic** tab of the Options dialog.

Customizing the Appearance of the Graphics Pane

GoldSim provides a number of options for customizing the graphics pane:

- You can add a background color to each Container;
- You can add a grid to each Container;

- You can adjust the size of the graphics pane in each Container;
- You can edit the appearance (e.g., shape, color) of influences in the Container; and
- You can filter (hide) influences of certain types.

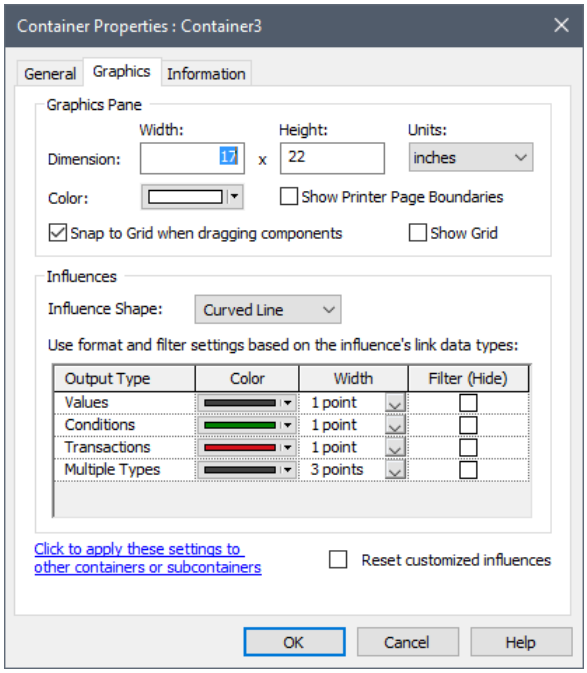
In addition, you can copy the graphical settings (e.g., background color, influence shape) for one Container to other Containers in your model.

These options are described in detail in the sections below.

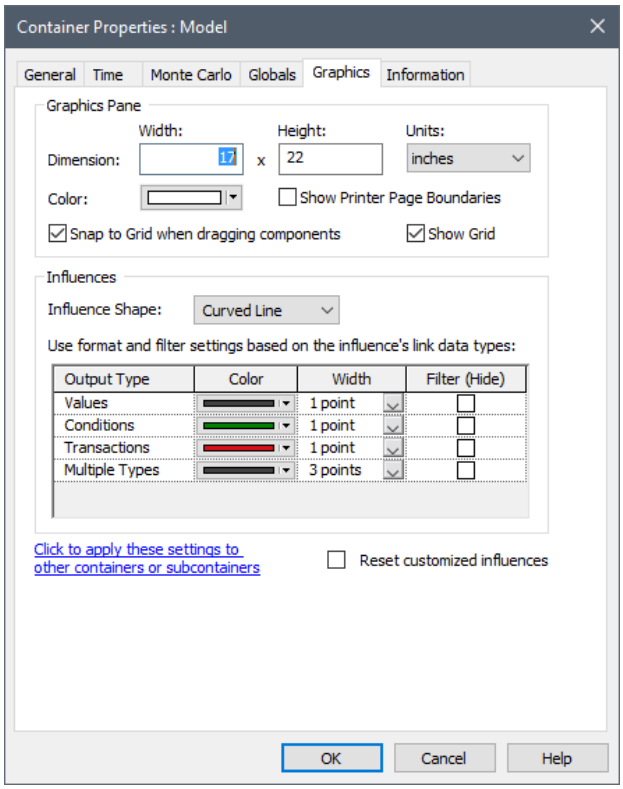
The Graphics Pane Grid and Background

The Container dialog can be accessed by right-clicking anywhere in the graphics pane and selecting **Properties…** from the context menu, by right-clicking on a Container and selecting **Properties**, or by double-clicking on a Container.

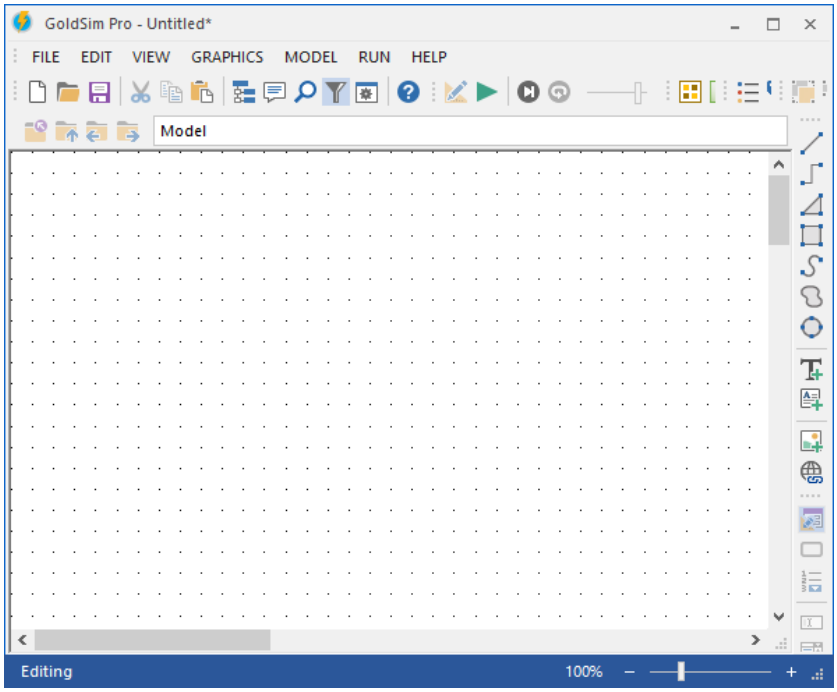
The **Graphics** tab of the Container dialog provides access to options for controlling the appearance of the graphics pane for the Container, including viewing a grid and adding a background color:



Note that right-clicking anywhere in the graphics pane and selecting **Properties…** from the context menu at the highest level of the model (the main Container) displays the properties for this highest level Container (referred to as the Model Container). When you do this, you will also see additional tabs for the various simulation settings for the model:



Checking the **Show Grid** checkbox for a Container (which is cleared by default) adds a grid to the graphics pane:



The grid spacing is fixed (it is a function of the size of the graphics pane) and cannot be modified.

Checking **Snap to Grid when dragging components** (which is checked by default) causes the center of objects (elements and graphic objects) to snap to the grid when they are moved in the graphics pane.

The **Color** drop-list provides a list of colors that can be applied to the background for the Container's graphics pane.

Read more: Using and Managing the Color Palette (page 437).

Note: When you insert a new Container into a model, it inherits the properties (e.g., grid setting and background color) of its parent Container. However, this inheritance is only applied when the new Container is created, and the properties of the new Container are not linked to the properties of the parent (e.g., if you subsequently change the parent's background color, it will not change the background color of any existing child).

Adjusting the Size of the Graphics Pane

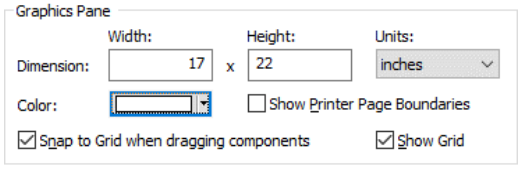
If you scroll far enough horizontally or vertically within the graphics pane you will eventually reach the "edge" of the graphics pane. That is, the graphics pane represents a document of fixed size.

By default the graphics pane has a width of 17 inches and a length of 22 inches (i.e., for any Container, if you view the graphics pane at a 100% scale, it will appear to be 17 inches wide and 22 inches long, although you will have to scroll to view the entire document).

If you would like to change the size of the graphics pane, you can do so from the **Graphics** tab of the Container dialog.

Note: The Container dialog can be accessed by right-clicking anywhere in the graphics pane and selecting **Properties…** from the context menu, by right-clicking on a Container and selecting **Properties**, or by double-clicking on a Container.

At the top of this tab are several options related to adjusting the size of the graphics pane:



The **Width** and **Height** fields can be used to change the size of the graphics pane. These dimensions can be specified in inches, centimeters or millimeters (as defined in the **Units** field). If **Show Printer Page Boundaries** is checked, the boundaries of the printed pages in the graphics pane (as determined by your printer settings) will also be shown in the graphics pane.

Note: When you insert a new Container into a model, it inherits the properties (e.g., size of graphics pane) of its parent Container. However, this inheritance is only applied when the new Container is created, and the properties of the new Container are not linked to the properties of the parent (e.g., if you subsequently change the graphics pane size in the parent, it will not change the graphics pane size in any existing child).

Saving the Graphics Pane's Position and Scale

Whenever you leave one Container in the graphics pane and enter (i.e., view the contents of) another, GoldSim remembers the position and scale for the previous Container, and this information is written to the file when you save it. Hence, when you (or someone else to whom you have given the file) enter a Container, it is automatically displayed at the same position and scale that it was last viewed.

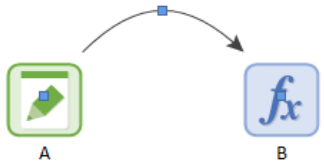
Editing the Appearance of Influences

GoldSim allows you change a number of the graphical properties of an influence. You can change its shape, thickness and color, and add text to the influence. In addition to editing each influence separately, you can also modify the appearance of all influences in a Container from the Container dialog.

The details of how you can edit the appearance of influences is described in the sections below.

Changing the Shape, Thickness and Color of an Influence

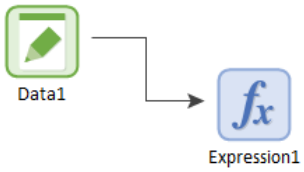
By default, all links are initially drawn as curves (but are drawn with no curvature). You can add curvature to the link by selecting it and dragging the control point with your cursor:



You can further modify the appearance of influences by changing their color and thickness, and changing their shape (straight lines or orthogonal lines). You can do so by right-clicking on an influences, which will cause the following menu to be displayed:

The **Shape** selection provides three options: **Straight**, **Orthogonal** and **Curved**.

Orthogonal influences consist only of vertical and horizontal lines:



The **Color** selection allows you to choose from a variety of colors. The **Width** selection allows you to choose from 1 point (the default) to 6 points.

Note: You can globally modify the appearance of all influences in a Container (or your entire model) based on the type of link they represent (e.g., values or conditions). This includes changing the default for all new influences that are drawn.

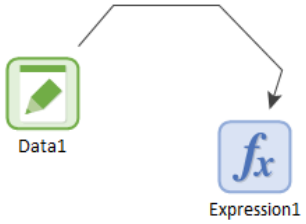
Read more: Controlling the Appearance of All Influences in a Container (page 447).

Creating a Segmented Influence by Adding Nodes

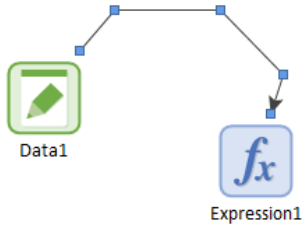
The shape of an influence can be set to either **Straight**, **Orthogonal** or **Curved**.

Read more: Changing the Shape, Thickness and Color of an Influence (page 445).

If the shape of an influence is defined as **Straight**, GoldSim allows you to add nodes to the influence, such that it is turned into a segmented line:



You add a node to an influence by clicking on it while holding the **Ctrl** key. You can add as many nodes as desired. When you select the influence, the nodes will be shown:



To delete a node, click on it while holding the **Ctrl** key.

Once a node has been added, you can move a node by dragging. You can also move the entire influence by grabbing within a segment and dragging.

Note: If you change the shape of an influence to **Orthogonal** or **Curve**, all nodes are immediately deleted.

Note: If **Snap to Grid when dragging components** is selected for the graphics pane, the segment or node will snap to the grid as you drag it.

Read more: The Graphics Pane Grid and Background (page 442).

Adding Text to an Influence

You can add text to an influence by right-clicking on the influence and selecting **Add Label** from the context menu, or Shft+double-clicking on the influence (double-clicking on the influence while pressing the **Shft** key). This will add a

textbox to the influence with the word "Text" inside (which you can subsequently replace with your own text).

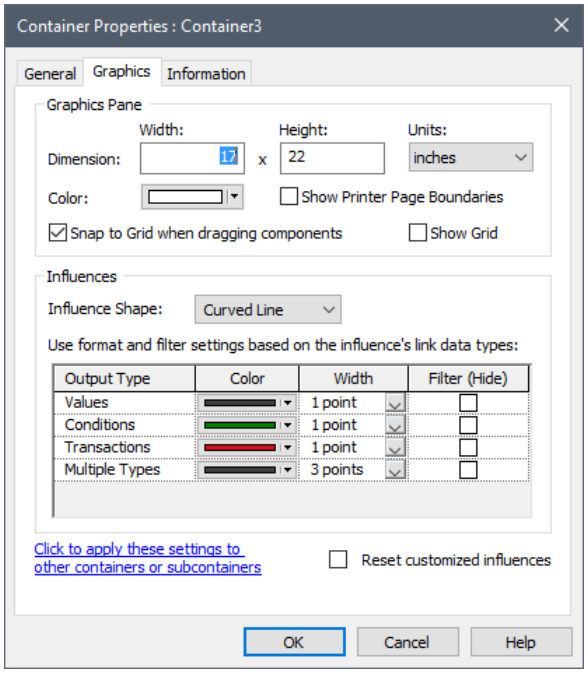
You can edit the properties of the label (e.g., font, color, outline) by right-clicking on the influence and selecting **Properties…**. This dialog is similar to that used to edit the properties of text objects in the graphics pane.

Read more: Changing the Appearance of Text Objects (page 814).

To delete the text associated with an influence, select the text box, and press the **Delete** key.

Controlling the Appearance of All Influences in a Container

The **Graphics** tab of the Container dialog provides access to options for controlling the default appearance of all influences in the Container:



Note: The Container dialog can be accessed by right-clicking anywhere in the graphics pane and selecting **Properties…** from the context menu, by right-clicking on a Container and selecting **Properties**, or by double-clicking on a Container.

The section of the dialog labeled “Influences” allows you to adjust the **Influence Shape**, **Color** and **Width** of all influences in the Container.

Read more: Using and Managing the Color Palette (page 437).

The appearance of the influences can be specified differently depending on the type of output(s) in the link(s) represented by the influence. By default, there are four types of outputs that can be represented in a link: Values (the most common type of output); Conditions (i.e., True/False); Transactions (discrete event and discrete change signals); and Multiple Types (for an influence that contains more than one type of output).

Note: Some GoldSim extension modules (e.g., the Contaminant Transport Module) may add additional output types to this list.

Warning: Although you can change the influence colors for the various types of outputs here, in most cases, you should refrain from doing so. This is because others looking at your model will be used to the visual cues provided by the default colors (e.g., dark gray for values, green for conditions, red for transactions), and changing these could make you model more difficult for others to understand.

If you change the **Influence Shape**, or the **Color** or the **Width** for an Output Type, and then press **OK**, GoldSim will modify all of the influences in the Container, with the following exceptions:

- GoldSim will not modify the appearance of influences inside any Containers within the Container being edited.
- If you have previously changed the appearance of an influence in the Container manually (by right-clicking on it) such that it is different from the default settings in the Container dialog, GoldSim will treat these as "customized influences" and will not reset them to the new defaults unless you first check the **Reset customized influences** checkbox in the dialog before pressing **OK**.

Note: When you insert a new Container into a model, it inherits the properties (e.g., Influence Shape, Colors and Widths) defined for its parent Container. However, this inheritance is only applied when the new Container is created, and the properties of the new Container are not linked to the properties of the parent (e.g., if you subsequently change the parent's Influence Shape, it will not change the Influence Shape of any existing child Container).

In addition to controlling the appearance of all the influences in a Container, GoldSim also provides the ability to copy the influence appearance settings from one Container to other Containers in your model.

Read more: Copying Container Settings to Other Containers in a Model (page 450).

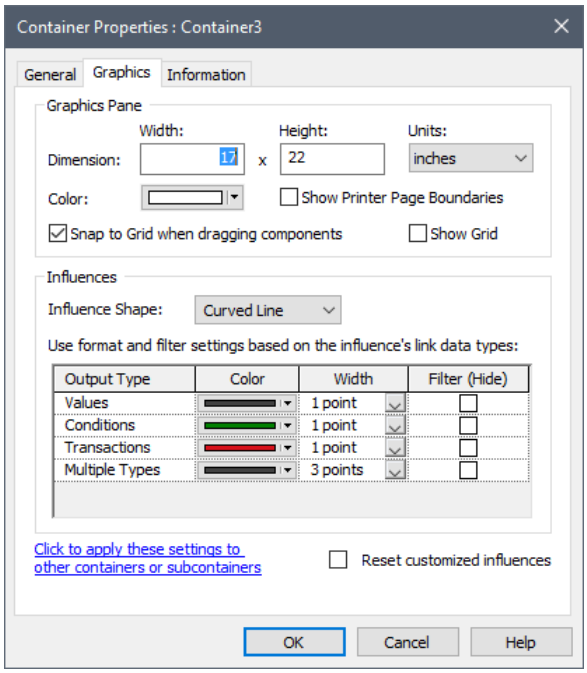
Finally, GoldSim provides you with the ability to temporarily filter (hide) influences in a Container

Read more: Filtering Influences (page 448).

Filtering Influences

In some situations, you may wish to temporarily "hide" or "filter" some types of influences in order to simplify the graphics pane. When you filter an influence, the link(s) within the influence still exist, but the influence is not shown on the graphics pane.

Influence filters are defined separately for each Container from the **Graphics** tab of the Container dialog:



Note: The Container dialog can be accessed by right-clicking anywhere in the graphics pane and selecting **Properties…** from the context menu, by right-clicking on a Container and selecting **Properties**, or by double-clicking on a Container.

The section of the dialog labeled "Influences" allows you to **Filter (Hide)** all of the influences in the Container. The filter can be specified differently depending on the type of output(s) in the link(s) represented by the influence. By default, there are four types of outputs that can be represented in a link: Values (the most common type of output); Conditions (i.e., True/False); Transactions (discrete event and discrete change signals); and Multiple Types (for an influence that contains more than one type of output).

Note: Some GoldSim extension modules (e.g., the Contaminant Transport Module) may add additional output types to this list.

For example, if the **Filter (Hide)** checkbox was checked for "Conditions", any influences in the Container that just represented Condition outputs would be hidden.

Filter button

When you press **OK** to close the dialog, the filter is applied. You can toggle the filter off (or on) by pressing **Ctrl+H**, by selecting **View|Filter** from the main menu or pressing the Filter button in the Standard toolbar. When the filter is on, the button will appear depressed.

Note: When you insert a new Container into a model, it inherits the properties (including the filter settings) defined for its parent Container. However, this inheritance is only applied when the new Container is created, and the properties of the new Container are not linked to the properties of the parent (e.g., if you subsequently change the parent's filter settings, it will not change the filter settings of any existing child Container).

In addition to defining the manner in which influences are filtered in a Container, GoldSim also provides the ability to copy the influence filter settings from one Container to other Containers in your model.

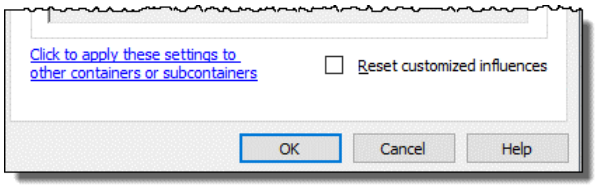
Read more: Copying Container Settings to Other Containers in a Model (page 450).

Copying Container Settings to Other Containers in a Model

When you insert a new Container into a model, it inherits the properties (e.g., background color, influence appearance) of its parent Container. However, this inheritance is only applied when the new Container is created, and the properties of the new Container are not linked to the properties of the parent (e.g., if you subsequently change the parent's background color, it will not change the background color of any existing child).

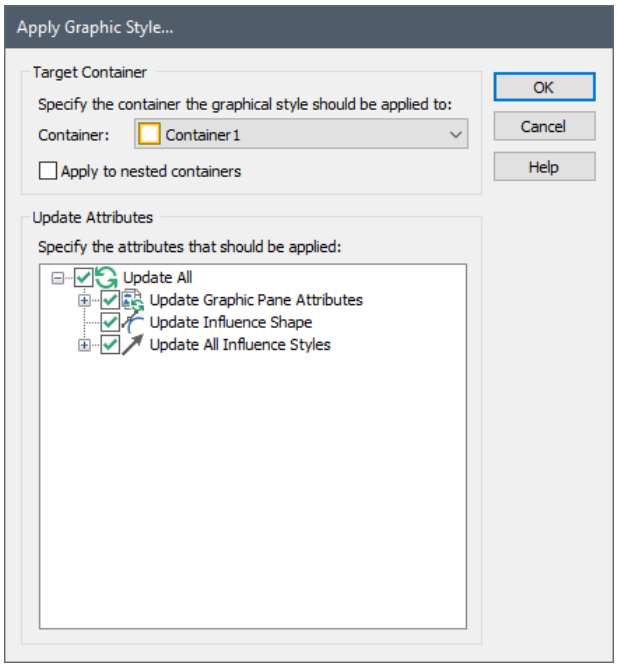
In some cases, however, you may wish to apply (copy) one or more of the graphical properties that you have defined for one Container to another existing Container in your model. GoldSim provides the ability to do this.

At the bottom of the **Graphics** tab of the Container dialog, GoldSim provides a text button allowing you to **Click to apply these settings to other containers or subcontainers**:



Note: The Container dialog can be accessed by right-clicking anywhere in the graphics pane and selecting **Properties…** from the context menu, by right-clicking on a Container and selecting **Properties**, or by double-clicking on a Container.

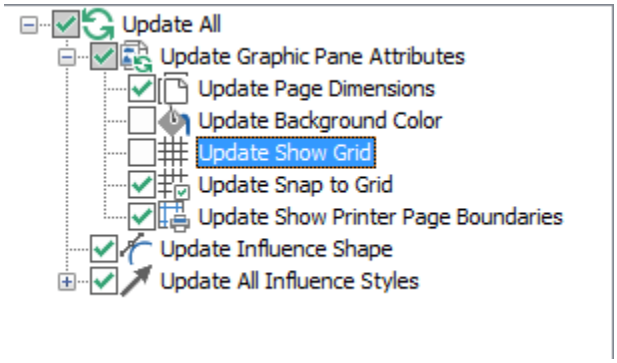
When you click on this text, the following dialog is displayed:



In the top part of the dialog, you specify the Container to which you wish to copy the graphical settings. If you click the **Apply to nested containers** checkbox, the settings will also be copied to all of the nested subcontainers within the selected Container.

Note: If you wish to copy the settings to all the Containers in your model, select the main Container (called "Model"), and check the **Apply to nested containers** button.

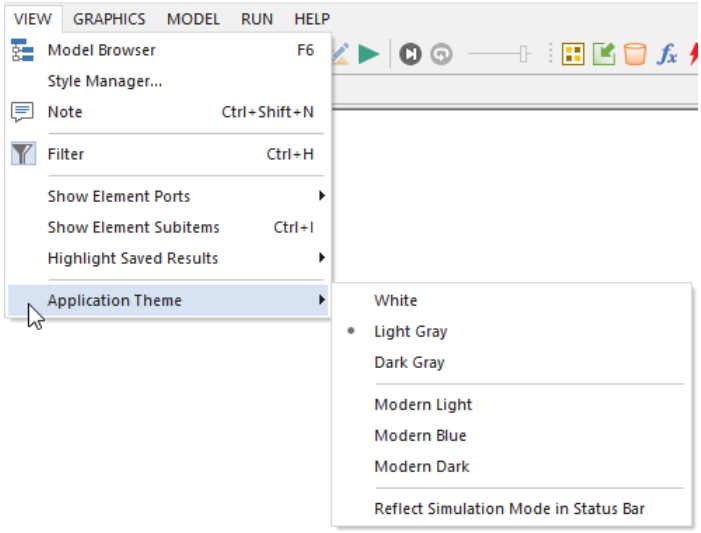
The "Update Attributes" section of the dialog allows you to select which settings you would like to apply. This is a tree that expands. If you want to apply all of the attributes at a particular level, check the box at the branch (e.g., Update Graphic Pane Attributes) and it will select all the items below it. Alternatively, you could open a branch, and clear some of the checkboxes so only certain attributes are copied:



After selecting the Container(s) to copy the attributes to, and the attributes to be copied, click the **OK** button to copy the settings.

Customizing the Application Theme

One way you can change the GoldSim user interface in a purely cosmetic way is to change the application theme. You can do this by selecting **View | Application Theme…** from the main menu:



GoldSim provides six different themes.

Themes change the color scheme of user interface items such as application windows and toolbars. You can experiment with the various themes to see if you prefer one over the others.

The final option in the menu is to "Reflect Simulation Mode in Status Bar". At any given time, a GoldSim model is in one of five simulation states (referred to as ***modes***): Edit Mode, Run Mode, Pause Mode, Result Mode and Scenario Mode. The mode that the model is in is clearly identified via text in the status bar (in the lower left-hand corner of the GoldSim window). More importantly, the status bar takes on a different color in each mode.

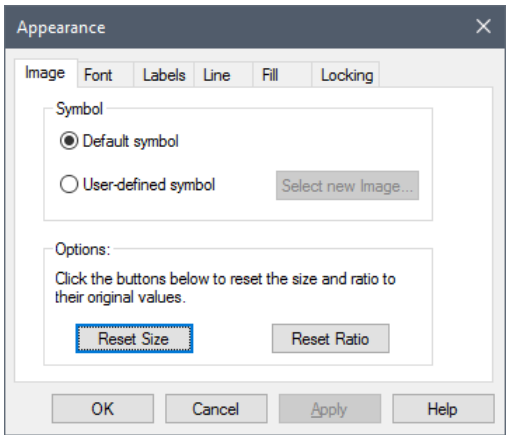
Read more: Understanding Simulation Modes (page 517).

If this option is checked (the default), the color of the status bar always reflects the simulation mode (it is not controlled by the application theme). If this option is cleared, the color of the status bar *does not* reflect the simulation mode (it is controlled by the application theme). In most cases, it is recommended that you choose the default for this option.

Editing the Appearance of Elements

You can edit the appearance of an element by clicking on the **Appearance…** button in the element's properties dialog, or selecting **Appearance…** from the context menu for the element.

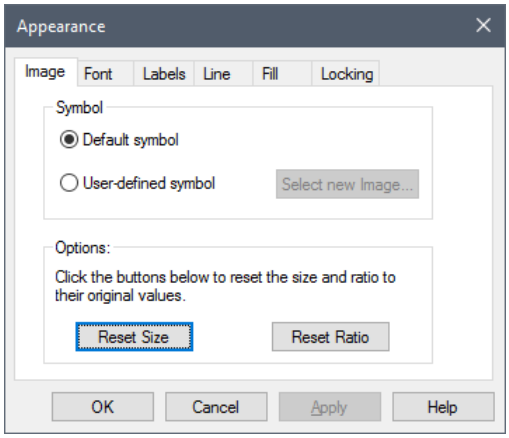
This provides access to the Appearance dialog:



The dialog is tabbed. The various tabs are discussed below.

Changing the Element's Symbol

The **Image** tab of an element's Appearance dialog (the default tab) allows you to change the image used for the element in the graphics pane:



If you select the **User-defined symbol** radio button in this tab of the dialog, you will be prompted for the name of a file to be used for the symbol.

The file must be an enhanced Windows metafile (.emf). Select a file and press **OK**. If the new image is a different size than the old image (which will typically be the case), you will be asked whether you want to adjust the size of the new image to match the size of the existing element or to adjust the size of the element to match the size of the new image.

GoldSim utilizes enhanced metafiles (emf) for element symbols because they are vector graphics (and therefore scale without losing image quality). Most advanced graphics programs can create enhanced metafiles (or convert other formats to an enhanced metafile). Note, however, that unless you create the original image using a vector format (i.e., an enhanced metafile), it will not be a true vector graphic and will lose image quality when scaling.

You can use GoldSim's graphic capabilities to convert other graphics formats to an enhanced metafile as follows:

1. Insert a graphic image (e.g., a bitmap) into the graphics pane;
2. Select the image and click **Graphics | Export…** from the main menu (or press **Ctrl+E**);
3. Specify that you wish to save the file as an enhanced metafile.

Read more: Adding Images (page 820).

Once the image for the element is defined using a user-defined symbol, you can change the symbol by pressing **Select new Image…**, or you can switch back to the default image provided by GoldSim by selecting the **Default symbol radio** button.

You can also change or reset the images for multiple elements in a model (e.g., all elements of one type) by selecting **Graphics|Change Symbols…** from the main menu.

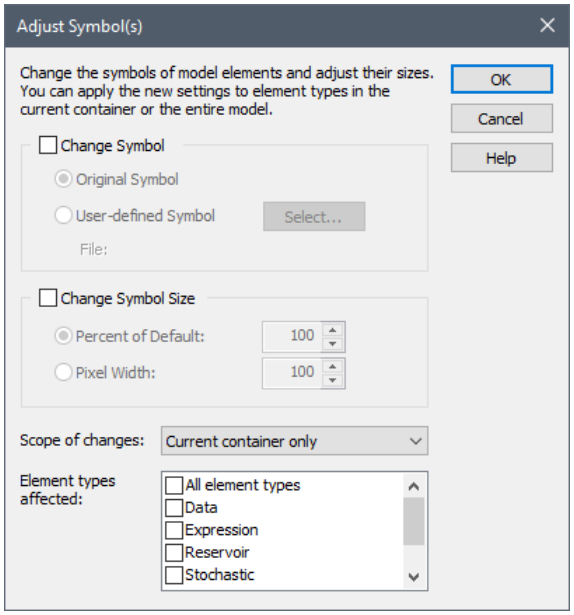
Two additional buttons are also present on the **Image** tab:

Reset Size: This resets the size of a scaled image back to its original size.

Reset Ratio: This resets the aspect ratio of a scaled image back to its original ratio (by changing the symbol's height).

Globally Resetting the Images of Multiple Elements

In some situations, you may wish to reset the images for all elements in a model (or in a particular Container) to a custom image or (if they have already been customized) back to the default symbol. You can accomplish this by selecting **Graphics|Change Symbols…** from the main menu, which will display a dialog for globally changing and resizing symbols.



Within this dialog, you first select whether you wish to **Change Symbol** and/or **Change Symbol Size** for the selected elements. When changing a symbol, you can either revert the selected elements to the original (default) symbol (assuming you have previously modified the symbols in some manner), or you can select a user-defined symbol.

If you wish to change the symbol to a user-defined symbol, the file must be an enhanced Windows metafile (.emf). GoldSim utilizes enhanced metafiles for element symbols because they are vector graphics (and therefore scale without losing image quality). Most advanced graphics programs can create enhanced metafiles (or convert other formats to an enhanced metafile). Note, however, that unless you create the original image as an enhanced metafile, it will not be a true vector graphic and will lose image quality when scaling.

When changing the symbol size, you can choose to either scale the image to a **Percent of Default** (a fraction of the element's default image size) or directly specify the **Pixel Width** (the width of the image in pixels).

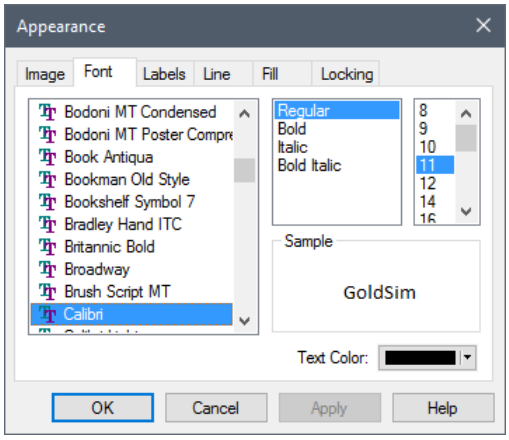
After specifying the type of change you wish to make, you must specify the scope of the changes (i.e., what elements the changes will be applied to). The **Scope of changes** drop-down list has up to four options:

- *Selected elements only*: Only the elements that have been selected (prior to opening the dialog) are modified. This option is only available if one or more elements have actually been selected.
- *Current container only*: Only the elements in the current Container (but not any elements in any child Containers) are modified.
- *Current container only + children*: Only the elements in the current Container (and any elements in child Containers) are modified. This option is only available if you are inside a Container that contains other Containers.
- *Entire model*: All elements in the model are modified.

The scope of the changes can be further refined by specifying the specific element types to which the modification will be applied. This is done by checking or clearing the boxes next to each element type in the **Element types affected** portion of the dialog.

Changing the Element's Label

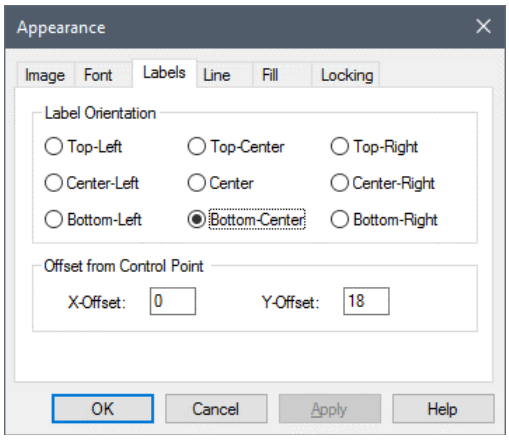
Two tabs within the Appearance dialog of an element control the appearance of the element's label. The **Font** tab controls the label's font.



In addition to controlling the font, you can also change the **Text Color**.

Read more: Using and Managing the Color Palette (page 437).

The **Labels** tab controls the position of the label relative to the symbol.

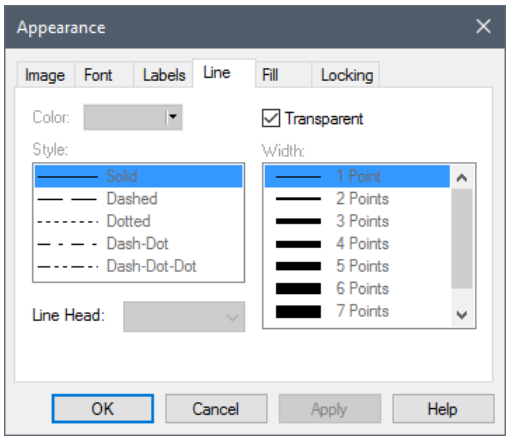


You can choose one of nine positions for the label. Note that if one of these nine positions is not sufficient, you can also manually move the label by selecting an **X-Offset** and/or a **Y-Offset** (these can be negative numbers). In addition, if **Allow Label Move** is checked in the **Locking** tab, you can select and manually move the label.

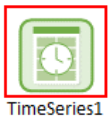
Read more: Limiting the Changes That Can Be Made to the Element's Appearance (page 457).

Changing the Element's Background and Outline

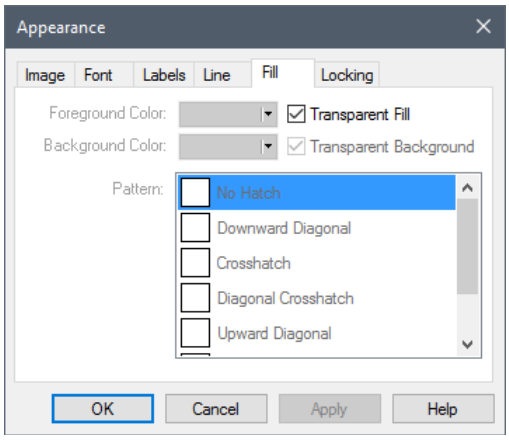
Two tabs within the Appearance dialog of an element control the appearance of the element's background and outline. The **Line** tab allows you to draw a line (a box) around the symbol and label.



By default, the line is transparent. You can, however, turn off the transparency and then edit the line's color, style (e.g., solid, dashed, etc.) and width (number of points or pixels):



The **Fill** tab allows you to change the appearance of the fill for the symbol and label.



The fill consists of a background and a foreground. The **Foreground Color** is superimposed on top of a **Background Color** according to a selected **Pattern**.

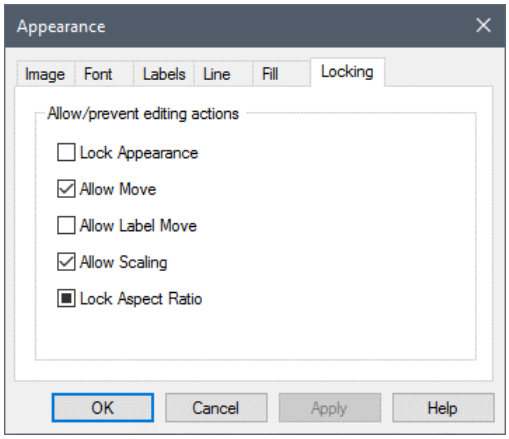
Read more: Using and Managing the Color Palette (page 437).

By default, both are transparent. By changing these, you can add a fill:

Note: The most common reason to add an outline or a fill to an element is to highlight it for a particular reason (e.g., to remind yourself that it needs to be modified, or perhaps to highlight key assumptions).

Limiting the Changes That Can Be Made to the Element's Appearance

The **Locking** tab is used to control the types of changes that can be made to the appearance of the element:



The options are as follows:

Lock Appearance: If you check this box and then close the dialog, you can no longer move or scale the element in any way (i.e., all of the subsequent options in this dialog are grayed out).

Allow Move: If this box is checked (the default), you can move the element around within the graphics pane. Otherwise, its position remains fixed.

Allow Label Move: If this box is checked, you can select and move the element's label (separately from the element). If the box is cleared (the default), the label can only be moved with the element symbol itself.

Allow Scaling: If this box is checked (the default), you can change the size of the object by selecting it and dragging one of the control handles (small boxes on the edges of the image).

Lock Aspect Ratio: If this box is checked (the default), the aspect ratio of the image is locked when it is scaled. Otherwise, you can stretch the image and change the aspect ratio.

Viewing and Creating Units

One of the more powerful features of GoldSim is that it is dimensionally-aware. You enable this capability by assigning display units (and hence dimensions) to the elements (and hence to the inputs and outputs) of your model. You can enter data and display results in any units

GoldSim has an extensive internal database of units (all of these units are listed in Appendix D). You can also create your own units.

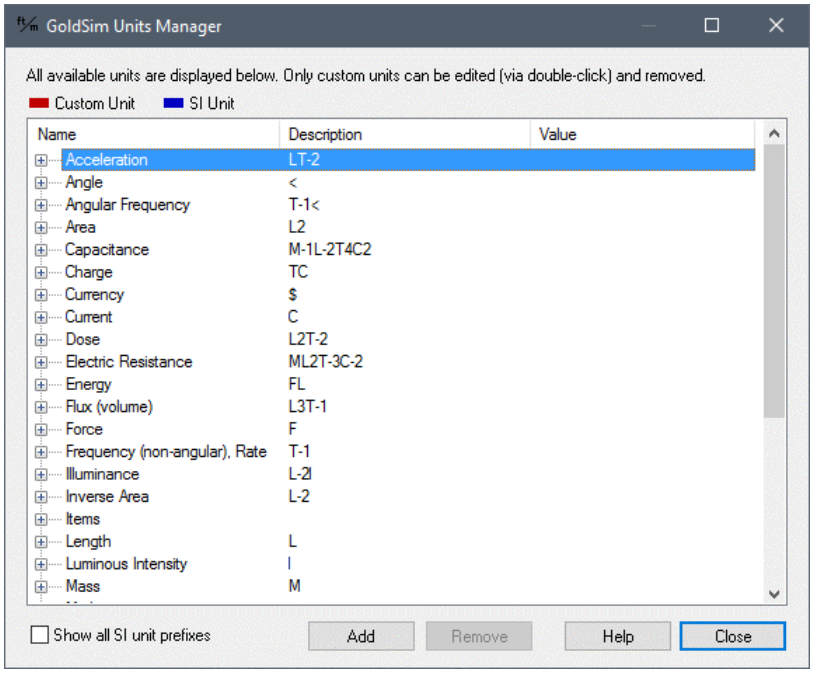
When you create a link, GoldSim ensures dimensional consistency and carries out all unit conversions internally. For example, you could add feet and meters in an expression, and GoldSim would internally carry out the conversion. (If you tried to add feet and seconds, however, GoldSim would issue a warning message and prevent you from doing so.)

Read more: Using Dimensions and Units (page 89).

The GoldSim Units Manager

The GoldSim Units Manager allows you to view all of the units that GoldSim recognizes. You can also use the Units Manager to add new units if necessary.

You can access the Units Manager by selecting **Model|Units…** from the main menu, which will display the following dialog:



Clicking the Plus sign next to a category expands the category to show its units.

There is also a button in the Advanced toolbar for accessing the Units Manager:

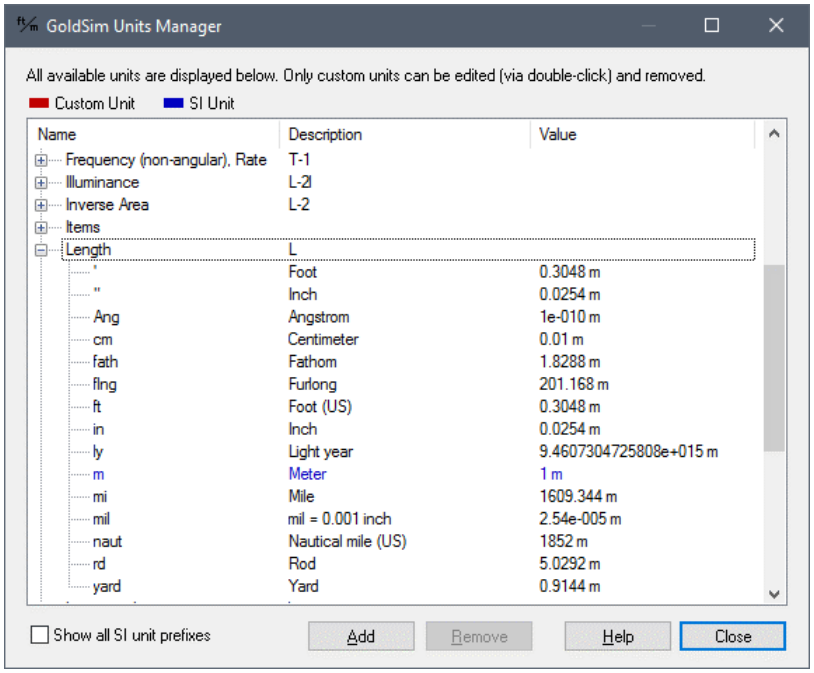
The Units Manager dialog initially displays the ***unit categories*** in the model. A unit category has a name and a specific set of dimensions (displayed in the Description column). The abbreviations for the dimensions are as follows:

Dimension	Abbreviation
Mass	M
Length	L
Time	T
Temperature	t
Current	C
Amount*	A
Luminosity	l
Angle	<
Currency	$

**Used for a quantity of matter (i.e., moles)*

Note: A category does not need to have dimensions. It can be dimensionless.

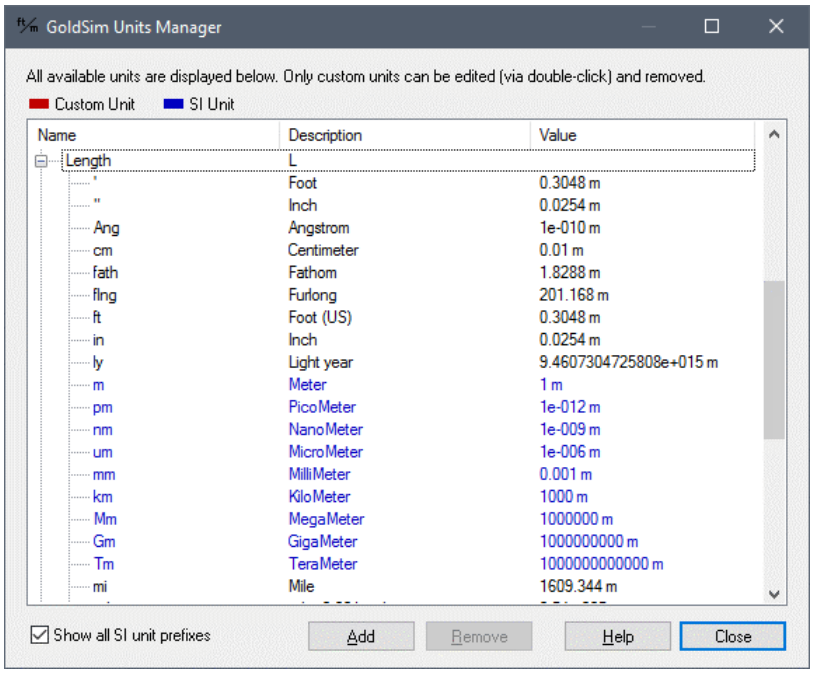
If you expand a category (by clicking on the category folder's "+"), the units in that category are displayed:



When a category is expanded to show units, the first column contains the unit's abbreviation, the second contains its description, and the third contains the

conversion factor between the unit and the "internal units" for that category (e.g., SI units).

By default, GoldSim only shows the primary SI unit (e.g., m for length). However, GoldSim recognizes all of the SI unit prefixes. If you check the **Show all SI unit prefixes** box, they will also be displayed:

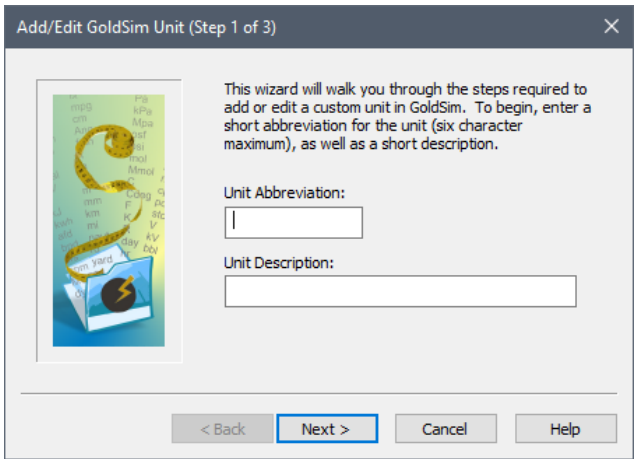


SI units are displayed in blue in the dialog.

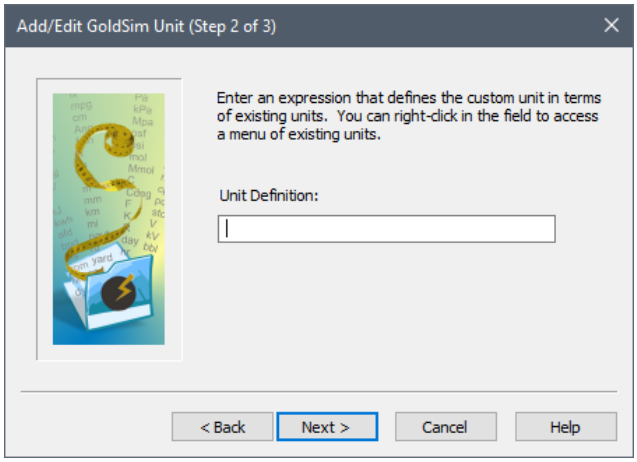
Note: The **Remove** button on the dialog is for deleting units. However, you cannot delete the built-in units (and the button is greyed out when these units are selected). Only custom units that you have created can be removed.

Creating New Units

Occasionally, the internal units supplied by GoldSim may not be sufficient, and you will want to create your own custom unit. You can do this by pressing the **Add** button in the Units Manager dialog (accessed via **Model|Units…** from the main menu). This will display the following wizard for creating a new unit:

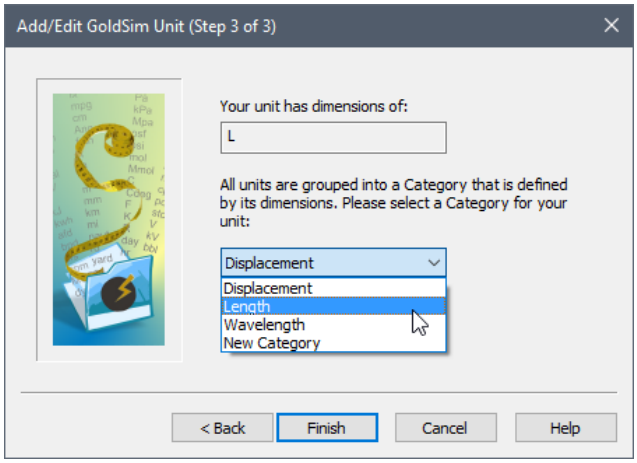


To create a new unit, enter the alphanumeric Abbreviation for your new unit, along with a brief Description string. Pressing **Next>** will bring up the second page of the wizard:



In this dialog, you must enter an expression that defines the new unit in terms of existing units. For example, if you were defining a new unit for length that was equal to 5 feet and 7 inches, you would type in 5 ft +7 in.

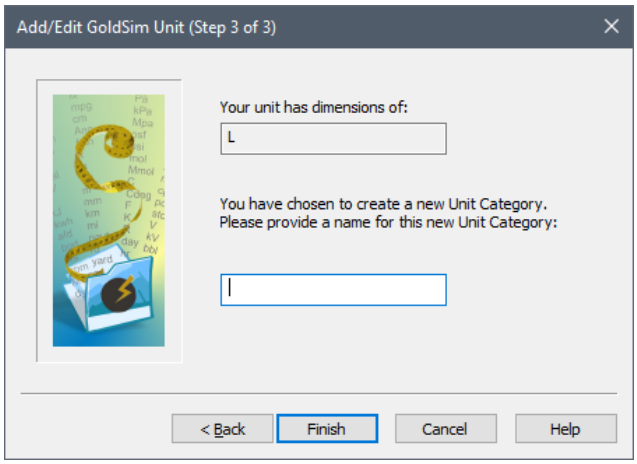
After defining the unit, pressing **Next>** will bring up the third (and final) page of the wizard:



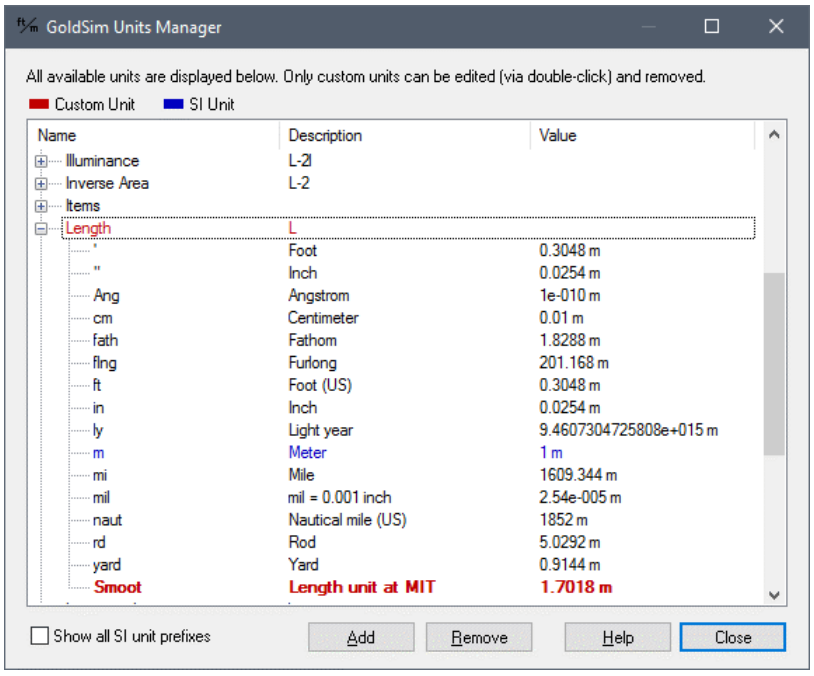
All units are placed into Categories, which are used to group the units within the Units Manager (and in context menus for units in element dialogs). When you define a new unit, GoldSim will display existing categories that have the appropriate dimension.

Note: The dimensions for a Category do not have to be unique. For example, the Categories Displacement, Length and Wavelength could all have dimensions of L (length).

If you select "New Category" (the only option if there are no existing Categories with the appropriate dimensions), the dialog prompts you for the name of the Category:



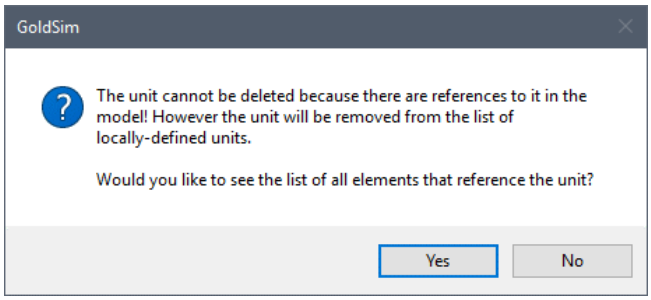
After selecting an existing Category or defining a new Category, press **Finish**. When you do so, the new unit (and the unit Category) will be marked in red to indicate that a custom unit has been defined:



You may want to add a new unit if you wish to use a different abbreviation in your expressions. For example, if you wished to use the unit “year” to denote a year of time, you could create a new unit with an abbreviation of "year" (the built-in abbreviations for a year of time in GoldSim are yr and a).

Note: Due to the special nature of currency units (unique, constant conversion rates cannot be assigned), GoldSim provides a special mechanism for creating and editing currency units. In particular, a special dialog for specifying and editing currency units can be accessed by pressing **Model | Currencies…** from the main menu. You cannot edit conversion rates in the Units Manager. Specifying and editing currency units is described in detail in Chapter 3 of the **GoldSim Financial Module User's Guide**.

The **Remove** button allows you to delete user-defined units (you can only delete user-defined units; built-in units cannot be deleted). Note that if you try to delete a user-defined unit that is being used in an expression somewhere in your model, GoldSim will not allow you to do so, and will provide the following message:



Pressing the **Yes** displays a list of all of the elements which reference the unit.

Creating New Units for Items (Such as Widgets)

In some cases, you may want to create a new unit to track particular items (such as widgets, boxes, patients, etc.). Such a unit actually represents an *amount* of something. You could leave objects like these dimensionless, but for the purpose of viewing and plotting results, it may often be useful to assign units (e.g., 10 boxes instead of simply 10).

To do this, you can create a new dimensionless, as follows:

1. Create a new unit (e.g., widgets, with the abbreviation wdg)
2. When defining a value for the unit, define it as: 1 item.
3. Assign your new unit to the “Items” category.

Item is a built-in unit with no dimensions assigned to the “Items” category. The “Items” category also has several other built-in commonly required dimensionless units (*pers* for persons, *kpers* for thousands of persons, and *Mpers* for millions of persons).

You can repeat this process for other items (e.g., bolts, nuts, cars, etc.).

Warning: If you define two “item units” like this, they can be added together and their resulting units would be dimensionless. For example, if a bolt was defined as 1 item, and a nut was defined as 1 item, you could add 100 bolts to 200 nuts, and express the result in any dimensionless unit (e.g., pers).

Managing User-Defined Units

There are two kinds of user-defined units:

- Units that are stored in your ***system units file***, and hence are available to any model that you edit on your computer. The system units file (units.dat) is located in an application data subfolder on your computer (the location of this file differs depending on the operating system). That is, these units are stored separately on your computer (i.e., not just in the model file itself). These are highlighted in bold red font in the Units Manager, and are referred to here as system units.
- Units that are only stored within the model file itself, and are not available to any other models that you edit on your computer. These are highlighted in red (but not bold) in the Units Manager, and are referred to here as model units.

Any unit that you create on your computer automatically becomes a system unit (i.e., it is stored in the system units file, and hence is subsequently available to any other model you open on your computer.

Whenever a file is saved, any user-defined units that it uses are saved with the file. Therefore, if you open a file that contains user-defined units created by someone else, these units will be available in the file (as model units). They will not, however, become part of your system units file. That is, they do not become system units and are only local to that model. Hence, they would appear in the Units Manager when viewing that file, but would not be bold.

Note: If you open a model with a user-defined model unit, and the same unit is defined as a system unit on your computer (but has a different definition), GoldSim will display a warning message. The model unit will be ignored and the system unit will be applied for that model (which could cause some expressions to become invalid).

If you have opened a file with a model unit, and you would like to convert this to a system unit (so it is available to other models that you open or create), you can do so as follows:

1. Open the Units Manager.
2. Find the unit and click on it.
3. Click through the Wizard until you press Finish.
4. The unit will then become a system unit.

If you want to *delete* a system unit from you computer (so it is no longer available to other models you open or create), you can do so as follows:

1. Open the Units Manager.
2. Find the unit and select it.
3. Press the Remove button.
4. If the unit does not exist in the current file, it will immediately be removed from the Units Manager (and hence will no longer be a system unit). If the unit does exist in the current file, it will be converted from a system unit to a model unit (and hence will no longer be bold in the Units Manager).

When managing user-defined units, you must take care when copying portions of a model that utilize user-defined units between files:

- If you copy a portion of one model which references a user-defined unit to a second model which does not have that unit, you will need to create the unit in the second model (since otherwise it will not recognize the unit).
- If you copy a portion of one model which has a user-defined unit to a second model which has the same user-defined unit *with a different definition*, the definition of the unit in the second (destination) model will be used in the combined model, and this may result in an incorrect calculation or an invalid expression.

Display Units for Dates

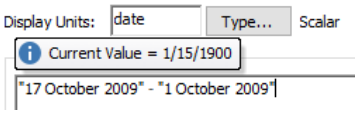
GoldSim provides two special units for displaying dates. These are "datetime" and "date". If "date" or "datetime" are the assigned display units for an element, the value is displayed as a date (or a date and a time). Note, however, that the value itself must represent a time or be entered directly as a date (e.g., 1/1/2021").

Note: A date is internally converted and stored as a Julian time (in particular, the time since December 30, 1899 00:00:00). Hence, a date has dimensions of time.

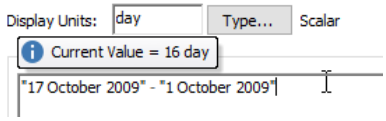
Read more: Referencing Dates in Expressions (page 135).

These can be entered as the display units (instead of an actual time unit) for an element. They cannot, however, be combined with other units in unit strings (e.g., to form strings like m3/date).

Note that "date" or "datetime" should not be used to represent a duration or an amount of time. For example, the difference between two dates ("17 October 2009" – "1 October 2009") represents an amount of time equal to 16 days. If such an expression was assigned units of "date", it would display a Julian date as shown below (Julian dates are computed from 30 December 1899):

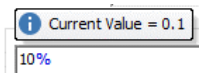


Obviously, this would not be appropriate. By specifying the Display Units as days, the value is displayed as follows:

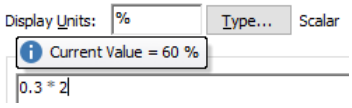


Using the Percentage Unit Symbol

GoldSim provides a special percentage unit (%). You can enter a number as a percentage, and GoldSim will automatically treat this as a fraction:



You can also use this as a display unit, so that fractions can be displayed as percentages:



The Options Dialog

The Options dialog (accessed via **Model|Options** from the main menu) provides access to a number of options for controlling how GoldSim behaves.

There are always at least three tabs on the Options dialogs (some extension modules add additional tabs).

The General Tab of the Options Dialog

The **General** tab of the Options dialog provides a number of options for controlling the way that GoldSim behaves. These options are listed below.

Update expressions (F9) automatically after all moves and pastes: If this checkbox is checked (the default), GoldSim automatically updates the model (reconnecting links) whenever an element is moved or pasted. Otherwise, you must press **F9** to update a model.

Show labels of elements with note attached in blue: If this checkbox is checked (the default), whenever a note is attached to an element, the element's label (which acts as a hyperlink to accesses the note) will be blue. Otherwise, it will use the specified label color (which defaults to black).

Read more: Creating, Editing and Viewing Notes (page 821).

Save crash recovery information every X minutes: If this checkbox is checked (the default), GoldSim saves a copy of the model file periodically in order to allow you to recover a copy of your model file should GoldSim unexpectedly terminate for some reason while your file is open. This would allow you to restore changes you made to the file since you last manually saved it.

Read more: Restoring Files After an Unexpected Failure Using Auto-Save (page 63).

Simulation Events to record in Run Log: These checkboxes allow you to capture information about key events that may affect the behavior of your model. Their purpose is to help you to understand and diagnose your model's behavior. The logging information identifies the exact time and nature of each of the selected events. The Run Log can be viewed via the main menu (**Run | View Run Log**) following a simulation. Note that once you have used the log information to identify elements of interest you may want to add Time History elements to track their behavior more closely, by monitoring all of their inputs and outputs.

Read more: The Run Log (page 569).

Reservoir and Pool element state changes: This option records when Reservoirs and Pools reach or drop below their upper bounds, and when they drop down to or rise above their lower bounds.

Read more: Defining Upper and Lower Bounds for a Reservoir (page 246); Defining Upper and Lower Bounds for a Pool (page 264).

Conditional Container activations and deactivations: This option records the times of activation and deactivation for all Conditional Containers, and in the case of deactivation events, indicates whether the Container's Completion status was true when it was deactivated.

Read more: Activating a Container (page 973); Deactivating a Container (page 974).

Associate GSM files with this GoldSim: Oftentimes, you might have multiple versions of GoldSim on your computer. Windows associates the extension (.gsm) with the last version that was installed. If you double-click

on a .gsm file, it opens it in the version with which that extension was associated. In some cases, however, you may want to ensure that the version that is currently open is the version that you want the .gsm file to be associated with. You can accomplish this by pressing the Associate button here.

The Graphic Tab of the Options Dialog

The Graphic tab of the Options dialog provides options for controlling the way that graphics behave in GoldSim. These options are listed below.

Default Text Font: This is the font used when you add a text object to the graphics pane (by inserting a text object or pasting text from the clipboard).

User-defined Colors: There are numerous places in the GoldSim user interface where you can specify colors for different objects (e.g., backgrounds, text, chart lines). Within those dialogs, GoldSim allows you to select and customize those colors. This section allows you to save custom colors such that you can use the same colors throughout your model. You can also export and import these custom colors.

The Results Tab of the Options Dialog

The Results tab of the Options dialog provides a number of options for controlling the way that Results are displayed. The first two options control how numeric values are displayed in charts, tables and tool-tips:

Minimum number of significant figures to display: This allows you to control the number of significant figures displayed in result displays and tool-tips (as described below). This setting can be changed dynamically from within most result displays using **Alt-Cursor Left** (i.e., **Alt-Left Arrow**) and **Alt-Cursor Right**.

Use scientific notation if absolute value is >=: This allows you to control when scientific notation is used in result displays and tool-tips (as described below). This setting can be changed dynamically from within most result displays using **Alt-Cursor Up** and **Alt-Cursor Down**.

When displaying numeric values (other than dates), GoldSim respects the two settings noted above. Several points related to how these are applied should be noted:

- If the magnitude of the value is less than 0.0001 or greater than 1e10, GoldSim will always use scientific notation (rounding it at the prescribed number of significant figures). Otherwise, it will use the specified setting.
- If the magnitude of the value is below the threshold for scientific notation, GoldSim rounds off any decimal places beyond the prescribed number of significant figures and displays the value conventionally, with a decimal point if it has a fractional part. For example, to display 123.456 with four significant figures, GoldSim would show 123.5.
- When displaying values conventionally (i.e., not using scientific notation), GoldSim never rounds off left of the decimal point; hence the setting represents the *minimum* number of significant figures, not necessarily the actual number of significant figures (i.e., GoldSim may show more). For example, to display 123456.7 with four significant figures specified, GoldSim would show 123457.
- When labeling chart axes, GoldSim respects the specified scientific notation setting, but ignores the significant figures setting (significant figures in chart axes are determined automatically and cannot be user-controlled).

- Values displayed in Result elements are limited to single precision (7 significant figures). This has (a minor) implication if you need to display a date as a result. Dates are stored as the number of seconds since a reference date (12/30/1899). By using single precision, a modern date (e.g., in 2021) displayed in a result will be off by about 20 minutes.
- Values in tool-tips can show up to 16 significant figures.

Other options on the Results tab are as follows:

Show condition result outputs as: This allows you to select how condition outputs are displayed in tables, tool-tips and input fields (e.g., 1/0, True/False, On/Off, etc.).

Avoid scientific notation for currencies. If this option is checked (the default), any value that represents a currency will never be displayed in any result using scientific notation. If it is cleared, the rules outlined above will be used.

Automatic Export for Result Elements. This option allows you to control how time histories are exported from Time History Result elements in your model. The options in the drop-list affect all Time History Result elements which are set to export automatically when the simulation completes. The default is "Export results after simulation". If "Prompt before exporting results" is selected, at the end of the simulation, you will be prompted to determine whether or not to carry out an automatic export. If "Do not export result" is selected, no automatic export is carried out (i.e., this overrides the selection for each individual Result element). Pressing the **Export Now** button manually exports results from all Time History Result elements which are set to export automatically when the simulation completes.

Chapter 7: Running a Model

> Computers are useless. They can only give you answers.
>
> Pablo Picasso

Chapter Overview

After you have created a model, you need to run the model in order to produce results. This chapter describes how to control your simulation (e.g., specify its duration), specify the types of results you wish to save, and run the model.

In this Chapter

The following topics are discussed in this chapter:

- Simulation Settings
- Understanding and Referencing Run Properties
- Saving Outputs as Results
- Running and Viewing the Status of a Simulation
- Creating, Running and Comparing Scenarios
- Running an Optimization
- Running Sensitivity Analyses
- The Run Log
- Running GoldSim from the Command Line

Simulation Settings

GoldSim is a dynamic simulator, which means that your model can evolve and change with time. In order to carry out a dynamic simulation, GoldSim steps through time in discrete intervals (referred to as *timesteps*).

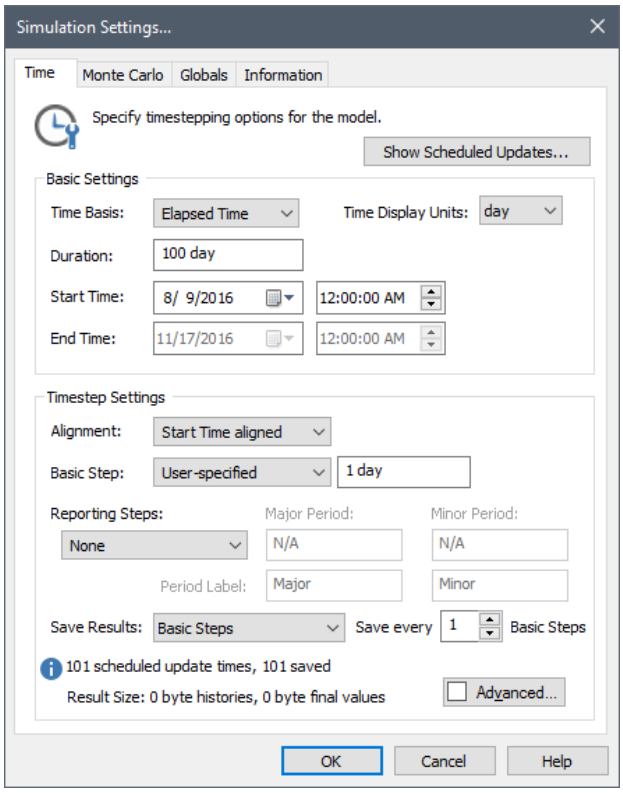
Calculations are carried out every timestep, with the values at the current timestep computed as a function of the values at the previous timestep. In GoldSim, you specify the duration of the simulation (e.g., 1 year) and the length of the timestep (e.g., 1 day).

The appropriate timestep length is a function of how rapidly the system represented by your model is changing: the more rapidly it is changing, the shorter the timestep required to accurately model the system. GoldSim allows you to change the timestep during a simulation (e.g., use short timesteps at early times when things are changing rapidly, and larger timesteps at later times).

Simulation Settings button

To run a model, you must first specify its *simulation settings.* When you create a new model, GoldSim will display the Simulation Settings dialog If you choose not to define the settings immediately, or if you wish to modify the settings subsequently, they can be accessed directly from the main menu under **Run | Simulation Settings…**, by pressing **F2**, or by clicking on the Simulation Settings button in the standard toolbar.

The simulation settings dialog is shown below:



The dialog consists of four tabs.

The **Time** tab is used to specify the time options for the simulation, such as the duration of the simulation, the length of the timestep, and the units in which time will be displayed in results.

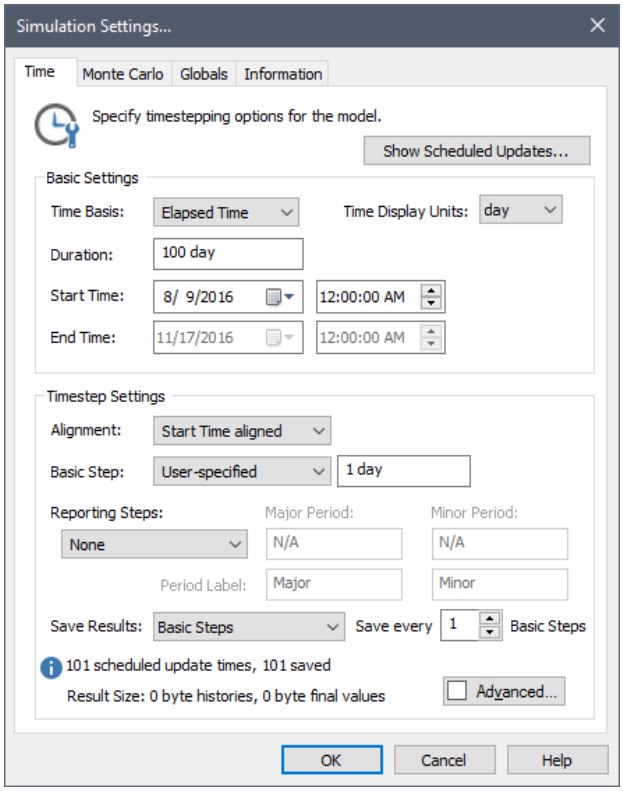
The **Monte Carlo** tab is used to specify Monte Carlo options (how probabilistic simulations will be carried out), such as the number of realizations, and whether Latin Hypercube sampling is to be used.

The **Globals** tab is used to define global properties that can be referenced throughout your model.

The **Information** tab is used to specify the model author and a description for the simulation. This tab also provides some summary information regarding the model (e.g., the number of elements and the number of levels of containment).

Setting the Basic Time Options

The **Time** tab of the Simulation Settings dialog is used to specify the time options for the simulation:



There are four primary things that you specify from this dialog:

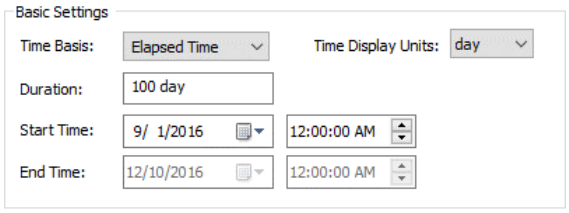
- The time basis and simulation duration;
- The timestep length and how the timesteps are aligned;
- Special *reporting periods* over which results can be accumulated and/or averaged; and
- When results will be saved.

This dialog also includes a button to **Show Scheduled Updates…**, which displays all of the model timesteps, and an **Advanced** button, for specifying a number of advanced time settings.

These items are discussed in detail in the sections below.

Defining the Time Basis and Simulation Duration

The top portion of the **Time** tab of the Simulation Settings dialog is used to specify the time basis for the simulation, as well as the simulation duration:



There are three ways in which you can represent time in GoldSim (controlled by **Time Basis** drop list):

- Elapsed Time
- Calendar Time
- Static Model

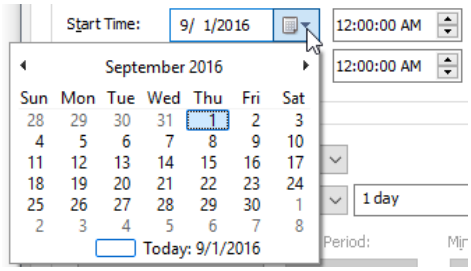
In an Elapsed Time simulation (the default), you must specify a simulation **Duration**. The Duration must be entered as a number (it cannot be defined as a link from an element), followed by a valid time unit. The simulation is then tracked in terms of elapsed time (e.g., when plotting time history results, the X-axis is plotted as elapsed time).

Note: When specifying the **Duration**, the unit "mon" should generally be avoided and the unit "yr" should only be used for long-term Elapsed Time simulations. This is because these units represent an average month (30.4375 days) and an average year (365.25 days). As such, their use could be confusing to someone viewing your model, unless it is very clear that you are referring to average months or years.

Read more: Understanding Units for Month and Year (page 93).

In a Calendar Time simulation (also referred to as a date-time simulation), you enter a **Start Time** and an **End Time**, and the simulation is then tracked in terms of the calendar time (e.g., when plotting time history results, the X-axis is plotted as dates/times).

If you select a Calendar Time simulation, you can click on the arrow in the box to view a calendar to assist you in selecting a start or end date:



You can select part of the date (month, day, year) in the input field and then enter a value or use the arrow keys to increment or decrement the value. Arrow buttons on the calendar move forward or backward one calendar month. Clicking the month on the calendar activates a menu with the twelve months. Clicking the year on the calendar activates a control for changing the year.

Note: GoldSim supports a date range from 1 January 1700 to 31 December 9999.

Note: The format in which the dates are displayed is determined by the Windows settings for your machine. To change these settings (e.g., to display dates in European format with the day before the month), go to Control Panel and edit the Regional Options.

Note: When running a Calendar Time simulation, you can also specify the **Duration**. When you do so, GoldSim will use the specified **Start Time**, and automatically update the **End Time** accordingly.

Whether you are running an Elapsed Time simulation, or a Calendar Time simulation, by referencing GoldSim's built-in Run Properties, you can reference calendar-based information in your models (e.g., what day of the week is it? What month is it?). This is possible in Elapsed Time simulations also since you can specify the **Start Time** for them.

Read more: Understanding and Referencing Run Properties (page 505).

Note: Specifying the **Start Time** for Elapsed Time simulations also allows you to enter time series data in terms of either elapsed time or calendar time; GoldSim uses the Start Time to convert between the two formats.

Read more: Entering Time Series Data as Dates or Elapsed Times (page 203).

The third option for carrying out your simulation is to run a Static Model. In a Static Model, the model does not step through time. This can be useful if you simply wish to carry out a static calculation using Monte Carlo simulation. A Static Model effectively sets the **Duration** to zero.

The **Time Display Units** provide the default time unit that is used in several parts of GoldSim. For example, for an Elapsed Time simulation, these are the units in which results (e.g., time history plots) will be displayed for all elements. Another example of where the default time unit is used is the Reservoir element. In this element, you specify a Display Unit, but several input fields require a rate. The default units for the rate are determined by the Time Display Units.

Example files which illustrate Elapsed and Calendar Time simulations (Elapsed.gsm and Calendar.gsm) can be found in the General Examples/ Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Understanding Timestepping in GoldSim

In order to carry out a dynamic simulation, GoldSim steps through time in discrete intervals (referred to as *timesteps*). Calculations (referred to as *updates* of the model) are carried out at end of every timestep, with the values at the end of the current timestep computed as a function of the values at the end of the previous timestep. Although the term timestep actually refers to an interval of time, it is often used interchangeably with the term *update* (indicating a calculation at a point in time).

In GoldSim, there are two kinds of updates/timesteps: *scheduled updates (or timesteps)* and *unscheduled updates (or timesteps)*.

Scheduled Updates

Scheduled updates are specified directly prior to running the model. That is, you tell GoldSim when you want these updates to occur.

There are four ways to specify scheduled updates:

- You define a Basic Step of a specified length;
- You define Reporting Periods (e.g., monthly, annual) which are used to accumulate or average results, and which force a scheduled timestep at the end of each period;
- You define Capture Times, which represent specific times during the simulation where "snapshots" of statistical values can be viewed. A scheduled timestep is created for each Capture Time. By default, there is only a single Capture Time (the end of the simulation), but you can add as many as desired; and
- You define Period Timesteps for specific time intervals in which even smaller timesteps are desired.

Read more: Specifying the Basic Step Length and Alignment (page 477); Defining Reporting Periods (page 479); Adding Shorter Timesteps Over Defined Periods (page 485); Creating Capture Times for Results (page 488).

The most common way to create scheduled updates will be by specifying some combination of Basic Steps and/or Reporting Periods:

- **Basic Steps only**. In many cases, you will simply create a Basic Step (and this is the default). This is the simplest way to create scheduled updates (but is not necessarily the most effective way, depending on your application). You specify a Basic Step at which results are computed. You can subsequently choose to save results at each Basic Step, or at only some Basic Steps (e.g., every other Step, or every tenth Step).

  Read more: Specifying When Time History Results Will Be Saved (page 482).

- **Reporting Periods only**. In many cases, you will not use a Basic Step at all, but will simply define your scheduled updates using Reporting Periods. Why would you do so? Whereas results saved at Basic Steps always represent instantaneous values, results saved at Reporting Periods can not only be displayed as instantaneous results, but can also report accumulated or averaged values over a specified period (e.g., monthly). Hence, if you needed average or accumulated flows over each step (e.g., over the last day or the last month), you can do so by defining your steps using Reporting Periods.

Note: Most spreadsheet models implicitly compute *accumulated* values (e.g., flows) over a step (or the change from one step to the next). Hence, if you want to compare or integrate GoldSim with a spreadsheet model, you should use Reporting Periods to define your steps.

- **Reporting Periods and Basic Steps**. In some cases, you may want to create Reporting Periods in order to report accumulated or averaged values over a specified period, but you may also need a shorter computational step in order to ensure accuracy. For example, you may require a daily timestep to ensure accuracy, but only need to view monthly averages or accumulated values in terms of results. In this

case, you would create a Basic Step as well as Reporting Periods. You could choose to save results only for Reporting Periods, or could also save results for the Basic Steps. When defining both Basic Steps and Reporting Periods, Reporting periods can be defined to coincide with Basic Steps (e.g., a 1 day Basic Step and a monthly reporting period), but they do not have to. However, if a Basic Step is specified, Reporting periods must always be at least twice as large as the Basic Step.

In some cases, you may also want to create Capture Times, which are typically used to capture and view statistical results at specified points in your simulation. In particular, Capture Times allow you to save and view "Final Value" type results at specified times during a simulation (rather than just at the final time point). Final Value results are associated with multiple realizations (or items in an array), and allow you to display distributions, multi-variate results (e.g., scatter plots) and array plots.

Read more: Viewing the Five Basic Result Types (page 580).

When you define a Capture Time, a scheduled timestep is added at that time (if one does not already exist).

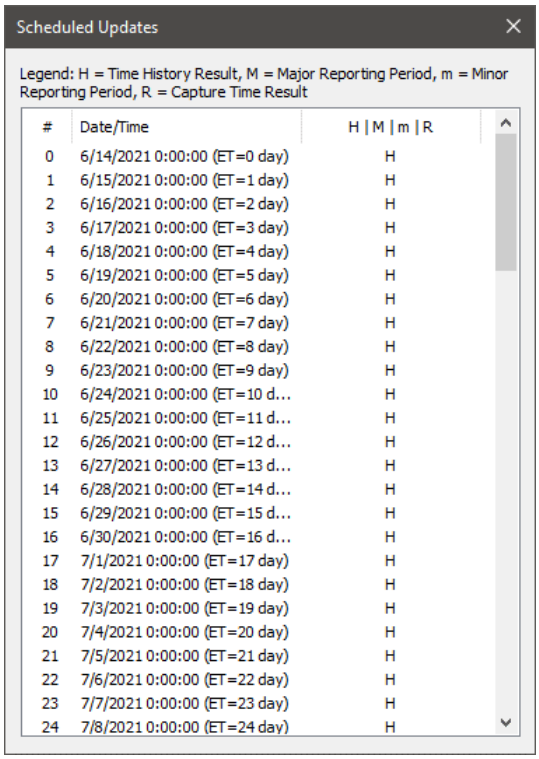
Finally, in rare cases, you may want to create smaller timesteps over a defined period of your simulation (e.g., if you know that early in your simulation, variables will change rapidly, and hence a small timestep is required).

Note: You can also specify a shorter timestep for different parts (i.e., Containers) of your model.

Read more: Specifying Containers with Internal Clocks (page 493).

When specifying scheduled timesteps, the appropriate timestep length is a function of how rapidly the system represented by your model is changing: the more rapidly it is changing, the shorter the timestep required to accurately model the system.

You can view all of the scheduled timesteps in your simulation by pressing the **Show Scheduled Updates…** button at the top of the **Time** tab. The following dialog will be displayed:



This provides a summary of the scheduled timesteps you have defined (with the final column listing the type of each time point).

Unscheduled Updates

In some cases, events or other changes in the model may not fall exactly on a scheduled update. That is, some events or changes may actually occur between scheduled updates of the model. These trigger an "unscheduled update" of the model. Unscheduled updates are timesteps that are dynamically inserted by GoldSim during the simulation in order to more accurately simulate the system. That is, they are not specified directly prior to running the model. GoldSim inserts them automatically (and, generally, without you needing to be aware of it).

"Unscheduled updates" can be generated in the following ways:

- When events are output by a Timed Event, Event Delay, Discrete Change Delay or Time Series element;
- By manually specifying a dynamic timestep (i.e., dynamically controlling the time between updates);
- When a Reservoir or Pool element reaches an upper or lower bound;
- When a Resource becomes exhausted;
- When any element is triggered by an *At Stock Test*, *At Date*, *At Etime* or *At Duration* triggering event; and
- By some specialized elements in GoldSim extension modules (Action and Function elements in the Reliability Module, Fund elements in the Financial Module, and Cell elements in the Contaminant Transport Module).

Read more: Understanding Event Triggering (page 369); Timed Event Elements (page 379); Event Delay Elements (page 391); Delaying a Discrete

Change Signal (page 405); Generating Discrete Changes Using Time Series Elements (page 430); Dynamically Controlling the Timestep (page 490); Defining Upper and Lower Bounds for a Reservoir (page 246); Defining Upper and Lower Bounds for a Pool (page 264); Using Resources (page 906).

When any of these events occur, GoldSim automatically inserts an unscheduled update at the exact time that the event or change occurs. For example, if you had specified a one day timestep, and a Timed Event occurs at 33.65 days (i.e., between the scheduled one-day updates), GoldSim would insert an unscheduled update at 33.65 days.

Note: By default, GoldSim always inserts unscheduled updates. However, although it is generally not recommended, you can override the default and instruct GoldSim not to insert the unscheduled updates. (This option is accessed via the **Advanced…** button in the **Time** tab of the Simulation Setting dialog).

Read more: Controlling Unscheduled Updates (page 489).

A key and important difference between scheduled updates and unscheduled updates is that scheduled updates are included in time history plots and tables (unless you choose to exclude them). Unscheduled updates, however, do not normally appear in time history plots and tables. That is, although these timesteps may affect the results (e.g., by making them more accurate at the scheduled timesteps), unscheduled updates of the model are not saved and plotted. Only the scheduled updates are actually saved and plotted.

Note: In some cases, it may be of interest to see the values of selected outputs at unscheduled updates. To facilitate this, GoldSim provides an option to do so (under a specified set of conditions) in the Advanced Time settings.

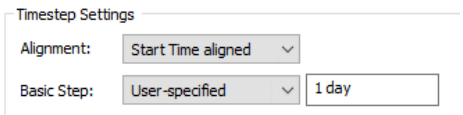
Read more: Including Unscheduled Updates in Time History Results (page 496).

A simple example file illustrating unscheduled updates (UnscheduledTimeSteps.gsm) can be found in the Running subfolder of the the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

The GoldSim timestepping algorithm is discussed in detail in Appendix F.

Specifying the Basic Step Length and Alignment

The middle portion of the **Time** tab of the Simulation Settings dialog is used to specify the Basic Step length and the manner in which the timesteps are aligned:



For many models, you will simply create a **Basic Step** of a specified length, and these will be the only scheduled timesteps you will need to define.

Read more: Understanding Timestepping in GoldSim (page 473).

The **Basic Step** field defines the length of the timestep. The **Alignment** field determines how the steps are aligned.

The manner in which these are specified differs based on whether the **Time Basis** is Elapsed Time or Calendar time.

Read more: Defining the Time Basis and Simulation Duration (page 471).

For an Elapsed Time simulation, the **Basic Step** is either "User-specified" or "No basic step". If the latter is selected, you will need to specify Reporting Periods in order to step through the model (i.e., if no Basic Step is defined, Reporting Periods must be defined).

Read more: Defining Reporting Periods (page 479).

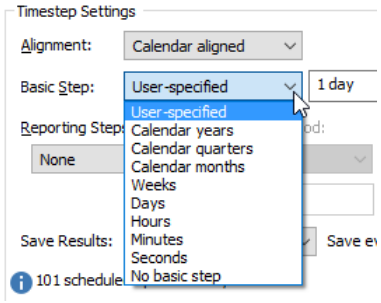
If "User-specified" is selected, you define a timestep length using any time unit. This can be specified as a number or an equation (but you cannot link to another element).

Note: When specifying a "User-specified" **Basic Step**, the unit "mon" should generally be avoided and the unit "yr" should only be used for long-term Elapsed Time simulations. This is because these units represent an average month (30.4375 days) and an average year (365.25 days). As such, their use could be confusing to someone viewing your model, unless it is very clear that you are referring to average months or years.

Read more: Understanding Units for Month and Year (page 93).

For Elapsed Time simulations, the **Alignment** is not applicable (it is always "Start-time aligned" indicating that the steps start at an elapsed time of zero).

For a Calendar Time simulation, there are multiple options for the **Basic Step**:



As is the case for an Elapsed Time simulation, if "No basic step" is selected, you will need to specify Reporting Periods in order to step through the model (i.e., if no Basic Step is defined, Reporting Periods must be defined).

If "User-specified" is selected, you define a timestep length using any time unit. This can be specified as a number or an equation (but you cannot link to another element).

"Calendar years", "Calendar quarters" and "Calendar months" represent the duration of the actual underlying calendar, and hence define a variable-length timestep. A spin-control can be used to specify the number of calendar units pers step. For example, if you selected "Calendar months" and specified a value of 1, then the length of the timestep would vary between 28 and 31 days, depending on the month.

"Weeks", "Days", "Hours" and "Seconds" provide a simple way to define a fixed-length timestep. A spin-control can be used to specify the number of fixed-length units per step.

For Calendar time simulations, the **Alignment** determines how the timesteps are aligned relative to the **Start Time** of the simulation. There are two options: "Calendar aligned" and "Start Time aligned". If "Start Time aligned" is selected, all timesteps are aligned with the start of the simulation. If "Calendar aligned" is selected, GoldSim uses the start of the selected calendar period to align the timesteps. To understand this, it is easiest to consider an example.

If you specified a **Basic Step** of "Calendar months" (and set it to 1), specified an **Alignment** of "Start Time aligned", and a **Start Time** of January 15, then GoldSim would create timesteps at January 15, February 15, March 15, April 15, etc. On the other hand, if you specified a **Basic Step** of "Calendar months" (and set it to 1), specified an **Alignment** of "Calendar aligned", and a **Start Time** of January 15, then GoldSim would create timesteps at January 15, February 1, March 1, April 1, etc.

Several points should be noted for Calendar Time simulations:

- The **Start Time** and the **End Time** are always included as scheduled timesteps, regardless of the Basic Step or Alignment.
- When using "Weeks" as the Basic Step, the first day of the week can be specified by the user. This is controlled via the **Advanced…** button at the bottom of the **Time** tab.

Read more: Controlling When Weeks and Years Start (page 496).

Note: If you are unsure how a particular combination of Basic Step, Alignment and Start Time will affect the scheduled timesteps, simply press the **Show Scheduled Updates…** button at the top of the **Time** tab. This will display all of the scheduled timesteps prior to actually running the model. By experimenting with the various options and viewing the resulting scheduled timesteps, you should be able to quickly create the timestepping schedule that you require.

Note: The maximum number of Basic Steps that GoldSim will support is one million.

If you are saving a large number of time history results and have a large number of Basic Steps, you may not wish to save values at every Basic Step (as this could require a large amount of disk space). In fact, if you have defined Reporting Periods, you may only want to save results at those times (and may not need to save results at Basic Steps at all). To facilitate this, at the bottom of the **Time** tab of the Simulation Settings dialog, GoldSim allows you to specify when results are to be saved (e.g., every other Basic Step, every Basic Step, Reporting Periods only).

Read more: Specifying When Time History Results Will Be Saved (page 482).

Example files which illustrate Elapsed and Calendar Time simulations (Elapsed.gsm and Calendar.gsm) can be found in the General Examples/ Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Defining Reporting Periods

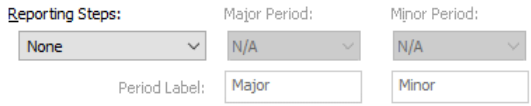
In some cases, you need to compute and report *accumulated*, *average*, the *change* or the *rate of change* of values over specified periods (e.g., monthly,

annually). For example, you may need to report the cumulative amount of money or water that moved from one point to another each month.

To support this, GoldSim allows you to define Reporting Periods. Scheduled updates (timesteps) are created at the end of each Reporting Period. Hence, these can also be thought of as "Reporting Steps". Whereas results saved at Basic Steps always represent instantaneous values, results saved at Reporting Periods can not only be displayed as instantaneous results, but can also report accumulated, averaged, the change or the rate of change of values over a specified period (e.g., monthly).

Read more: Understanding Timestepping in GoldSim (page 473).

Reporting Periods are defined toward the bottom of the **Time** tab of the Simulation Settings dialog:

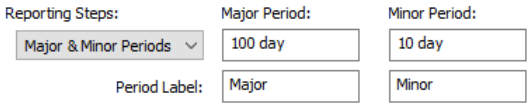


There are three options for Reporting Periods (referred to in the dialog explicitly as Reporting Steps to remind you that these actually create scheduled updates): "None" (the default), "Major" (in which your define a single Reporting Period), and "Major & Minor" (in which you define two Reporting Periods).

The manner in which Reporting Periods are specified differs based on whether the **Time Basis** is Elapsed Time or Calendar time.

Read more: Defining the Time Basis and Simulation Duration (page 471).

For an Elapsed Time simulation, you simply specify the length of the Reporting Period for the Major and Minor Period:



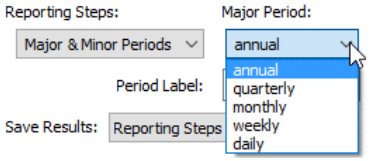
In this example, a Major Period would be created every 100 days from the start of the simulation; a Minor Period would be created every 10 days from the start of the simulation.

You define the length using any time unit. This can be specified as a number or an equation (but you cannot link to another element).

Note: The Major Period must be a multiple of the Minor Period.

You must also define a **Period Label** for each type of period (which defaults to Major and Minor). These IDs are referenced when displaying Reporting Period results.

For a Calendar Time simulation, there are five options for the Major Period:



These create Reporting Periods every year, quarter, month, week or day, respectively.

Depending on what you select for the Major Period, limited options will be valid for the Minor Period, since the Major Period must be a multiple of the Minor Period. For example, if you select "annual" for the Major Period, only three options are valid for the Minor Period (quarterly, monthly and daily). If you were to pick "monthly" for the Major Period, there is only one valid option for the Minor Period: daily. Weekly is never a valid option (and is not provided in the drop-list) for the Minor Period, because it does not divide evenly into any of the possible Major Periods.

Calendar Periods are placed according to the following rules:

- Monthly Periods are added on start of the first day of the calendar month (at midnight).
- Daily Periods are added at midnight on each day.
- Where Annual and Quarterly Periods are added is controlled by how you define the "Start of reporting year" which is controlled via the **Advanced…** button at the bottom of the **Time** tab. Annual Periods are added on the first day of the month selected as the "Start of the reporting year". Quarterly Periods are added on the first day of the month selected as the "Start of the reporting year", and the first days of the months 3, 6 and 9 months after the selected month.
- Where Weekly Periods are added is controlled by how you define the "First day of model week" which is controlled via the **Advanced…** button at the bottom of the **Time** tab. Weekly Periods are added at midnight of the start of the specified first day of the week.

  Read more: Controlling When Weeks and Years Start (page 496).

It is important to understand that in many cases, you should define your scheduled updates using Reporting Periods (and not bother to use a Basic Step at all). Recall that whereas results saved at Basic Steps always represent instantaneous values, results saved at Reporting Periods can not only be displayed as instantaneous results, but can also report the change, rate of change, accumulated or averaged values over a specified period (e.g., monthly). Hence, if you needed the change, rate of change, average or accumulated flows over steps (e.g., over the last day or the last month), you can do so by defining your steps using Reporting Periods.

Note: Most spreadsheet models implicitly compute *accumulated* values (e.g., flows) over a step (or the change from one step to the next). Hence, if you want to compare or integrate GoldSim with a spreadsheet model, you should use Reporting Periods to define your steps.

Of course, in some cases, you may want to create Reporting Periods in order to report accumulated or averaged values over a specified period, but you also may need a shorter computational step in order to ensure accuracy. For example, you may require a daily timestep to ensure accuracy, but only need to view monthly averages or accumulated values in terms of results. In this case, you would create a Basic Step as well as Reporting Periods.

When defining both Basic Steps and Reporting Periods, Reporting periods can be defined to coincide with Basic Steps (e.g., a 1 day Basic Step and a monthly reporting period), but they do not have to. However, if a Basic Step is specified, Reporting periods must always be at least twice as large as the Basic Step.

Once you have defined Reporting Periods, how can they be used? Reporting Periods impact your model in three ways:

1. Reporting Periods automatically create a scheduled timestep for your model (regardless of how you have defined your Basic Step).

   Read more: Understanding Timestepping in GoldSim (page 473).

Note: If you press the **Show Scheduled Updates…** button at the top of the **Time** tab, all of the scheduled timesteps in the model will be displayed. Because Reporting Periods add scheduled timesteps, you can use this to see exactly where they will be added. Updates associated with Major and/or Minor Periods are specifically identified (since Minor Periods must divide evenly into Major Periods, any Major Period listed automatically also represents a Minor Period).

2. Results based on Reporting Periods (e.g., cumulative values over each period, average values over each period, etc.) can be accessed and viewed via Time History Result elements.

   Read more: Viewing Reporting Period-Based Results in Time History Result Elements (page 631).

3. When Reporting Periods are defined, a number of additional Run Properties are created that can be referenced in your model (e.g., the elapsed time from the start of the last Reporting Period, the remaining time to the start of the next Reporting Period).

   Read more: Understanding and Referencing Run Properties (page 505).

A simple example file illustrating Reporting Periods (ReportingPeriods.gsm) can be found in the Running subfolder of the the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

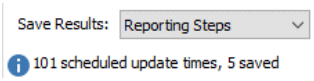
Specifying When Time History Results Will Be Saved

If you are using Reporting Periods, time history results are always saved at the end of each reporting period. (Results are also always saved at the beginning and end of the simulation).

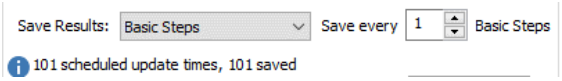
Read more: Defining Reporting Periods (page 479).

Note, however, that if you are using Basic Steps, you may not need to save values at every Basic Step (as this could require a large amount of disk space). To address this, GoldSim allows you to save only selected ***plot points***.

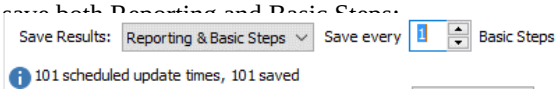
At the bottom of the **Time** tab of the Simulation Settings dialog, GoldSim allows you to specify when time history results will be saved. If you only have defined Reporting Periods (and have not defined a Basic Step), this section of the dialog looks like this:



If you have only defined a Basic Step (and have not defined Reporting Periods), it looks like this:



If you have defined both a Basic Step and Reporting Periods, you can select to save both Reporting and Basic Steps:



Whenever Reporting Periods are defined (as in the first and third cases), results will automatically be saved at the end of every Reporting Period (as well as at the beginning and end of the simulation). In fact, in the first case (only Reporting Periods), you have no options for specifying when results are to be saved.

Whenever a Basic Step is defined, however, you have the option of specifying how often you want to save Basic Steps. If **Save Every** is entered as 1, every Basic timestep is saved; if it is specified as 2, every other timestep is saved; if it is specified as 5, every fifth timestep is saved, and so on. If it is specified as 0 (the default), no Basic Steps are saved.

Note: The discussion above is only associated with *when* time history results are saved. It does not control *which* time history results are saved. Whether or not time history results are saved for a specific element is a function of 1) whether the simulation has multiple realizations, 2) the status of the check box for the element defining if Time History results are to be saved; and 3) whether or not the element is referenced by a Time History Result element.

Read more: Saving Outputs as Results (page 514).

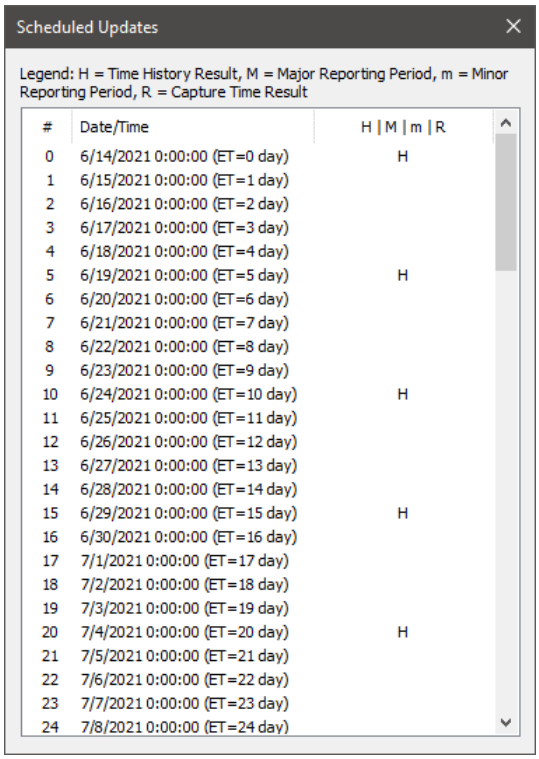
Note: As an advanced timestepping option, GoldSim allows you to define shorter timesteps over a defined period. For example, if you know that early in your simulation, variables will change rapidly, you may want to use a small timestep initially. To support this, GoldSim allows you to select periods during your simulation in which the timestep is decreased for a specified duration, before returning to the timestep defined via the Basic Step (or Reporting Period). When this is done, the **Save Every** option applies to these shorter steps. For example, if you have a 100 day simulation, a 5 day basic step, a 1 day step applied for the first 10 days, and **Save Every** is set to 2, then GoldSim would save time history results at 0, 2, 4, 6, 8, 10, 20, 30, 40, 50, 60, 70, 80 90, and 100 days.

Read more: Adding Shorter Timesteps Over Defined Periods (page 485).

Based on the number of Basic Steps (and how often they are to be saved), the number of Reporting Periods, the number of elements for which time histories are being saved, the number of realizations, and several other settings (e.g., whether or not some advanced timestepping options are being used), GoldSim reports the amount of disk space required to store the results at the bottom of the **Time** tab. This is also provided in the **Information** tab of the Simulation Settings dialog and the **Information** tab of each Container.

Read more: Viewing and Editing Model Summary Information (page 505); Summary Information for a Container (page 145).

If you press the **Show Scheduled Updates…** button at the top of the **Time** tab, all of the scheduled timesteps in the model will be displayed:



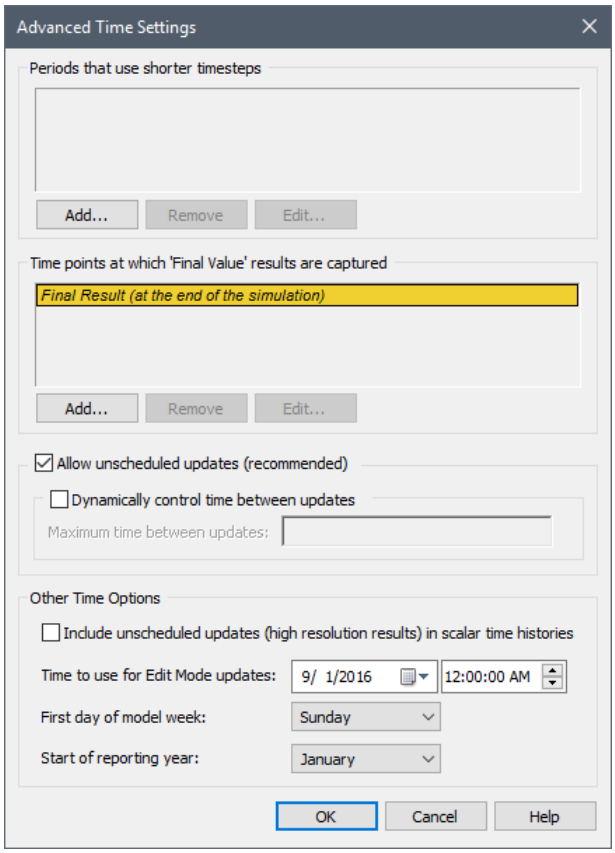
The dialog not only indicates when the scheduled timesteps will occur, but it also indicates which of these steps will be saved for time history display. In the example above, it indicates that every fifth Basic Step is being saved for display.

Note: In some cases, it may be of interest to display the values of selected outputs that were computed not only at scheduled updates (e.g., Basic Steps and Reporting Periods), but also at unscheduled updates (e.g., when random events occur). To facilitate this, GoldSim provides an option to do so (under a specified set of conditions) in the Advanced Time settings. When you display results that show unscheduled updates, *all* Basic Steps are also displayed (i.e., for these specific displays, the **Save Every** option does not apply).

Read more: Understanding Timestepping in GoldSim (page 473); Including Unscheduled Updates in Time History Results (page 496).

Advanced Timestep Options

The **Advanced…** button in the **Time** tab of the Simulation Settings dialog provides access to a dialog for specifying a number of advanced timestepping features:

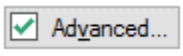


This dialog is used to specify several different things:

- Adding shorter (magnified) timesteps over specified periods;
- Adding Capture Times during a simulation, at which results are captured in order to display distributions, multi-variate results (e.g., scatter plots), bar charts, pie charts and arrays at specified points in time.
- Controlling unscheduled updates;
- Dynamically controlling the timestep during a simulation;
- Including unscheduled updates in time history results;
- Referencing and displaying Time when editing a model; and
- Defining the first day of the week and first month of the year.

These are discussed in detail in the sections below.

Note that the settings shown above are the default settings. If any of the default settings are changed, GoldSim indicates this in the **Time** tab of the Simulation Settings dialog by placing a check on the **Advanced…** button:

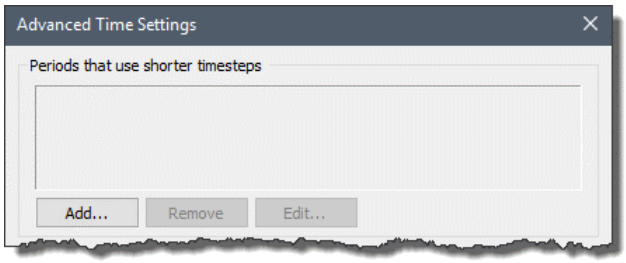


Adding Shorter Timesteps Over Defined Periods

In some cases, you may want to create smaller timesteps over a defined period of your simulation. For example, if you know that early in your simulation, variables will change rapidly, you may want to use a small timestep initially. To support this, GoldSim allows you to select periods during your simulation in

which the timestep is decreased for a specified duration, before returning to the timestep defined via the Basic Step (or Reporting Period).

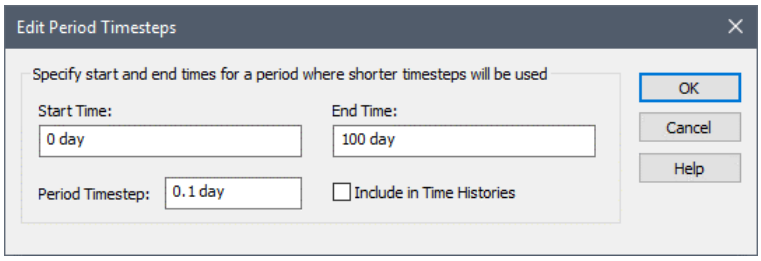
These periods during which the timestep is shorter are defined at the top of the Advanced Time Settings page (accessed via the **Advanced…** button on the **Time** tab of the Simulation Settings dialog):



You can add a new time period with a shorter timestep by pressing the **Add…** button. When you do so, a dialog for specifying the period will be displayed. The dialog differs based on whether the Time Basis is Elapsed Time or Calendar time.

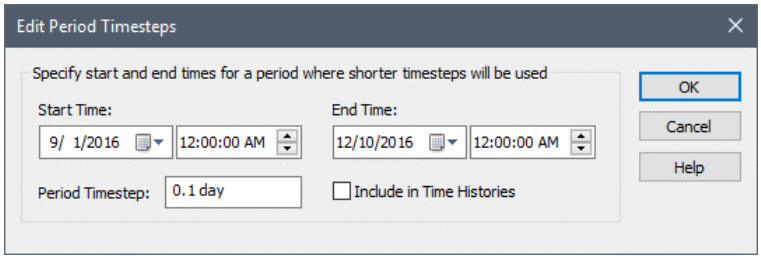
Read more: Defining the Time Basis and Simulation Duration (page 471).

If you are carrying out an Elapsed Time simulation, the dialog looks like this:



The elapsed **Start Time** and **End** cannot overlap with another defined period. The **Period Timestep** must divide evenly into the Basic Step (if one is defined), or the shortest Reporting Period (if there is no Basic Step). It must be smaller than the period it is dividing. The **Start Time**, **End Time** and **Period Timestep** can be defined using any time unit. This can be specified as a number or an equation (but you cannot link to an element).

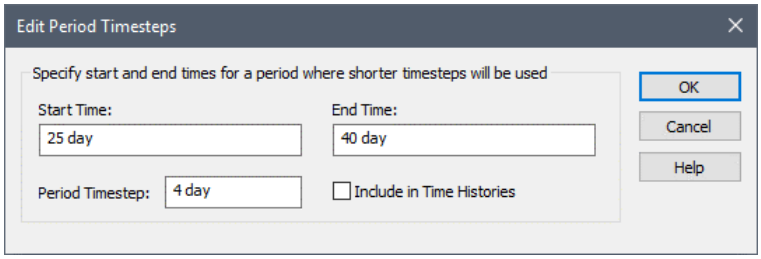
If you are carrying out a Calendar Time simulation, the dialog looks like this:



The **Start Time** and **End Time** are specified as dates/times cannot overlap with another defined period. The **Period Timestep** must divide evenly into the Basic Step (if one is defined), or the shortest Reporting Period (if there is no Basic Step). If the Basic Step is defined as a calendar duration (e.g., Calendar months), then the **Period Timestep** must divide evenly into a day. The **Period Timestep** must be smaller than the period it is dividing. It can be defined using any time unit. This can be specified as a number or an equation (but you cannot link to an element).

Note: If you press the **Show Scheduled Updates…** button at the top of the **Time** tab, all of the scheduled timesteps in the model will be displayed. Because Period Timesteps add scheduled timesteps, you can use this to see exactly where they will be added.

It is important to understand how GoldSim actually schedules these Period Timesteps, and this can best be done by considering an example. Consider a 100 day simulation with a 20 day basic timestep. By default, scheduled updates would then occur at 0, 20, 40, 60, 80 and 100 days. Now assume that we schedule a Period Timestep that looks like this:



When would the updates occur? In this case, they would occur at 0, 20, 28, 32, 36, 40, 60, 80 and 100 days. Note that there is not a step at 25 days. The first shortened step occurs at 28 days. GoldSim simply adds timesteps at all multiples of the Period Timestep (in this case 4 days) that fall within the Period (in this case 25 to 40 days). The first multiple of 4 that falls within the Period is 28.

By default, Period Timesteps are not saved as part of time history results. However, if you check **Include in Time Histories**, these scheduled timesteps will be saved. In this case, the **Save Every** option on the main **Time** tab applies to these shorter steps. For example, if you have a 100 day simulation, a 5 day basic step, a 1 day step applied for the first 10 days, and **Save Every** is set to 2, then GoldSim would save time history results at 0, 2, 4, 6, 8, 10, 20, 30, 40, 50, 60, 70, 80 90, and 100 days.

Read more: Specifying When Time History Results Will Be Saved (page 482).

Once you have added a Period Timestep, you can edit it by pressing the **Edit** button, or delete it by pressing the **Remove** button.

Note: In addition to allowing you to create a predefined schedule of timestep changes using Period Timesteps, you can also instruct GoldSim to dynamically adjust the timestep during a simulation based on the values of specified parameters in your model, or adjust the timestep locally within different portions of your model.

Read more: Dynamically Controlling the Timestep (page 490); Specifying Containers with Internal Clocks (page 493).

A simple example file illustrating adding shorter timesteps over defined periods (PeriodsWithShorterSteps.gsm) can be found in the Running subfolder of the the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

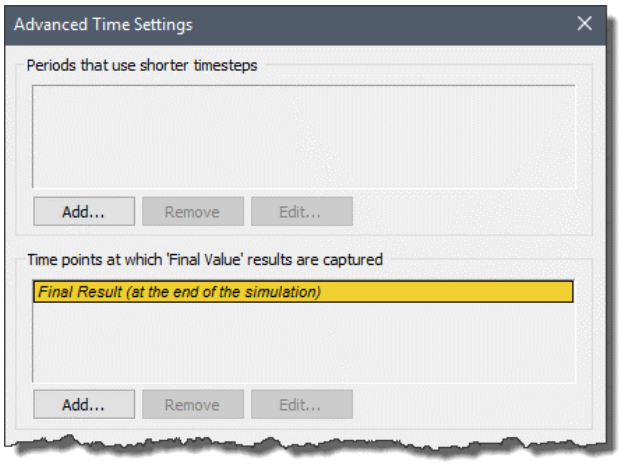
Creating Capture Times for Results

There are two types of results that you can save for an element: Time Histories or Final Values. Final Value type results allow you to display distributions, multi-variate results (e.g., scatter plots), bar charts, pie charts and array plots at specific points in time.

Read more: Viewing the Five Basic Result Types (page 580).

By default, "Final Value" type results are only available at the final time point in the simulation. In some cases, however, you may also want to capture these results at other times in the simulation. This can be useful, for example, if you wanted to view a result distribution for an output at various times during a simulation. GoldSim facilitates this by allowing you to create ***Capture Times*** at which these results are also made available.

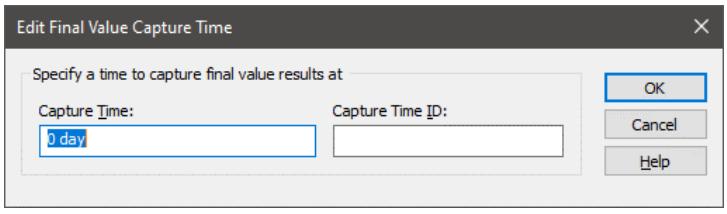
Capture Times are defined toward the top of the Advanced Time Settings page (accessed via the **Advanced…** button on the **Time** tab of the Simulation Settings dialog):



Note that there is always a Capture Time at the end of the simulation (that cannot be deleted). You can add a new Capture Time by pressing the **Add…** button. When you do so, a dialog for specifying the Capture Time will be displayed. The dialog differs based on whether the Time Basis is Elapsed Time or Calendar time.

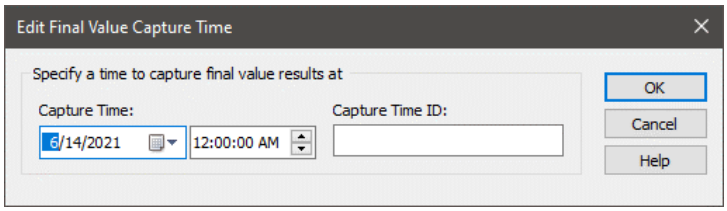
Read more: Defining the Time Basis and Simulation Duration (page 471).

If you are carrying out an Elapsed Time simulation, the dialog looks like this:



The elapsed **Capture Time** should be within the specified simulation duration, and can be defined using any time unit. This can be specified as a number or an equation (but you cannot link to an element).

If you are carrying out a Calendar Time simulation, the dialog looks like this:



The **Capture Time** is specified as a date/time, and should be within the specified simulation period.

When creating a Capture Time, you must provide it with an ID (which can be up to 20 characters long). This ID is used as a label when accessing Capture Time results in various result displays.

Read more: Viewing Results at Capture Times (page 592).

Once you have added a Capture Time, you can edit it by pressing the **Edit** button, or delete it by pressing the **Remove** button.

When you define a Capture Time, a scheduled timestep is added at that time (if one does not already exist).

Note: If you press the **Show Scheduled Updates…** button at the top of the **Time** tab, all of the scheduled timesteps in the model will be displayed. Because Capture Times add scheduled timesteps, you can use this to see exactly where they will be added. Note, however, that although Capture Times are scheduled timesteps, they are not included in time history results.

A simple example file illustrating Capture Times (CaptureTimes.gsm) can be found in the Running subfolder of the the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Controlling Unscheduled Updates

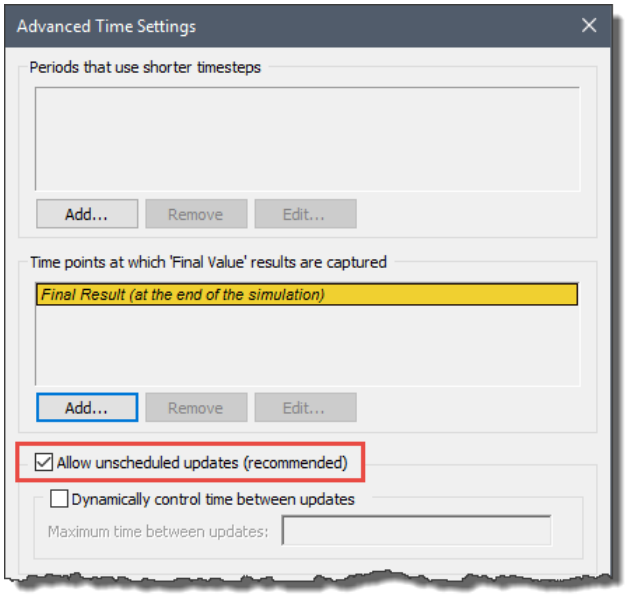
In order to carry out a dynamic simulation, GoldSim steps through time in discrete intervals (referred to as *timesteps*). Calculations (referred to as *updates* of the model) are carried out at end of every timestep. Although the term timestep actually refers to an interval of time, it is often used interchangeably with the term *update* (indicating a calculation at a point in time). In GoldSim, there are two kinds of updates/timesteps: *scheduled updates (or timesteps)* and *unscheduled updates (or timesteps)*.

Read more: Understanding Timestepping in GoldSim (page 473).

Scheduled updates are specified directly prior to running the model. That is, you tell GoldSim when you want these updates to occur. Unscheduled updates are timesteps that are dynamically inserted by GoldSim during the simulation in order to more accurately simulate the system. That is, they are not specified directly prior to running the model. GoldSim inserts them automatically (and, generally, without you needing to be aware of it).

By default, scheduled updates are always dynamically inserted by GoldSim. However, in some (rare) cases, you may want to prevent unscheduled updates from being inserted. For example, if your model included a specialized algorithm that was designed based on the assumption that the timestep was constant, inserting unscheduled updates could invalidate the algorithm.

To support such situations, GoldSim allows you to disable unscheduled updates. You can do so by clearing the checkbox labeled **Allow unscheduled updates (recommended)**:



Warning: Because unscheduled updates are intended to more accurately represent a complex dynamic system, disabling this feature should be done with caution, and is generally not recommended. In most cases, it will have the effect of deferring events to the next scheduled update, which under some circumstances could cause significant inaccuracies. In some cases (e.g., a Reservoir or Pool hitting an upper bound), its effects can be somewhat more complex (e.g., it changes how an overflow rate is computed). Some advanced features in GoldSim cannot function properly at all without using unscheduled updates. In these situations, GoldSim will throw a fatal error during a simulation if you have disabled unscheduled updates and are using such a feature.

Read more: How a Reservoir Computes the Overflow Rate (page 248).

Dynamically Controlling the Timestep

GoldSim allows you to decrease the timestep length according to a specified schedule during a simulation (e.g., start with a small timestep, and then telescope out to a larger timestep) by defining time periods which have different timestep lengths.

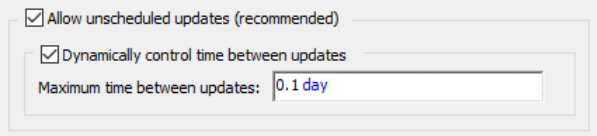
Read more: Adding Shorter Timesteps Over Defined Periods (page 485).

Although defining such time periods can be very useful, you must fully specify them prior to running the simulation. That is, you must know how you would like to alter your timesteps prior to running the model. In some cases, however, it may not be possible to do this. That is, in complex systems (particularly ones with uncertain parameters), variables may change at different rates in different realizations, in ways that you cannot predict prior to running the model.

To better simulate these kinds of systems, GoldSim provides an advanced feature that allows you to dynamically adjust the timestep during a simulation (i.e., insert unscheduled updates) based on the values of specified parameters in

your model. For example, you could instruct GoldSim to use a maximum timestep of 1 day if X was greater than Y, and 10 days if X was less than or equal to Y. Similarly, you could instruct GoldSim to use a short timestep for a period of 10 days after a particular event occurs, and then return to the default timestep.

This feature can be accessed in the Advanced Time Settings dialog (accessed from the **Advanced…** button on the **Time** tab of the Simulation Settings dialog). Within this dialog is a checkbox labeled **Dynamically control time between updates**:



By default, this checkbox is cleared. Checking it allows you to edit the **Maximum time between updates** field, which can be used to dynamically control the timestep (by inserting unscheduled updates).

Note: In order to access this checkbox, **Allow unscheduled updates** must also be checked (the default).

After GoldSim completes all the calculations for a timestep, it must decide when to insert the next timestep. Normally, the next timestep is specified by the Basic Step (or Reporting Periods or Period Timesteps, if defined).

GoldSim uses the value in the **Maximum time between updates** field (referred to as DT_{max} below) to override the normally scheduled timestep according to the following rules:

1. If DT_{max} is greater than or equal to DT_{sched} (the length of time until the next scheduled timestep), the field is ignored and the next timestep is simply the regularly scheduled timestep ($T_{curr} + DT_{sched}$), where T_{curr} is the current time.
2. If DT_{max} is less than or equal to (DT_{sched} /2), the next timestep is $T_{curr} + DT_{max}$.
3. If DT_{max} is greater than (DT_{sched} /2), but less than DT_{sched}, the next timestep is T_{curr} + (DT_{sched} /2) – that is, DT_{sched} is divided into two equal halves.

These rules can be best understood by considering several simple examples:

Example 1: Assume that the next scheduled timestep length is 10 days, and you have specified a **Maximum time between updates** (DT_{max}) of 4 days. GoldSim would compute timesteps at the following points in the first 10 days:

- When time = 0 day, DT_{sched} = 10 days, so DT_{max} is less than (DT_{sched} /2), and according to rule 2, the next step would be computed at 4 days.
- At time = 4 days, DT_{sched} = 6 days, so DT_{max} is greater than (DT_{sched} /2), but less than DT_{sched}, and according to rule 3, the next step would be computed at 7 days.
- At time = 7 days, DT_{sched} = 3 days, so DT_{max} is greater than DT_{sched}, and according to rule 1, the next step would be computed at 10 days.

Example 2: Assume that the next scheduled timestep length is 10 days, and you have specified a **Maximum time between updates** (DT_{max}) of 6 days. GoldSim would compute timesteps at the following points in the first 10 days:

- When time = 0 day, DT_{sched} = 10 days, so DT_{max} is greater than (DT_{sched} /2), but less than DT_{sched}, and according to rule 3, the next step would be computed at 5 days.
- At time = 5 days, DT_{sched} = 5 days, so DT_{max} is greater than DT_{sched}, and according to rule 1, the next step would be computed at 10 days.

Example 3: Assume that the next scheduled timestep length is 10 days, and you have specified a **Maximum time between updates** of 1 day. GoldSim would compute timesteps at the following points in the first 10 days:

- When time is equal to 0 through 8 days, rule 2 applies, and a timestep of 1 day is used (steps occur at 1, 2 ,3 ,4 ,5 ,6 ,7, 8, and 9 days).
- At time =9 days, DTsched = 1 day, so DT_{max} is equal to DT_{sched}, and according to rule 1, the next step would be computed at 10 days.

In all three of these examples, the actual timestep length is always less than or equal to the specified **Maximum time between updates**. Moreover, the scheduled timesteps defined by the Basic Step, Reporting Periods or Period Timesteps are always observed.

Note: Because certain events (e.g, triggered by a Timed Event or a Reservoir hitting an upper bound) are automatically represented by GoldSim with greater accuracy by allowing them to fall between scheduled timesteps, any events that occur could result in a smaller timestep than that computed using the rules presented above. That is, after GoldSim computes the next timestep based on the rules presented above, it then checks to see if an event would fall within that interval. If an event does fall into that interval, the timestep could be shortened in order to represent the event.

Read more: Understanding Timestepping in GoldSim (page 473).

In practice, you would not normally specify the **Maximum time between updates** as a constant (as you could accomplish the same thing by simply appropriately defining scheduled timesteps. Instead, you would specify it as a variable (i.e., a function). For example:

- If you wanted to reduce the timestep of a model from 10 days to 1 day whenever variable X was close to (say within 10% of) variable Y, you would define your Basic Step as 10 days, and define **Maximum time between updates** as the function: if(abs(X-Y)/Y < 10%, 1 day, 10 day).
- If you wanted to reduce the timestep to 1 day for a period of 20 days after a particular event occurred, and then return the timestep to its default (e.g., 10 days), you could do this by: 1) triggering an Event Delay when the original Event occurs, with a delay time of 20 days; and 2) defining **Maximum time between updates** as the function: if(EventDelay.Num_in_Transit>0, 1 day, 10 day).

In addition to providing this dynamic timestepping algorithm on a global scale (i.e., for the entire model), GoldSim also enables you to apply a Maximum time

between updates to specific Containers. As a result, you could apply a maximum timestep length only to a portion of your model (represented by a particular Container).

Read more: Specifying Containers with Internal Clocks (page 493).

Note: If the **Maximum time between updates** is less than or equal to zero, a warning message will be written to the Run Log, and it will be ignored (which is equivalent to clearing the **Dynamically control time between updates** checkbox).

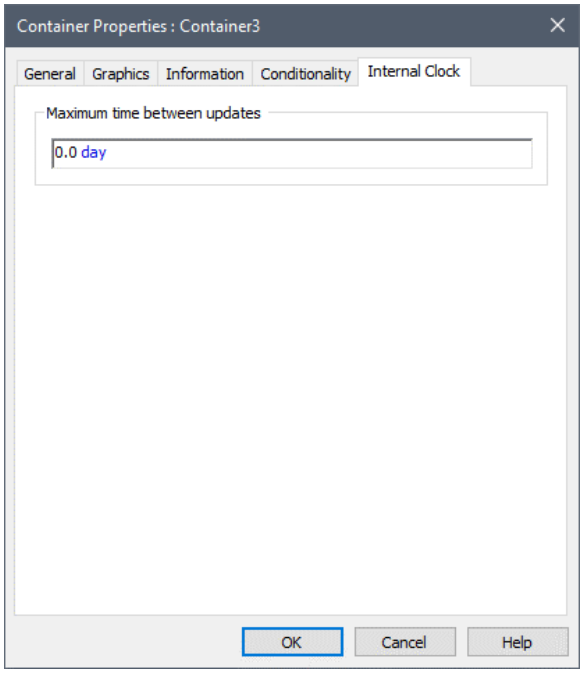
Note: By default, time history displays only include scheduled timesteps, and will not capture unscheduled updates. However, GoldSim provides an option (under a specified set of conditions) in the Advanced Time settings that allows you to include both scheduled and unscheduled updates in a time history display. This provides a mechanism to display and view the exact times at which unscheduled updates are inserted.

Read more: Including Unscheduled Updates in Time History Results (page 496).

Specifying Containers with Internal Clocks

In some situations, you may wish to use different timesteps in different portions of your model. This is useful, for example, if the processes represented in one portion of your model occur rapidly and hence require a short timestep to model accurately, while processes represented in the rest of your model occur much more slowly, such that a larger timestep can be used.

You can specify smaller timesteps for a Container by assigning the Container an "internal clock". Containers can be assigned internal clocks by selecting the **Internal Clock** feature in the Container dialog. When you assign an internal clock to a Container, an **Internal Clock** tab is added to the Container dialog:



Containers with internal clocks are represented in the graphics pane as follows:

Note: When you specify a Container as having an **Internal Clock**, you cannot also define it as having **Looping Capability** (these two options are mutually exclusive).

Certain events (e.g, triggered by a Timed Event or a Reservoir hitting an upper bound) are automatically represented by GoldSim with greater accuracy by allowing them to fall between scheduled timesteps.

Read more: Understanding Timestepping in GoldSim (page 473).

An important implication of an Internal Clock Container is that any unscheduled timesteps generated *inside* the Container only interrupt the clock pertaining to that Container (and hence cause the elements in the Container to update). They do not cause elements *outside* the Container to be updated.

To understand this, consider the following simple example. Suppose that your model had a 10 day timestep. Within an Internal Clock Container, you added a Timed Event that occurred at 5 days. This Timed Event triggered two elements: one inside the Container and one outside the Container. In this model, the element inside the Container would be updated at 5 days. However, the element outside the Container would not be updated until 10 days (the first scheduled timestep after the event occurred). That is, the unscheduled update does not interrupt the clock outside the Container. The element outside the Container is still impacted by the event, but not until it is updated (e.g., due to a scheduled update, or due to an unscheduled update triggered outside of the Container).

It is also important to understand that while unscheduled updates within an Internal Clock Container do not cause elements outside the Container to update, unscheduled updates *outside* the Container *do* cause elements inside the Container to update. That is, unscheduled updates within the Container cannot "flow" outside the Container, but unscheduled updates outside the Container do "flow" in.

While it is important to understand this behavior with regard to unscheduled timesteps automatically inserted by GoldSim, perhaps the most common use of an Internal Clock Container is to manually force a shorter timestep within the Container.

By default, the **Maximum time between updates** is set to 0 (and if you leave it unchanged or set it to a negative number, it will be ignored, as a non-positive length has no meaning).

When GoldSim starts to carry out the calculations for a Container that has an internal clock (or after GoldSim completes a timestep within the Container), and it is at a time we will call T_{curr}, it must decide when to insert the next timestep inside the Container.

GoldSim uses the value in the **Maximum time between updates** field (referred to as DT_{max} below) to compute the next timestep inside the Container according to the following rules:

1. If DT_{max} is greater than DT_{glob} (the length of time until the next global timestep), the field is ignored and the next timestep is simply the

regularly scheduled timestep (T_{curr} + DT_{glob}). (As a result, a Container with an internal clock can never have a timestep that is *longer* than the global timestep.)

2. If DT_{max} is less than DT_{glob}, GoldSim computes an internal timestep length (an unscheduled update), DT_{int}, equal to DT_{glob}/N, where N is the smallest integer such that $DT_{glob}/N <= DT_{max}$. That is, GoldSim subdivides DT_{glob} such that the internal step is as large as possible, but less than or equal to DT_{max}.

Note: Because certain events (e.g, triggered by a Timed Event or a Reservoir hitting an upper bound) are automatically represented by GoldSim with greater accuracy by allowing them to fall between scheduled timesteps, any events that occur could result in a smaller timestep than that computed using the rules presented above. That is, after GoldSim computes the next timestep based on the rules presented above, it then checks to see if an event would fall within that interval. If an event does fall into that interval, the timestep could be shortened in order to represent the event.

Read more: Understanding Timestepping in GoldSim (page 473).

In most cases, you will specify the **Maximum time between updates** as a constant in order to specify a shorter timestep for a portion of your model (e.g., assigning a **Maximum time between updates** of 1 day to a Container in which the global timestep is 10 days). This variable can also be specified to vary dynamically in response to parameter values inside the Container.

Note: By default, time history displays only include scheduled updates, and will not capture unscheduled updates. However, GoldSim provides an option to do so (under a specified set of conditions) in the Advanced Time settings. This provides a mechanism to display and view the exact times at which unscheduled updates are inserted within a Container with an Internal Clock.

Read more: Including Unscheduled Updates in Time History Results (page 496).

Warning: When you assign an internal clock to a Container, the **Treat as SubSystem** feature is also automatically selected (and cannot be deselected unless you first turn off **Internal Clock**). That is, a Container with an internal clock, by definition, is treated as a SubSystem. Because a Container with an internal clock is treated as a SubSystem, this puts certain limitations on how these Containers can be used.

An example file which illustrates the use of Internal Clocks for Containers (InternalClock.gsm) can be found in the Containers subfolder of the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Read more: Treating a Container as a SubSystem (page 140).

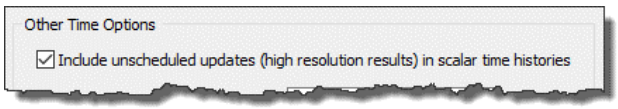
Including Unscheduled Updates in Time History Results

In some cases, events or other changes in the model may not fall exactly on a scheduled update. That is, some events or changes may actually occur between scheduled updates of the model. These trigger an "unscheduled update" of the model. Unscheduled updates are timesteps that are dynamically inserted by GoldSim during the simulation in order to more accurately simulate the system.

Read more: Understanding Timestepping in GoldSim (page 473).

Unlike scheduled updates, unscheduled updates do not normally appear in time history plots and tables. That is, although these timesteps may affect the results (e.g., by making them more accurate at the scheduled timesteps), unscheduled updates of the model are not saved and displayed. Only the scheduled updates are actually saved and displayed.

In some cases, however, it may be of interest to see the values of selected outputs at unscheduled updates. To facilitate this, GoldSim provides an option in the Advanced Time settings to save results at unscheduled updates (referred to as "high resolution" results). This option appears at the bottom of the Advanced Time Settings dialog (accessed from the **Advanced…** button on the **Time** tab of the Simulation Settings dialog):



By default, the checkbox labeled **Include unscheduled updates (high resolution results) in scalar time histories** is cleared. If you check this box, GoldSim will save unscheduled updates for time history results (referred to as "high resolution" results) under the following conditions:

- High resolution results can only be viewed from within Time History Result elements. If the output is not referenced by a Time History Result element, high resolution results will not be displayed.

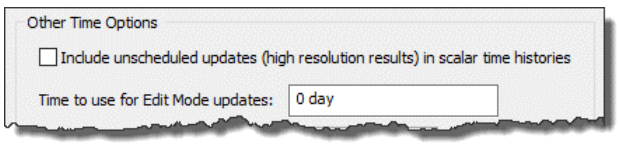
  Read more: Viewing Unscheduled Updates in Time History Result Elements (page 652).

- High resolution results are only available for single realization runs (Deterministic simulations or probabilistic simulation with a single realization).

- High resolution results are only available for scalar outputs.

Referencing Time in Edit Mode

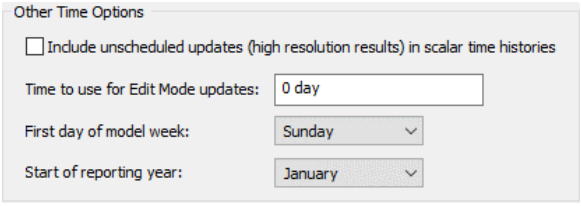
When you place the cursor over an element, an input or an output prior to running a simulation, GoldSim displays a tool-tip showing the object's current (expected) value. If the object is a function of Etime, by default this calculation assumes a value of 0. You can modify the value used in such a calculation by editing **Time to use for Edit Mode updates** at the bottom of the Advanced Time Settings dialog (accessed from the **Advanced…** button on the **Time** tab of the Simulation Settings dialog):



Controlling When Weeks and Years Start

In some situations, you may wish to directly specify what GoldSim considers to be the first day of the week (**First day of model week**) and the first month of the year (**Start of reporting year**).

These can be specified at the bottom of the Advanced Time Settings dialog (accessed from the **Advanced…** button on the **Time** tab of the Simulation Settings dialog):



This information is then used in the following ways:

First day of model week

- When using "Weeks" as the Basic Step, and selecting "Calendar aligned" for the Alignment, the specified "First day of model week" controls where each new timestep is placed.

  Read more: Specifying the Basic Step Length and Alignment (page 477).

- If you define a "weekly" Reporting Period, where the Periods are added is controlled by how you define the "First day of model week". Weekly Periods are added at midnight on the specified first day of the week.

  Read more: Defining Reporting Periods (page 479).

- The "DayofWeek" Run Property (a number from 1 to 7) is controlled by how you define the "First day of model week". The value 1 corresponds to the specified first day.

- The "WeekofYear" and "YearOfWeek" Run Properties are used to track the week of the year. When these are incremented is a function of the "First day of model week".

- ***Read more:*** Understanding and Referencing Run Properties (page 505).

Start of reporting year

- If you define an "annual" or "quarterly" Reporting Period, where the Periods are added is controlled by how you define the "Start of reporting year". Annual Periods are added on the first day of the month selected as the "Start of the reporting year". Quarterly Periods are added on the first day of the month selected as the "Start of the reporting year", and the first days of the months 3, 6 and 9 months after the selected month.

Setting the Monte Carlo Options

The **Monte Carlo** tab of the Simulation Settings dialog is used to specify the Monte Carlo options for a simulation. This consists of those parameters which control how probabilistic simulations will be carried out, such as the number of realizations, and how the sampling of Stochastic variables is to be carried out (e.g., whether Latin Hypercube sampling is to be used).

Note: Appendix A provides an introduction to probabilistic simulation techniques, and introduces the basic terminology required to understand the Monte Carlo options presented in this dialog. The discussion that follows assumes that you are familiar with the concepts discussed in that appendix.

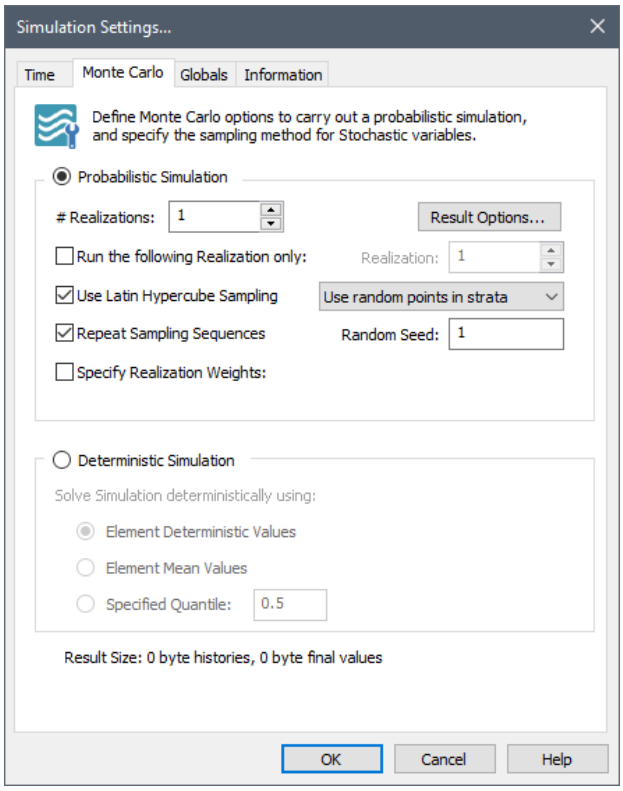
There are two basic types of simulations that you can carry out with GoldSim:

- In a **Probabilistic Simulation**, one or more input parameters are represented as probability distributions (and/or some processes are represented as being stochastic) and a simulation is carried out by running the model multiple times.
- In a **Deterministic Simulation**, single values are used for each input parameter, and a simulation is carried out by running the model a single time.

These two types of simulation are discussed in detail in the sections below.

Probabilistic Simulation Options

To run a probabilistic simulation in GoldSim, select the **Probabilistic Simulation** radio button in the **Monte Carlo** tab of the Simulation Settings dialog (which is the default):



You must then select the number of realizations **(# Realizations**), which defaults to 1.

If you check the **Run the following Realization only** checkbox, GoldSim runs only a single realization (specified in the **Realization** field immediately to the right). In this case, the random number sequence that is used is based on the **Realization** specified and (if Latin Hypercube Sampling is on) the total number of realizations (**# Realizations)**. Hence, if you first run a 100 realization simulation, and then run a second simulation with **Run the following Realization only** checked (and, for example, **Realization** set to 14), the result of the second simulation will be identical to the 14th realization of the first simulation.

This is used in cases where you first run a large number of realizations (but only save a limited number of time histories) and then want to examine the details

(i.e., the time history) for a particular realization for which you did not save time histories, but which exhibited some interesting behavior.

GoldSim provides two primary ways in which you can control the manner in which the Monte Carlo sampling of Stochastic elements takes place:

- implementing Latin Hypercube sampling; and
- repeating sampling sequences.

If **Use Latin Hypercube Sampling** is checked (the default), GoldSim uses Latin Hypercube sampling. This sampling method causes probability distributions (i.e., Stochastic elements) to be divided into a number of equally likely "strata". This has the effect of ensuring that the probability space of the parameter is uniformly spanned. When using Latin Hypercube sampling, you can choose whether each stratum is sampled randomly ("Use random points in strata"), or if the mid-point of each stratum is used ("Use mid-points of strata").

In addition to Latin hypercube sampling, you can also specify ***importance sampling*** for individual Stochastic elements. Importance sampling allows you to over-sample the tails of a distribution.

Read more: Applying Importance Sampling to a Stochastic Element (page 187).

Note: Importance sampling changes the weight of realizations so they are not all equal. If using importance sampling *and* specifying realization weights, the relative realization weights are applied after the importance sampling is applied.

If **Repeat Sampling Sequences** is checked (the default), a repeatable random number sequence is used (based on the specified **Random Seed**), allowing you to repeat the simulation exactly. If this box is cleared, the random number is based on the current date and time, such that the random number sequence will be different every time you run the model.

Note: Each element that exhibits random behavior (e.g., Stochastics, Delays) is assigned an "internal" random number seed when it is first created and this is stored with the element. The random number used for that element is then a function of both its "internal" random number seed, the number specified in the **Random Seed** field, and the realization number. Hence, if you create a file and then copy it to another person, when they run it, they will produce the same random numbers as you (as long as you both have the same number specified for the **Random Seed**). However, if that person builds the exact same model independently, you will always produce different random numbers, since the "internal" seeds for the Stochastics will be different.

The **Specify Realization Weights** option is an advanced feature that provides the ability to manually specify the relative weight for each realization. Realization weights are used to compute statistics and create the CDF. If doing simple Monte Carlo sampling, each realization, by definition, has an equal weight (i.e., each realization is equally likely). The primary reason to manually specify realization weights is to carry out *customized* importance sampling of Stochastic elements.

Read more: Customized Importance Sampling Using User-Defined Realization Weights (page 1089).

If you select the **Specify Realization Weights** box, an Insert link dialog appears, and you must select an element that defines the *relative* realization weights (e.g., equally weighted realizations could all have weight of 1). It must be a non-negative, dimensionless scalar, and GoldSim will use the value at the end of the realization. Obviously, to be of any value, this must vary from realization to realization. If you simply link to a value that is independent of the realization (e.g., a constant), it will have no impact on the weights.

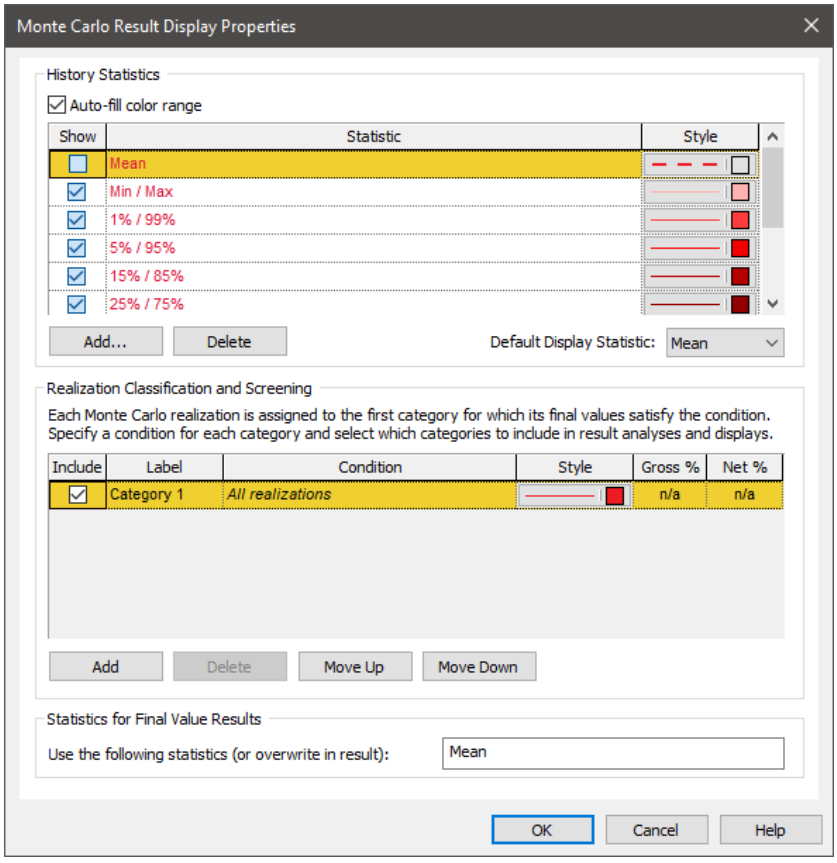
The manner in which GoldSim implements random seeds, as well as other details of the sampling algorithm (such as Latin Hypercube sampling and importance sampling) are discussed in Appendix B.

The **Result Options…** button provides access to a dialog for controlling how various Monte Carlo results are saved and displayed.

Read more: Controlling Monte Carlo Result Options (page 500).

Controlling Monte Carlo Result Options

The Monte Carlo Result Display Properties dialog allows you to control how Monte Carlo results (simulations with multiple realizations) are saved and displayed:



This dialog can be accessed from the **Monte Carlo** tab of the Simulation Settings dialog (via the **Result Options…** button), and is also accessible from result properties dialogs.

Read more: Viewing and Editing Result Properties (page 587).

The top section of the dialog (History Statistics) is used to specify how time history results with multiple realizations will be displayed. In particular, it

allows you to define the percentiles of a particular presentation option for Monte Carlo time histories (referred to as probability histories), and also allows you to define a default custom statistic (**Default Display Statistic**) that is the default when viewing time history statistics for multiple realization simulations.

Read more: Viewing Probability Histories for Multiple Realizations (page 623); Viewing Custom Statistics for Multiple Realizations.

The middle portion of the dialog (Realization Classification and Screening) allows you to define "categories" of realizations (e.g., "realizations in which X > 10"). You can then choose to show these categories on charts in different colors and/or choose to screen certain categories entirely from result displays.

Read more: Classifying and Screening Realizations (page 601).

The bottom portion of the dialog (Statistics for Final Value Results) allows you to specify the default statistics displayed by Final Value results for multiple realization simulations. Multiple statistics can be specified:

When defining these statistics, the following should be noted:

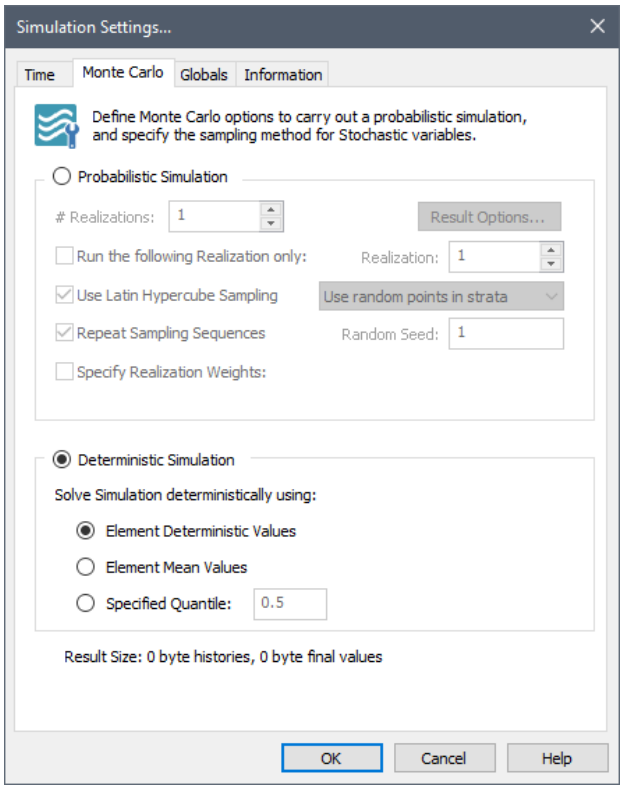
- Values can be separated by commas, spaces or semicolons (the latter two are converted to commas).
- Percentiles can be entered as percentages (between 0% and 100% inclusive) or numbers (between 0 and 1 inclusive).
- 50% can also be entered as the word "median".
- 0% and 100% can be entered as the words "min" and "max", respectively.

Note: The default statistics can be overwritten in each specific Final Value result.

Read more: Displaying Multiple Realizations in Final Value Results (page 715).

Deterministic Simulation Options

To run a deterministic simulation in GoldSim, select the **Deterministic Simulation** radio button in the **Monte Carlo** tab of the Simulation Settings dialog:



In a deterministic simulation, a single realization will be carried out using a deterministic value for each Stochastic element. When you do so, it is necessary to specify what deterministic values are to be used for each Stochastic element.

As can be seen, there are three options for running a deterministic simulation:

Element Deterministic Values: In this case, the deterministic value explicitly specified in the Stochastic element property dialog is used for each Stochastic element.

Element Mean Values: In this case, the mean value of each Stochastic is used (overriding any deterministic value specified for each Stochastic).

Specified Quantile: In this case, the specified quantile (a number between 0 and 1) of each Stochastic is used (overriding any deterministic value specified for each Stochastic).

Read more: Specifying a Deterministic Value for a Stochastic (page 186).

Note: If you are resampling a Stochastic during a **Deterministic Simulation**, its value will not change (i.e., it will not behave stochastically), unless the distribution itself is changed as a function of time.

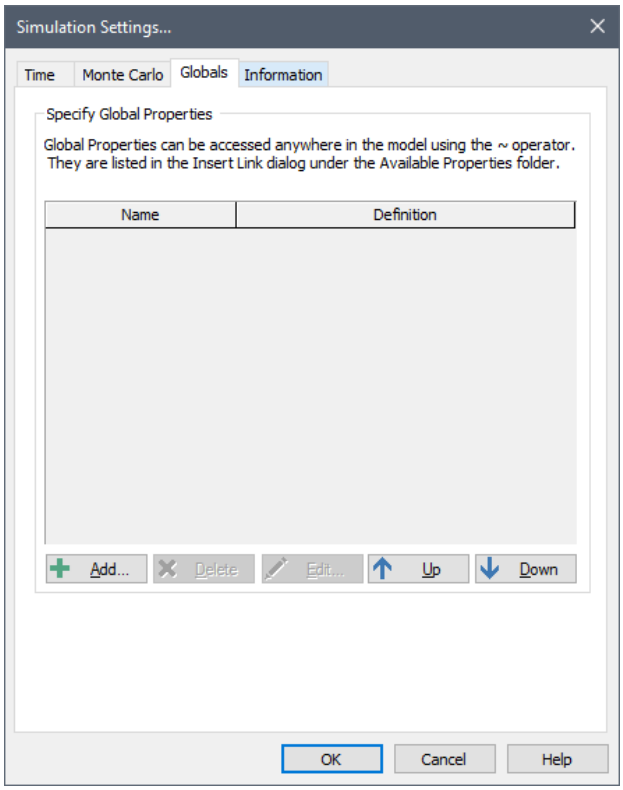
Stochastic elements are not the only elements that behave probabilistically. Several other elements in GoldSim also do so. In a Deterministic Simulation, these elements also behave deterministically (i.e., their behavior is no longer random):

- Randomly time-shifted Time Series are sampled from the middle of the historic data (i.e., the starting point is based on the median value of the series).
- Random Timed Events occur regularly, not randomly.
- Random Choice elements use the mean value.
- History Generator elements assume zero volatility.
- Delay elements assume zero dispersion.
- Elements from the Reliability Module that simulate failures and repairs assume mean values (and hence the events occur regularly).

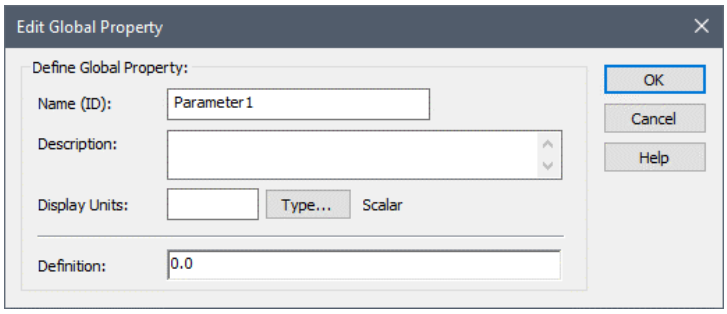
Defining and Referencing Global Properties

In some cases, you may want to define global properties that can be referenced throughout your model. Of course, one way to do this is to simply define Data elements at the global level of the model (i.e., outside of any localized Containers).

GoldSim also provides a more convenient way to do this via the **Globals** tab of the Simulation Settings dialog:



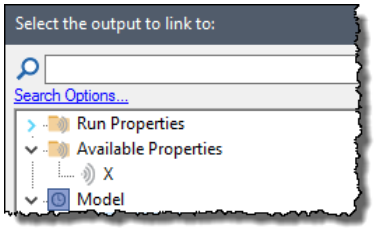
This dialog allows you to add Global variables (referred to as Global properties) to your model. This is done by pressing the **Add…** button. When you do so, the following dialog is displayed:



The **Name (ID)** is the name by which the Global variable can be referenced throughout your model. This Name has the same restrictions as an element ID. The **Description** is an optional description of the variable. You must then specify the **Display Units** and **Type** information (e.g., value/condition, scalar/vector/matrix) for the variable. Finally, you specify the **Definition** for the variable. Typically, this will be a single value However, it can also be an equation (involving constant values). This field, cannot, however, reference any other outputs in the model.

Once you have added a Global property, you can subsequently reference the variable by using the specified **Name** that you defined previously, preceded by a ~. For example, if you create a Global called X, you could reference it in input fields anywhere within the model as ~X.

Global properties are special instances of what are referred to as locally available properties in GoldSim. Locally available properties are accessed by using a ~. Global properties are available in the Insert Link dialog within the Available Properties folder:



Read more: Understanding Locally Available Properties (page 874).

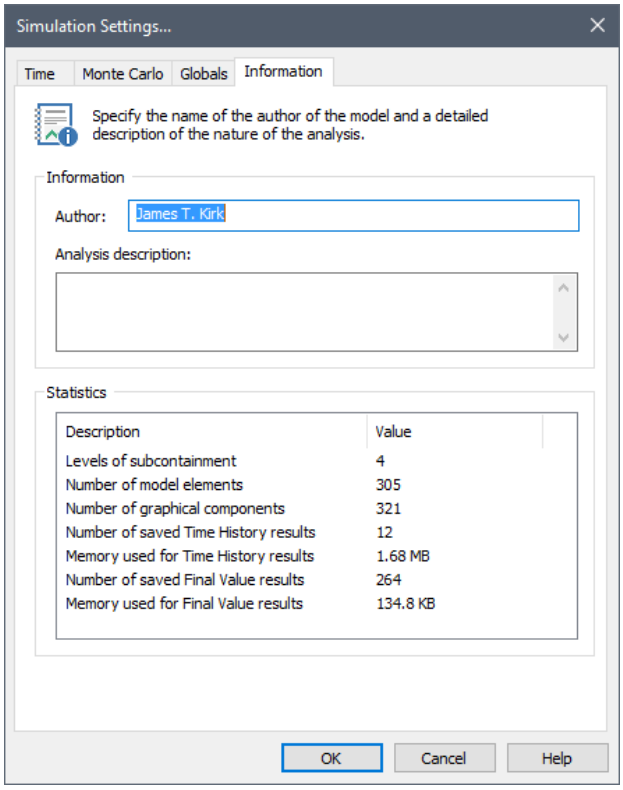
Note: Because a Global property is always referenced using a ~, a Global property can share a name with an element. For example, if a Global property existed named X and a Data element also existed with the same name, there would be no conflict. The Global property would be referenced as ~X, and the Data element's output would be referenced as X.

Note: The Global properties tab is also used to "hold" the input interface for a SubModel that has been exported as a standalone model.

Read more: Using SubModels to Embed Models Within Models (page 1047).

Viewing and Editing Model Summary Information

The **Information** tab of the Simulation Settings dialog displays some summary information regarding your simulation:



The top part of the dialog provides two fields (**Author** and **Analysis description**) which allow you to identify the author and provide a brief description for your run. These fields have two uses:

- They are written to the Run Log; and
- They can be inserted into result charts using keywords.

Read more: The Run Log (page 569); Using Keywords in Styles (page 783).

The bottom part of the dialog provides some useful summary statistics for the model, including the number of model elements and graphical components, and the degree of subcontainment. The number of levels of subcontainment does not refer to the number of Containers; it refers to the number of hierarchical levels of Containers. For example, if the model contained Containers B and C (in parallel), the model would have 1 level of subcontainment; if B contained another Container named C, the model would have 2 levels of subcontainment.

The dialog also indicates the total size of the results being saved for all elements within the model. This information can be very useful in helping you to manage the size of the model file.

Understanding and Referencing Run Properties

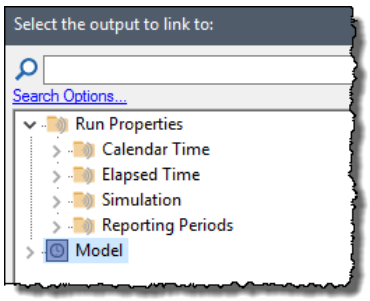
Within a simulation model, you often need to reference within input expressions internal model variables like the elapsed time, the date/time, and the realization number. To facilitate this, GoldSim provides a number of special reserved names, referred to as Run Properties, that can be directly referenced in

expressions. The most commonly used Run Properties are ETime (the simulated elapsed time) and DateTime (the simulated calendar date-time).

Read more: Referencing Time in GoldSim (page 102).

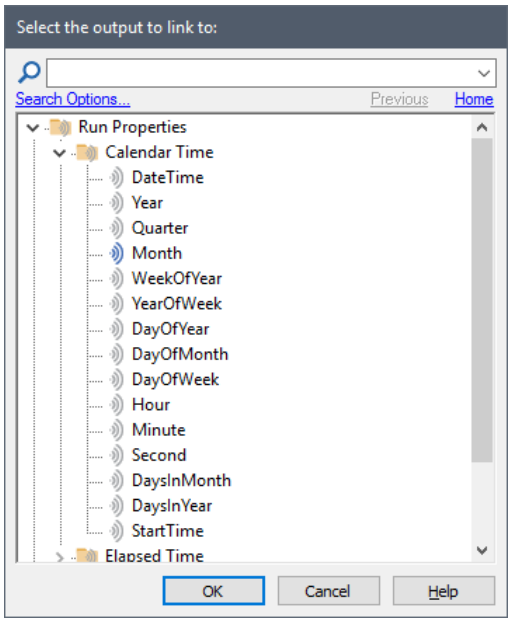
In addition to ETime and DateTime, GoldSim also provides many additional Run Properties that can be referenced in your model.

You can enter the names of the Run Properties directly when creating expressions (just as you would enter the name of an output), or you can insert them into an expression using the Insert Link dialog (accessed by right-clicking in an input field and selecting **Insert Link…** from the menu).



As can be seen above, at the top of the dialog is a folder labeled "Run Properties". If you expand this folder, you will see that all of the Run Properties are organized into four categories (Calendar Time, Elapsed Time, Simulation and Reporting Periods).

Expanding any particular category folder lists all of the Run Properties in that category:



As can be seen, the icon for the various Run Properties is different than that used for element outputs. This is because the Run Properties don't actually represent the output of any particular element. They are special model properties that are "broadcast" throughout the model and can be referenced anywhere.

Note: The color of the symbol changes if the Run Property is actually being referenced in a model. If it is not being referenced, it is gray. Otherwise, it is blue. In the example above, the Run Property "Month" is being referenced.

Note: Run Properties are an instance of a class of variables called Locally Available Properties. Locally Available Properties derive their name from the fact that in specialized cases, they may only be available, or may take on different values (i.e., be over-ridden), in "local" parts of your model (e.g., within particular Containers). In the case of Run Properties, they are always available throughout the model, but some of these properties are overridden locally if a Container is defined to have an internal clock (a local timestep).

Read more: Understanding Locally Available Properties (page 874); Specifying Containers with Internal Clocks (page 493).

Note: All the Run Properties are protected names, so, for example, you cannot create an element named "ETime" or "DateTime".

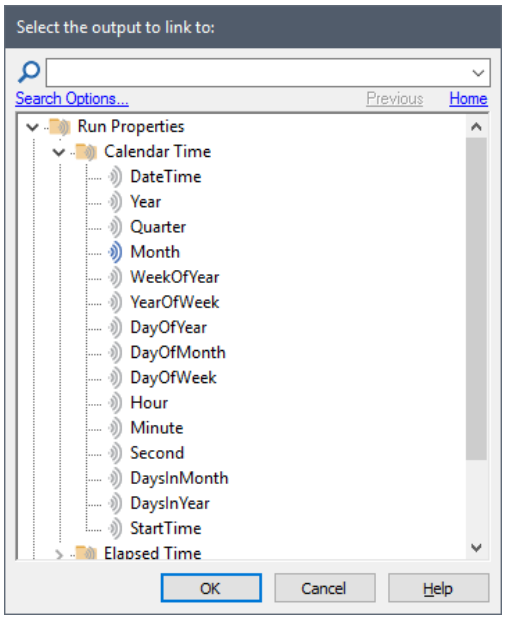
Note: You cannot directly save a time history of a Run Property, or reference it in a Result element. If you wish to do so, link it to an Expression and save or reference the Expression element in the Result element.

The four categories of Run Properties are discussed in the sections below.

Run Properties: Calendar Time

GoldSim provides a number of special reserved names, referred to as Run Properties, that can be directly referenced in expressions. Some Run Properties are associated with Calendar Time. That is, they return information regarding the simulated date and time of a simulation.

These can be found under the "Calendar Time" folder:



Note: Because even Elapsed Time simulations have a specified Start Time, Calendar Time Run Properties are available for both Elapsed Time and Calendar Time simulations.

The Calendar Time Run Properties are described below:

DateTime: This represents the elapsed time from a reference point (December 30, 1899 at 00:00:00 – that is, one day before the beginning of the twentieth century). It has units of time.

Note: You can compare the DateTime Run Property to an actual calendar date by enclosing the date in quotation marks within an expression. For example, this if statement would compare the simulated date to the specified date of 15 April 2012: if(DateTime > "15 April 2012", 1, 2).

Read more: Referencing Dates in Expressions (page 135).

Year: This is the calendar year. It is unitless.

Note: The Run Property "Year" (an integer representing the calendar year) should not be confused with the unit "yr" (which is defined as 365.25 days).

Quarter: This is the calendar quarter (an integer between 1 and 4), assuming the first quarter starts on January 1. It is unitless.

Month: This is the calendar month (an integer between 1 and 12). It is unitless.

Note: The Run Property "Month" (an integer between 1 and 12) should not be confused with the unit "mon" (which is defined as 30.4375 days).

WeekOfYear: This is the week number for the current YearOfWeek (see below). It is a unitless integer between 1 and 53. Each week starts (and hence WeekOf Year changes) on the "first day of model week" specified in the Advanced Time Settings dialog.

Read more: Controlling When Weeks and Years Start (page 496).

YearOfWeek: This is the nominal year for the current WeekOfYear (see above). It is a unitless integer. YearOfWeek is incremented at the start of the first week that has the majority of its days in the next calendar year. Thus at the beginning of the first week that starts after December 28, YearOfWeek is incremented to the next calendar year, and WeekOfYear is reset to 1.

DayOfYear: This is the calendar day of the year (an integer number between 1 and 366). It is unitless.

DayOfMonth: This is the calendar day of the month (an integer between 1 and 31). It is unitless.

DayOfWeek: This is the calendar day (an integer between 1 and 7). It is unitless. The weekday corresponding to the value 1 is determined by the specified "First day of model week" specified in the Advanced Settings of the Time tab of the Simulation Settings dialog.

Hour: This is the calendar hour (an integer between 0 and 23). It is unitless.

Minute: This is the calendar minute (an integer between 0 and 59). It is unitless.

Second: This is the calendar second (an integer between 0 and 59). It is unitless.

DaysInMonth: This is the number of days in the current calendar month (an integer between 28 and 31). It is unitless.

DaysInYear: This is the number of days in the current calendar year (either 365 or 366). It is unitless.

StartTime: This is the simulated Start Time for the simulation (expressed relative to December 30, 1899 at 00:00:00). It has units of time and is generally viewed as a date. It can be compared to other dates in expressions.

Note: An example file which illustrates the use of Calendar Time Run Properties (RunProperties.gsm) can be found in the General Examples/ Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

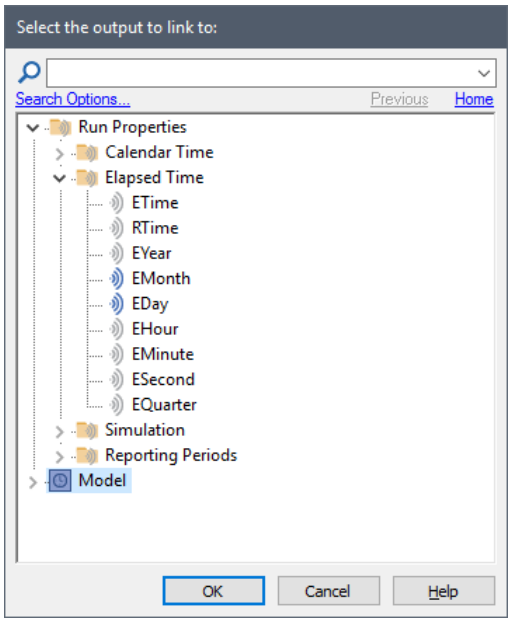
Note: The Run Properties Year, Quarter, Month, WeekofYear, DayOfMonth, DayofWeek, DayofYear, Hour, Minute and Second can be particularly useful for triggering events that must occur exactly every year, quarter, month, week, day, hour, minute or second. For example, if you had a 1 day timestep (or smaller), defining an OnChanged trigger as DayofYear or DayOf Month would force the element to be triggered every day. An example file which illustrates this (RunProperties.gsm) can be found in the General Examples/ Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Read more: Specifying Triggering Events (page 370).

Run Properties: Elapsed Time

GoldSim provides a number of special reserved names, referred to as Run Properties, that can be directly referenced in expressions. Some Run Properties are associated with Elapsed Time. That is, they return information regarding the simulated elapsed time.

These can be found under the "Elapsed Time" folder:



The Elapsed Time Run Properties are described below:

Etime: This is the elapsed time since the start of the simulation. It has units of time.

RTime: This is the remaining time in the simulation (computed as total duration minus the elapsed time). It has units of time.

EYear: This is the integer number of *average* years that have elapsed since the start of the simulation (hence, at the start of the simulation, it is zero). For the purposes of the calculation, an average year is computed as 365.25 days. It is unitless.

EQuarter: This is the integer number of *average* quarters that have elapsed since the start of the simulation (hence, at the start of the simulation, it is zero). For the purposes of the calculation, an average quarter is assumed to have 365.25/4 = 91.3125 days. It is unitless.

EMonth: This is the integer number of *average* months that have elapsed since the start of the simulation (hence, at the start of the simulation, it is zero). For the purposes of the calculation, an average month is assumed to have 365.25/12 = 30.4375 days. It is unitless.

EDay: This is the integer number of days that have elapsed since the start of the simulation (hence, at the start of the simulation, it is zero). It is unitless.

EHour: This is the integer number of hours that have elapsed since the start of the simulation (hence, at the start of the simulation, it is zero). It is unitless.

EMinute: This is the integer number of minutes that have elapsed since the start of the simulation (hence, at the start of the simulation, it is zero). It is unitless.

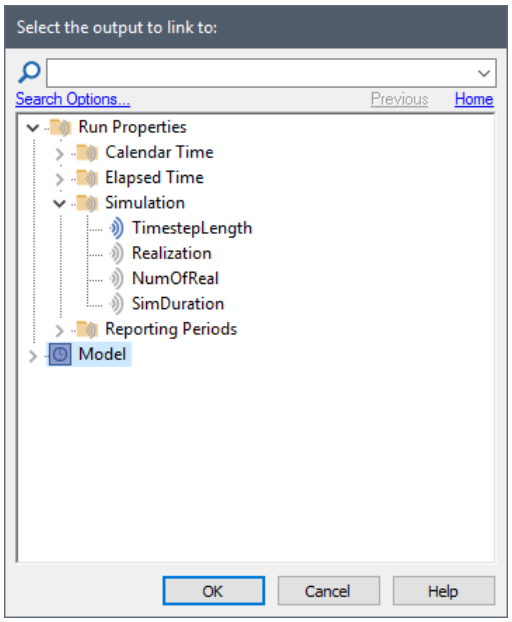
ESecond: This is the integer number of seconds that have elapsed since the start of the simulation (hence, at the start of the simulation, it is zero). It is unitless.

Note: An example file which illustrates the use of Elapsed Time Run Properties (RunProperties.gsm) can be found in the General Examples/ Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Run Properties: Simulation

GoldSim provides a number of special reserved names, referred to as Run Properties, that can be directly referenced in expressions. Some Run Properties return basic information about the simulation.

These can be found under the "Simulation" folder:



The Simulation Run Properties are described below:

TimestepLength: This is the length of the current timestep. More specifically, it is the time since the last model update. (At time = 0, the TimestepLength is set to the length of the first scheduled timestep). Note that under some circumstances (e.g. when creating "unscheduled updates"

to better represent discrete events, or to dynamically adjust the timestep during a simulation), a model can be updated between scheduled timesteps, and this will be reflected by the TimestepLength Run Property.

Read more: Understanding Timestepping in GoldSim (page 473); Dynamically Controlling the Timestep (page 490).

Note: At Etime = 0, TimestepLength returns the anticipated length of the first step (i.e., the length of the first scheduled timestep).

Note: An example file which illustrates the use of TimestepLength (RunProperties.gsm) can be found in the General Examples/ Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Realization: This is the realization number. For a deterministic simulation, it is always equal to 0. It is unitless.

NumOfReal: This is the total number of realizations being carried out in the simulation.

Note: NumOfReal actually represents the value entered into the **# Realizations** field in the Simulation Settings dialog, and this is not necessarily the same as the number of realizations that are carried out. In some cases (e.g., if you specify a Deterministic run, if you instruct GoldSim to run a particular realization, or if you are doing distributed processing), GoldSim will actually only run a single realization, but would still report the value from the **# Realizations** field as the NumOfReal.

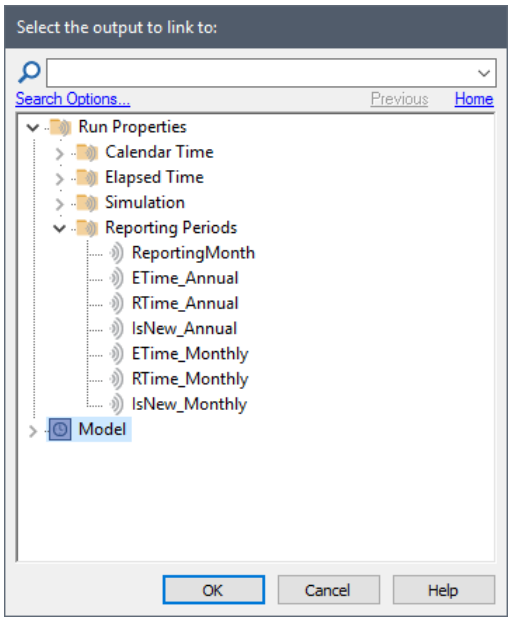
SimDuration: This is the total duration (i.e., the amount of simulated time) represented by the simulation.

Run Properties: Reporting Periods

GoldSim provides a number of special reserved names, referred to as Run Properties, that can be directly referenced in expressions. Some Run Properties are associated with Reporting Periods that you have defined in the Simulation Settings dialog.

Read more: Defining Reporting Periods (page 479).

These can be found under the "Reporting Periods" folder:



The Reporting Periods Run Properties are described below:

ReportingMonth: This is the current reporting month, relative to the month specified as the "Start of reporting year" in the the Advanced Settings of the Time tab of the Simulation Settings dialog. For example, if the "Start of reporting year" was defined as April, and the current month in the simulation was June, ReportingMonth would be 3; if the current month in the simulation was April, ReportingMonth would be 1. This Run Property is always available (even if no Reporting Periods are defined). It is unitless.

Read more: Controlling When Weeks and Years Start (page 496).

ETime_*Major* (where ***Major*** is the user-defined Major Period Label): This is elapsed time since the start of the current Major Reporting Period. Note that at the start of a new Major Period, this displays the duration of the just-completed period. It has units of time, and is only available if a Major Reporting Period is defined.

RTime_*Major* (where ***Major*** is the user-defined Major Period Label): This is time remaining in the current Major Reporting Period. Note that at the start of a new Major Period, this displays the duration of the period which is starting. It has units of time, and is only available if a Major Reporting Period is defined.

IsNew_*Major* (where ***Major*** is the user-defined Major Period Label): This is a condition which is True if the current time is the start of a Major Reporting Period. Otherwise it is False. It is only available if a Major Reporting Period is defined. Note that when this is True, ETime_*Major* displays the duration of the just-completed period and RTime_*Major* displays the duration of the period which is starting.

ETime_*Minor* (where ***Minor*** is the user-defined Minor Period Label): This is elapsed time since the start of the current Minor Reporting Period. Note that at the start of a new Minor Period, this displays the duration of the just-completed period. It has units of time, and is only available if a Minor Reporting Period is defined.

RTime_*Minor* (where ***Minor*** is the user-defined Minor Period Label): This is time remaining in the current Minor Reporting Period. Note that at the

start of a new Minor Period, this displays the duration of the period which is starting. It has units of time, and is only available if a Minor Reporting Period is defined.

IsNew_*Minor* (where ***Minor*** is the user-defined Minor Period Label): This is a condition which is True if the current time is the start of a Minor Reporting Period. Otherwise it is False. It is only available if a Minor Reporting Period is defined. Note that when this is True, ETime_*Minor* displays the duration of the just-completed period and RTime_*Minor* displays the duration of the period which is starting.

Note: An example file which illustrates the use of Reporting Period Run Properties (RunProperties.gsm) can be found in the General Examples/ Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Saving Outputs as Results

A GoldSim simulation has the potential to produce a large amount of results. GoldSim does not produce separate input and output files. The model definition and the results generated by the model are all stored in one file: the gsm (GoldSim Model) file. Hence, for large models, particularly those with many timesteps and/or multiple realizations, when in Result Mode, your model file could potentially become very large.

In most cases, however, you will only be interested in a small subset of these results, and GoldSim provides powerful tools to allow you to selective about which results you save, and when they are to be saved.

Specifying Results to be Saved

Before you run a model, you select the results that you wish to save. With regard to saving results, there are two things that you must specify:

- *Which* specific results do you want to save (i.e., which outputs of which elements)?
- *When* do you want to save these results?

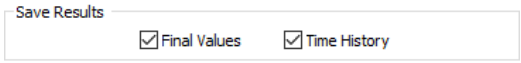
Within GoldSim, there are two fundamental types of results:

Final Value Results: These allow you to display distributions, multi-variate results (e.g., scatter plots), bar charts, pie charts and array plots (and their associated tables). By default, "Final Value" type results are only available at the final time point in the simulation (hene the name). In some cases, however, you may also want to view results (e.g., scatter plots, distributions, bar charts) at other points in time (other than the end of the simulation). GoldSim facilitates this by allowing you to create additional Capture Times at which these results are also made available.

Read more: Creating Capture Times for Results (page 488).

Time History Results: These are saved at selected timesteps, and allow you to display how an output changes as a function of time.

All element property dialogs have check boxes (at the bottom of the dialog) to specify whether output(s) of the element are to be saved. You can save the **Final Values** (the values at the end of each realization in the simulation) and/or **Time History** (the value at selected timesteps throughout the simulation):



In general, by default when you create a new scalar element, the Save Results checkboxes will be checked on. For array elements, the **Time History** checkbox defaults off.

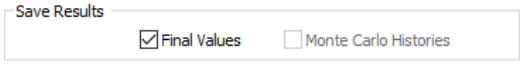
Note: For some GoldSim extension modules, the default for some elements is not to save Time History (or Final Value) results.

The **Final Values** checkbox always controls whether Final Value results are saved. However, the **Time History** checkbox can be overridden. In particular, it is always applied for single realization runs, but is overridden for multiple realization runs. Time History results for multiple realization runs are only saved for outputs that are connected to Result elements.

Read more: Creating and Using Result Elements (page 593); Viewing Time Histories of Multiple Realizations (page 620).

That is, regardless of the setting of the **Time History** checkbox, if you are running multiple realizations, the Time History box is ignored, and unless an output of the element is connected to a Time History Result element, no time history results will be saved at all for the element.

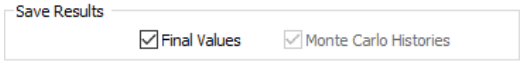
In fact, in such a case, the Save Results section would look like this:



In this example, multiple realizations are being run, and none of the outputs are referenced by a Time History Result element

In this particular case, because the simulation involves multiple realizations, the "Time History" checkbox is replaced by a "Monte Carlo Histories" checkbox. This checkbox is grayed out, since it is only used for information purposes. You cannot edit it directly, and its appearance is completely determined by whether or not the element's outputs are connected to a Time History Result element.

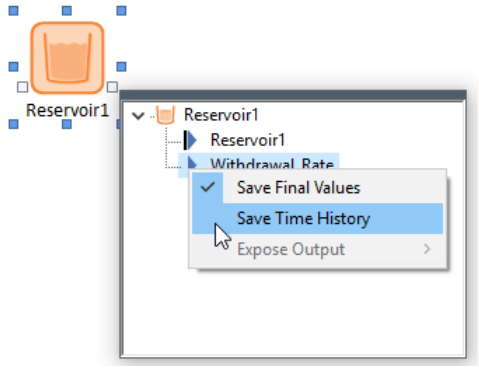
If no outputs of the element are connected to a Time History Result element, the box is cleared (as above). If all the outputs of the element are connected to a Time History Result element, the box will be checked:



In this example, multiple realizations are being run, and all of the element's outputs are referenced by a Time History Result element

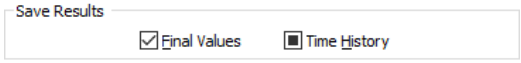
Some elements have multiple outputs. For these elements, you can control which outputs you wish to save. A check indicates that all of the outputs of the element are being saved.

If you wish to save some of the element's results (but not all), and you are not running multiple realizations, you can use the context menu of the output interface (or the browser) to turn one or more of the outputs on or off:



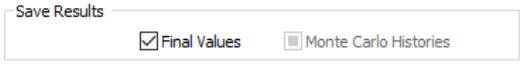
Read more: Element Inputs and Outputs (page 75).

In some, but not all, of the outputs are being saved, the checkbox in the properties dialog will become a box (instead of a check) to indicate this:



In this example, only a single realization is being run, and some, but not all, of the outputs are referenced by a Time History Result element

Similarly, if you wish to save some of the element's results (but not all), and you are running multiple realizations, you can do so by connecting some (but not all) of the outputs to Time History Result elements:



In this example, multiple realizations are being run, and some, but not all, of the outputs are referenced by a Time History Result element

You can globally deactivate all of the result flags for the elements inside a Container (that are not connected to active Result elements) from the Container dialog.

Read more: Controlling Result Flags for Elements in the Container (page 146).

The **Information** tab on the properties dialog for a Container displays the total amount of disk space required to store the results for the elements within the Container. The total amount of disk space required to save the results *for the entire model* is displayed in the **Information** tab of the Simulation Settings dialog.

Note: When Time History results for specific outputs are saved (either because you are running a single realization and have checked the Time History box, or because you have referenced an output in a Time History Result element), by default GoldSim saves the values of outputs at the beginning and end of the simulation, and at every Basic Step (and Reporting Period). You can instruct GoldSim to only save results at selected timesteps (e.g., every tenth Basic Step) when defining timestepping options in the Simulation Settings dialog.

Read more: Understanding Timestepping in GoldSim (page 473); Specifying When Time History Results Will Be Saved (page 482).

Highlighting Outputs that Will be Saved

In some cases, you may want to quickly ascertain which outputs in a model are set to be saved. This is important, for example, if you discovered (from the Container dialog) that a large amount of disk space will be required to store all of the results, and you wish to turn some of the save flags off.

GoldSim provides a quick way to do this. In particular, you can instruct GoldSim to highlight all elements (and outputs) for which results are to be saved. You do this by selecting **View | Highlight Saved Results** from the main menu. You can toggle highlighting on and off separately for Final Values and Time Histories. After doing so, elements and outputs for which results will be saved will be displayed in **bold** text within the browser. Moreover, the output ports for elements for which results will be saved will be changed to green.

Note: By default, only elements are displayed in the browser. If you also wish to view all of the elements' inputs and outputs in the browser, right-click anywhere in the browser window and select **Show Element Subitems**. You can also do this directly from the main menu by selecting **View | Show Element Subitems**.

Archiving a File with Results

GoldSim provides a utility that allows you to **archive** a file. Archiving a file saves a copy of it under a different filename (which you provide) *while keeping the current file open*. This can be useful if you want to save the current file (with results), and then edit the model and rerun it. You archive a file by selecting **File|Save Copy As…** from the main menu.

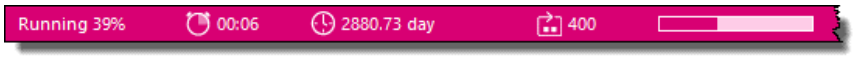
Running and Viewing the Status of a Simulation

GoldSim simulations are run and controlled using the ***Run Control toolbar***:

(You can also run and control some aspects of a simulation from the main menu and/or by using shortcut keys).

In addition to running (and resetting) a model, the Run Control toolbar can also be used to pause and resume a simulation, and/or step through the simulation one timestep or one realization at a time.

The status of a run can be monitored in the status bar:



While the model is running, the status bar displays the status of the run.

The topics below discuss the details of how you can run, control and monitor the status of your simulations.

Understanding Simulation Modes

In order to fully understand how to run, control and monitor the status of your simulations, it is necessary to first understand the various simulation modes (model states) that a GoldSim model can be in at any given time.

At any given time, a GoldSim model is in one of five states (referred to as ***modes***):

Edit Mode: The model is currently being edited and does not contain any simulation results.

Run Mode: The model is currently running. In this mode, you can pause the simulation and view the model, but elements cannot be added, deleted or edited. Only cosmetic changes can be made to the model (e.g., adding text, moving elements around the screen).

Pause Mode: This is a special version of Run Mode. The model is in the middle of running and has been paused. While a model is paused, you can navigate it, open property dialogs, and view result plots. You cannot, however, edit the model in any way that would change its behavior (e.g., you cannot change values in property dialogs or add or delete elements). You also cannot close or save a model while it is paused.

Result Mode: The model has been run and contains simulation results. In this mode, you can navigate the model and view results, but no elements (other than Result elements) can be added, deleted or edited. Only cosmetic changes can be made to the model (e.g., adding text, moving elements around the screen).

Scenario Mode: This is a special mode that only exists if you are using GoldSim's scenario feature. To be in this mode, the model must contain at least one scenario that has been defined by the user, and at least one scenario must have scenario results. In this mode, you can navigate the model and compare scenario results, but no elements (other than Result elements and Scenario Data elements) can be added, deleted or edited.

Read more: Creating, Running and Comparing Scenarios (page 525).

The mode that the model is in is clearly identified in the status bar (in the lower left-hand corner of the GoldSim window). In addition, the status bar takes on a different color in each mode:

This model is in Edit Mode. The status bar is blue.

This model is in Run Mode. The status bar is pink.

This model is in Run Mode, but is paused. The status bar is rust brown.

This model is in Result Mode. The status bar is green.

This model is in Scenario Mode. The status bar is orange.

Note: GoldSim provides a cosmetic option in the user interface to adjust the application theme. As part of this, you can disable the status bar from reflecting the simulation mode by changing color (instead, it is unchanged and determined by the selected theme). As a general rule, however, it is recommended that you do not do this (i.e., it is typically quite useful for the color of the status bar to reflect the simulation mode).

Read more: Customizing the Application Theme (page 452).

One of the key ways that the various modes can be distinguished is by whether or not you can edit your model while in that mode. As pointed out above, elements can only be edited while in Edit Mode (and under special circumstances, in Scenario Mode). In the other two modes, element editing is completely disabled.

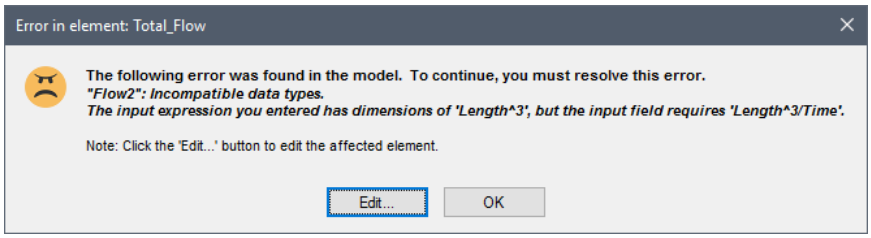
Run Mode and Result Mode are discussed in more detail in the following sections.

Carrying Out a Simulation (Run Mode)

Once you have finished editing your model, you can run the model by selecting **Run | Run Model** from the main menu, pressing **F5**, or pressing the **Run** button in the Run Control toolbar. This causes GoldSim to check the model for errors (to see if it can be run).

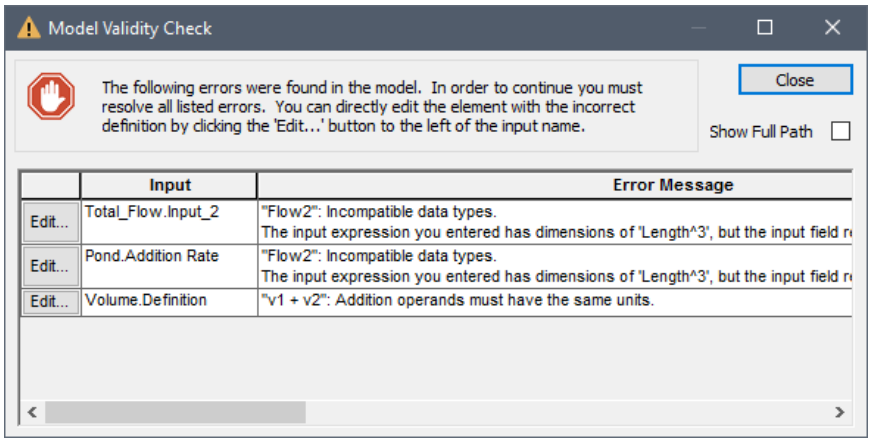
Run button

If an error is found in the model such that it cannot be run, GoldSim will display a fatal error message describing the problem. The error message will identify the element that is causing the problem:



Pressing the **Edit…** button from this dialog returns the model to Edit Mode and immediately opens the properties dialog of the element which prevented the model from running.

If multiple errors are discovered, the error message dialog will look like this:



Pressing the **Edit…** button from this dialog returns the model to Edit Mode and immediately opens the properties dialog of the element associated with the selected error. Selecting **Show Full Path** shows the full path to the input causing the error.

If GoldSim does not detect any errors, the model will be placed into Run Mode.

When GoldSim is in Run Mode, it can have one of three states (the state or status is displayed on the left side of the status bar):

- Ready
- Running
- Paused

Run Mode States

When GoldSim is in Run Mode, it can have one of three states (the state or status is displayed on the left side of the status bar).

Ready

In the "Ready" state, all elements have been checked, and the simulation is ready to begin.

By default, when you press the **Run** button (or **F5**), the model skips through the "Ready" state and immediately starts the simulation. However, you can instruct GoldSim to pause and wait in the "Ready" state by holding down the Ctrl key when you press the **Run** button (or **F5**). You must then press **F5** again to start the simulation. This is only of value if you wish to pause and step through a simulation.

Read more: Pausing and Stepping through a Simulation (page 522).

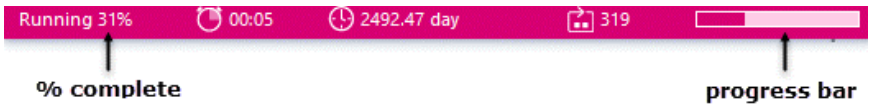
In the "Ready" state, the toolbar is still blue (same color as if in Edit Mode), but simulation status information is now displayed (all set to initial values):

If you want to return to Edit Mode when you are in the "Ready" state (to edit the model), press the **Edit** button on the Run Control toolbar (the first button from the left in the toolbar), or press **F4**.

Note: A model can not be opened in Run Mode. It can only be opened in Edit Mode, Result Mode or Scenario Mode. Hence, if you save and close a model while it is in the "Ready" state (Run Mode), the next time it opens it will be placed in Edit Mode.

Running

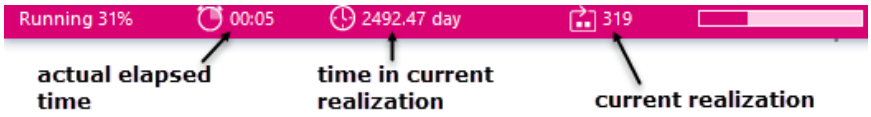
Once the simulation is started, the status bar changes color and "Running" is displayed on the left side of the bar. Next to "Running", an estimate of the progress of the simulation (in terms of what fraction is currently complete) is displayed. The progress is displayed both as a percentage, and as a progress bar (on the right side of the status bar):



Note: For a single realization run, the progress represents the fraction of scheduled timesteps that have been completed. For a multi-realization run, the progress represents the fraction of realizations that have been completed (accounting for the fraction of the current realization completed). Progress is an estimate because unscheduled timesteps could potentially occur that cause some portions of a realization (or different realizations) to require significantly more time to complete. (Interrupt elements could also shorten some realizations in an unpredictable way).

Read more: Understanding Timestepping in GoldSim (page 473).

More detailed information on the simulation status is also displayed. In particular, the status bar displays the progress of the simulation in terms of the the actual elapsed time (i.e., how long has the simulation been running), the simulated time for the current realization, and the current realization being run:



The Run Control toolbar changes its appearance when the model starts running. Prior to the start of the simulation, it looks like this:

Once the simulation begins, the toolbar looks like this:

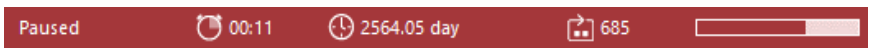
The **Abort** (first button from the left) and **Pause** button (second button from the left) can be used to abort and pause the simulation, respectively.

Just to the right of the **Run** button are two additional buttons for stepping through the simulation one timestep or one realization at a time. To the right of these is a slider that can be used to artificially slow down the speed of a simulation.

Read more: Aborting a Simulation (page 523); Pausing and Stepping through a Simulation (page 522).

Paused

If you press the **Pause** button while a simulation is running, the status will change to "Paused", and the status bar will indicate this:

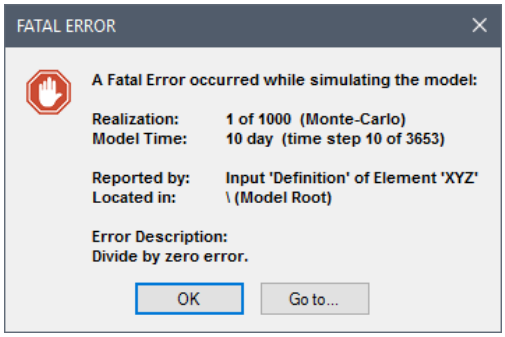


The Run Control toolbar changes its appearance:

The **Run** button can be used to restart the run. Just to the right of the **Run** button are two additional buttons for stepping through the simulation one timestep or one realization at a time.

Read more: Pausing and Stepping through a Simulation (page 522).

Note that if a fatal error occurs while your simulation is running (e.g., if you set up a model so that an element tries to divide by zero), a dialog explaining the error is shown:



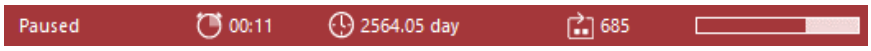
The model will actually be placed in Result Mode (as any realizations that completed prior to the error can be viewed).

Pausing and Stepping through a Simulation

Once a simulation begins, the toolbar looks like this:

The **Pause** button (second button from the left) can be used to pause the simulation.

If you press the **Pause** button in the Run Control toolbar while a simulation is running, the model will be paused, and this will be indicated in the status bar:



Note: GoldSim also provides the option to pause the model immediately (in the "Ready" state, before the simulation begins) by pressing the **Ctrl** key while pressing the **Run** button or **F5**.

Once a model is paused, you can browse the model and view results in the same manner you would if you were in Result Mode.

Read more: Viewing Results (Result Mode) (page 524).

When a model is paused, tool-tips displayed when you hold the cursor over an element or output show the Last Value calculated prior to pausing the model. Since a model can be paused in the middle of a timestep (such that some of the elements have been updated for the timestep and others have not), the tool-tip indicates whether or not the value has been updated for the current timestep.

If you are viewing a Time History Result element while running the simulation, GoldSim will plot a update the time history of the current realization whenever you pause the model.

Read more: Viewing a Result Element (page 596).

While a model is paused, you can navigate it, open property dialogs, and view result plots. You cannot, however, edit the model in any way that would change its behavior (e.g., you cannot change values in property dialogs or add or delete elements). You also cannot close or save a model while it is paused.

Note: You can change values for some elements (Data elements) while a model is paused if and only if the element is linked to a Dashboard control. Dashboard controls are discussed in the **GoldSim Dashboard Authoring Module User's Guide**.

While the model is paused, the Run Control toolbar changes its appearance:

Pressing the **Abort** button (first button from the left) aborts the simulation.

Read more: Aborting a Simulation (page 523).

The **Run** button can be used to restart the run. Just to the right of the **Run** button are two additional buttons for stepping through the simulation one timestep or one realization at a time:

Simulate one timestep

Simulate one realization

If you press the button for simulating one timestep, GoldSim will complete the next timestep and then pause. If you press the button for simulating one realization, GoldSim will complete the next realization and then pause.

On the right side of the Run Control toolbar is a slider that can be used to artificially slow down a simulation. This is useful primarily if you want to pause the simulation at a specific point, or you have set up some results plots (or Dashboards) that you want to be able to view evolving slowly over the course of a simulation.

Warning: By default, the slider is all the way to the right (Fast). If you want the simulation to run as quickly as possible, make sure that the slider stays in this position. If you move it to the left, the simulation will take longer!

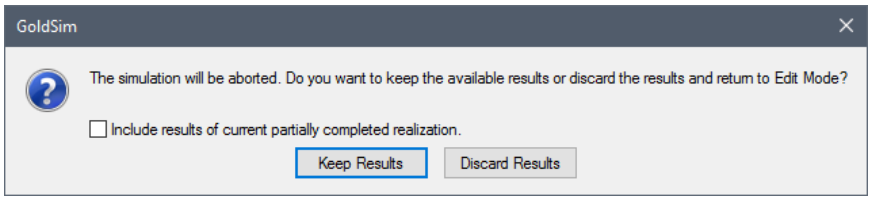
Aborting a Simulation

Once a simulation begins, the toolbar looks like this:

If the simulation is paused, the toolbar looks like this:

The **Abort** (first button from the left) can be used to abort the simulation.

If you press the **Abort** button while a model is running (or paused), the following dialog will be displayed:



The dialog provides you with two options:

Keep Results: This button will keep the existing results and place the model in Result Mode.

Discard Results. This button will discard all results, and place the model in Edit Mode.

If you are aborting during the first realization and you choose to keep results, in order to generate results for the remainder of the partial realization, GoldSim will skip to the end of the realization (i.e., skip all further calculations for the realization, keeping the values of all elements constant at their last compute value).

If you are running multiple realizations, and abort after the first realization, you will have the choice to **Include results of current partially completed realization**. If this box is cleared (the default) and you choose to keep results, the current partially completed realization will be discarded (only the completed realizations will be saved). If this box is checked, GoldSim will generate results for the remainder of the partial realization by skipping to the end of the realization (i.e., skipping all further calculations for the realization, keeping the values of all elements constant at their last compute value).

Warning: When you abort a simulation and include the results from the last (partially complete) realization, you should be careful as to how you interpret the results. In particular, because the last realization was not complete, it may be inappropriate to combine it with or compare it to other (full) realizations.

Viewing Results (Result Mode)

After a simulation is complete, the model will be placed in Result Mode. The status bar turns green and "Results" is displayed on the left side:

More importantly, editing the model will be disabled.

In addition, the cursor takes on a different appearance (it turns green).

When in Result Mode, elements with outputs that have been saved are identified in two ways: 1) the elements (and their outputs) are **bold** in the browser (and output interfaces); and 2) the element output ports in the graphics pane are green.

When a model is in Result Mode, you can navigate it, open property dialogs, and view result plots. You can also move elements around within the graphics pane, add graphics (e.g., text, images), and add and edit result elements. You cannot, however, edit the model in any way that would change its behavior (e.g., you cannot change values in property dialogs or add or delete elements).

Read more: Chapter 8: Displaying Results in GoldSim (page 577).

In Result Mode, the Run Control toolbar looks like this:

If you press **F4**, choose **Run|Return to Edit Mode** from the file or press the first button from the left in the Run Control toolbar, the results will be discarded and the model will be returned to Edit Mode.

Creating, Running and Comparing Scenarios

GoldSim provides a specialized capability that allows you to create, run and compare different scenarios for your model. Scenarios are differentiated by having different sets of input data. In particular, different scenarios have different values for one or more Data elements. GoldSim's scenario modeling capability allows you to directly compare results generated by your model by different sets of input parameters. In effect, when you use this capability, your model can store (and subsequently compare) multiple sets of inputs and outputs.

This can be very useful for carrying out sensitivity analyses, testing and comparing alternative designs, and asking "what if" questions.

A simple example file which illustrates the use of Scenarios (Scenarios.gsm) can be found in the General Examples/Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

The details of how to create, run and compare scenarios are presented in the sections below.

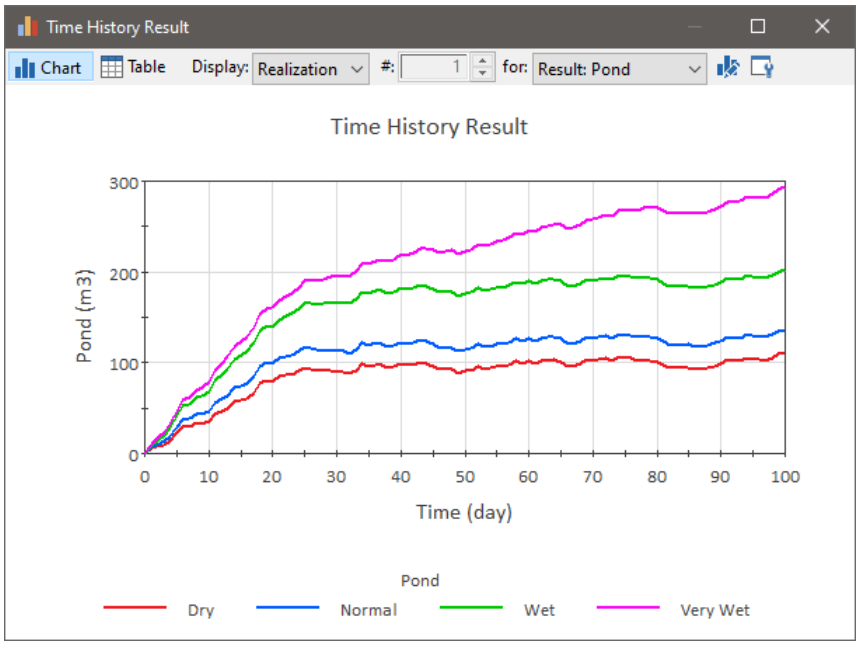
Warning: Scenarios are an advanced modeling capability. Prior to using this capability, it is strongly recommended that you first learn how to create, run and view model results in the standard way (without scenarios).

Warning: Because scenario modeling is somewhat complex (as your model will be storing multiple sets of inputs and results), it is strongly recommended that you read the documentation below before using this feature. The first section (Introduction to Scenarios) is of particular importance. It provides an overview of how the scenario modeling capability works. This is required reading prior to using this capability.

Note: Scenario modeling is not supported when doing distributed processing (using the Distributed Processing Module).

Introduction to Scenarios

GoldSim's scenario modeling capability allows you to directly compare results generated by different sets of input parameters. In effect, when you use this capability, your model can store (and subsequently compare) multiple sets of results (and inputs):



Because scenario modeling is somewhat complex (as your model will be storing multiple sets of inputs and results), it is strongly recommended that you read the introductory sections below before using this feature. Note that these sections do not provide details on how to create and edit scenarios (that is provided subsequently). Rather, they introduce key concepts and provide an overview of GoldSim's scenario modeling capability that must be understood before attempting to use this powerful feature.

What Are Scenarios?

A scenario is a specific set of input data (and corresponding outputs) for a model. Multiple scenarios can be defined for a model. Different scenarios within a model are specifically differentiated by having different values for one or more Data elements.

Specifically, a particular scenario is defined by the following:

- A unique Scenario ID (an alphanumeric name);
- An optional description; and
- A set of values for the Data elements in the model for that scenario.

Note that the only elements that can differ between scenarios are Data elements. Of course, not all Data elements in a model will actually differ between scenarios. You typically define a subset of the model's Data elements as being ***Scenario Data***.

Read more: Scenario Data: Defining Inputs for Different Scenarios (page 527).

Once you have defined multiple scenarios, GoldSim allows you to run the model for each scenario and directly compare results generated by each scenario. That is, when you use this capability, your model can store (and subsequently compare) multiple sets of inputs and results.

Read more: Running Scenarios and Comparing Scenario Results (page 531).

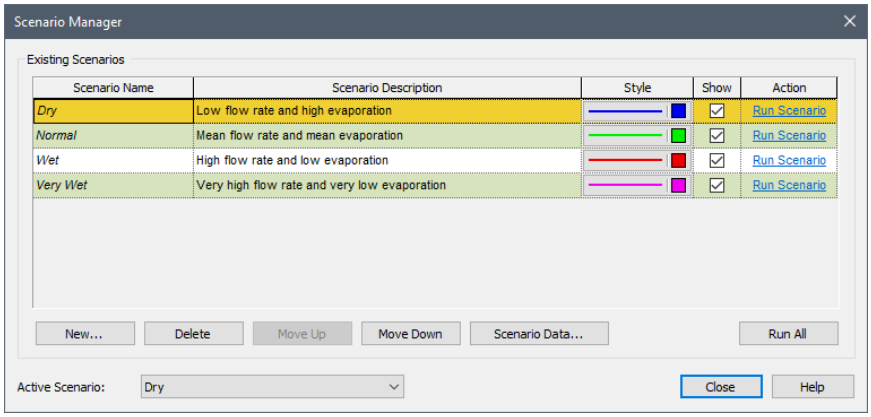
How Are Scenarios Created?

GoldSim provides several ways to create scenarios.

The most straightforward way to create scenarios is to use the Scenario Manager. The Scenario Manager can be accessed from the main menu (**Run | Scenario Manager…**) or by pressing **F7**.

Read more: Creating and Editing Scenarios Using the Scenario Manager (page 534).

The Scenario Manager dialog looks like this:



Using this dialog, you can create new scenarios, and delete existing ones. When you add a new scenario, you are prompted for a Scenario Name and Description. In the example shown above, three scenarios have been defined.

Of course, simply creating and naming a scenario is of no value if you do not specify the Scenario Data for each scenario (i.e., the specific Data elements that differentiate the scenarios). As discussed below, this can also be done via the Scenario Manager.

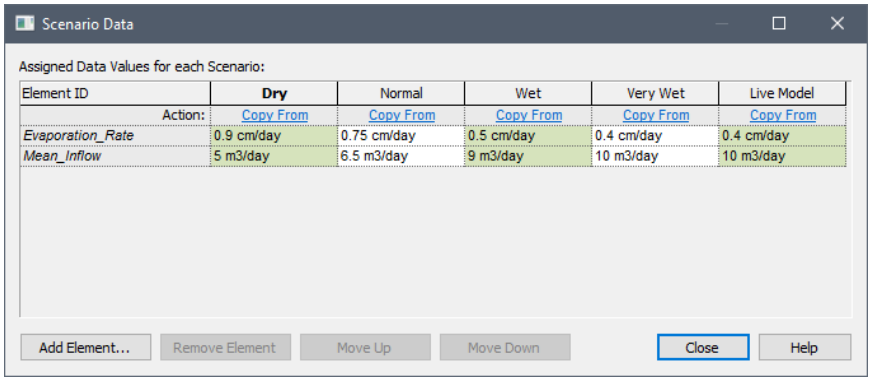
In addition to using the Scenario Manager to create scenarios, once you are experienced with modeling scenarios, you will likely also create scenarios "on the fly" outside of the Scenario Manager using other methods provided by GoldSim. You can even create scenarios via a Dashboard.

Read more: Creating and Editing Scenarios in Dashboards (page 548).

Scenario Data: Defining Inputs for Different Scenarios

Scenario Data are the Data elements that differentiate the various scenarios in your model. GoldSim provides several ways to specify Scenario Data.

The most straightforward way to specify Scenario Data is to use the Scenario Manager. The Scenario Manager can be accessed from the main menu (**Run | Scenario Manager…**) or by pressing **F7**. Within this dialog, you will find a button labeled **Scenario Data…**. Pressing this button displays the following dialog:

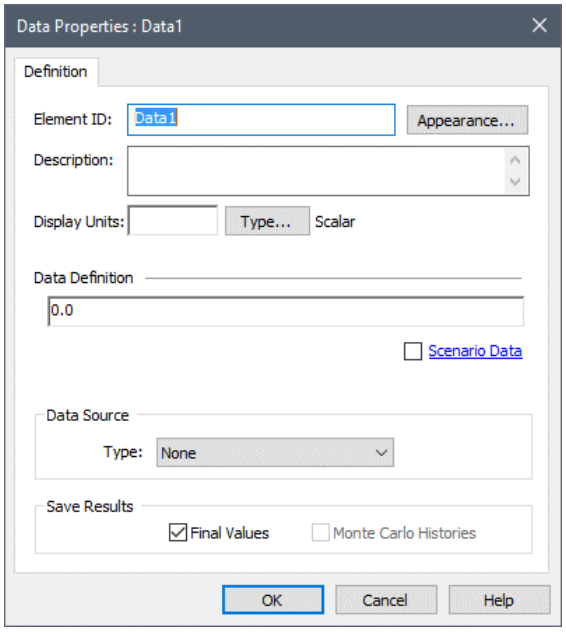


Each row in this dialog represents a Scenario Data element. Each column represents a scenario. You can add new Scenario Data using the **Add Element…** button. You can subsequently edit the value for any Scenario Data

element in any defined scenario. This table is very convenient because it displays all Scenario Data values for all defined scenarios side-by-side.

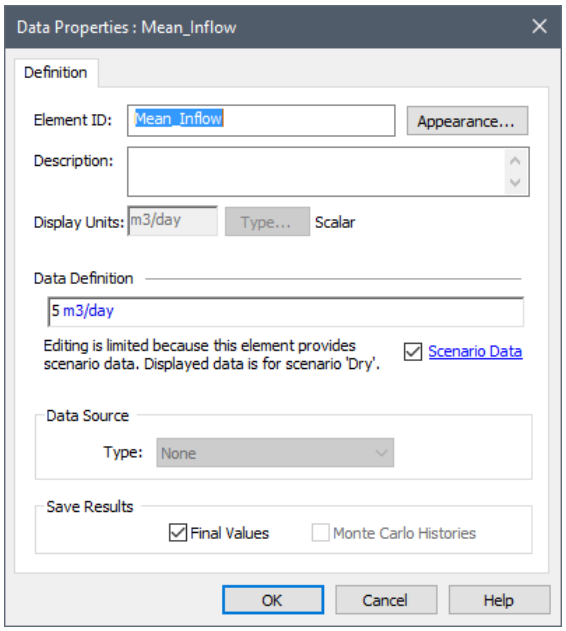
Read more: Creating and Editing Scenario Data Using the Scenario Manager (page 536).

You can also edit Scenario Data directly in your model. Once you have defined at least one Scenario in your model, the dialog for Data elements is modified slightly. In particular, the dialog provides an option to define a Data element as a Scenario Data element:



In this particular example, we are viewing a Data element that has not yet been defined as being Scenario Data (and hence it has the same value for all Scenarios). As can be seen, a **Scenario Data** checkbox is available (and in this case, unchecked). Checking this box would add this to the list of Scenario Data elements displayed in the Scenario Data dialog accessed via the Scenario Manager.

Here is the dialog for a Data element that has already been defined as Scenario Data:



Note that in this case, the **Scenario Data** box is checked. Like all Data elements, a Scenario Data element has a single value. That is, it cannot display the value for all scenarios; it can only show you the value for one scenario at a time. The dialog indicates which scenario is being displayed (in this example, the "Dry" scenario is being displayed).

As discussed below, you can control which scenario you are viewing in your model by selecting the ***Active Scenario***.

Note: In addition to editing Scenario Data directly in your model as described above, you can also link Scenario Data elements to Dashboard controls and edit (and create) Scenarios via a Dashboard.

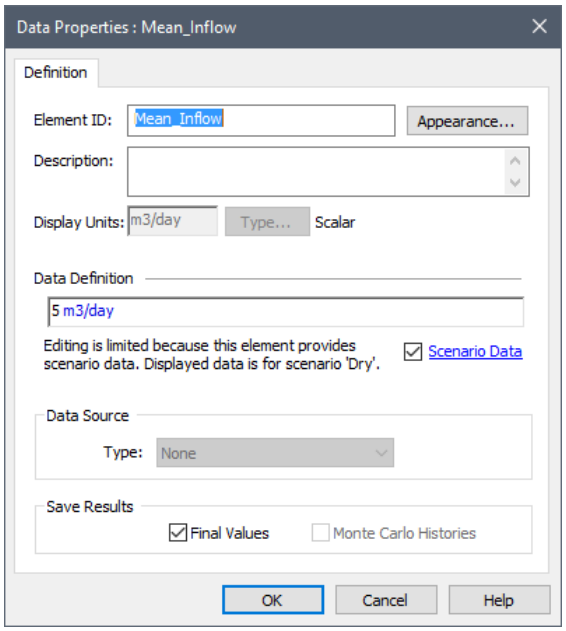
Read more: Creating and Editing Scenarios in Dashboards (page 548).

To highlight those Data elements that are Scenario Data, they have different symbols in the graphics pane:

For Scenario Data, the pencil is orange instead of green.

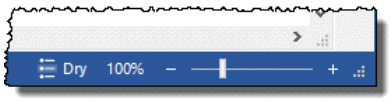
Viewing the Active Scenario

After you have defined scenarios in your model, you can browse the model and view Data elements that have been defined as Scenario Data. Note, however, that like all Data elements, a Scenario Data element has a single value. That is, it cannot display the value for all scenarios; it can only show you the value for one scenario at a time. The dialog indicates which scenario is being displayed (in the example below, the "Dry" scenario is being displayed):

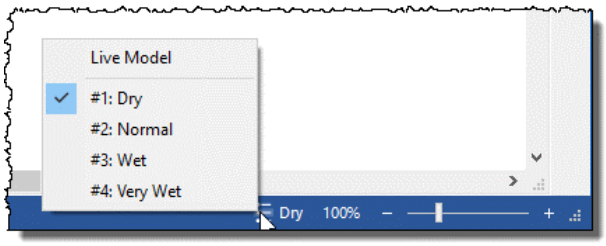


Because this is a Scenario Data element, some of the editing is locked (e.g., you cannot change the Type or dimensions). However, in Edit Mode you can change the value itself. If you were to do so, it would change the value of this Data element *only for the Active Scenario* (in this case, "Dry" scenario).

The Active Scenario is the scenario that is being viewed when you are browsing a model (and hence is only applicable if the model has scenarios defined). That is, whenever a model has scenarios, one of the scenarios is the Active Scenario. The Active Scenario is indicated in the ight-hand side of the GoldSim status bar:



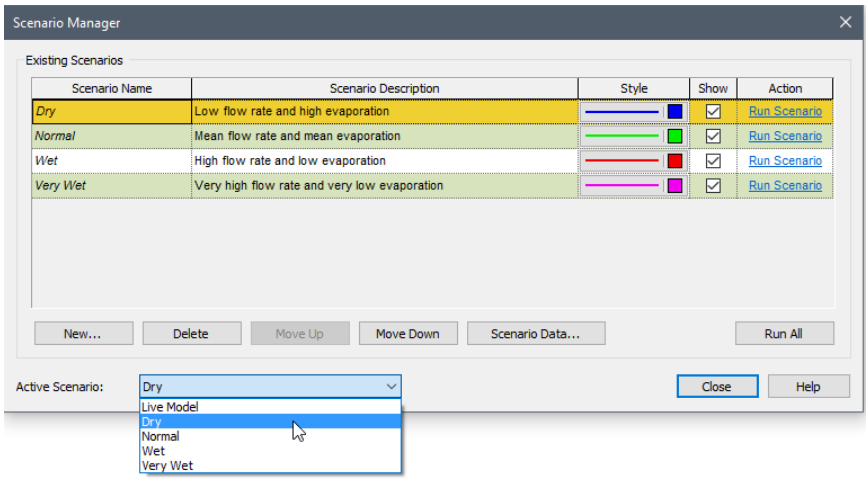
If you click on this portion of the status bar, GoldSim will display all of the scenarios (and you can select one to become the Active Scenario):



If you change the Active Scenario and then view a Scenario Data element, it will display the value for the selected scenario.

Note that one of the options here is always the "Live Model". Live Model can be thought of as a "scratch" scenario, or a temporary placeholder scenario where you can experiment before saving something as an actual scenario. As will be discussed below, when comparing scenario results, only defined scenarios are shown (the Live Model is not included in the comparison).

You can also select the Active Scenario directly from within the Scenario Manager:



Running Scenarios and Comparing Scenario Results

The real power of GoldSim's scenarios capability is being able to run and view the results of different scenarios in a single plot or table. In order to do this, after defining scenarios, you need to run the different scenarios and compare their results.

It is important to understand two key concepts:

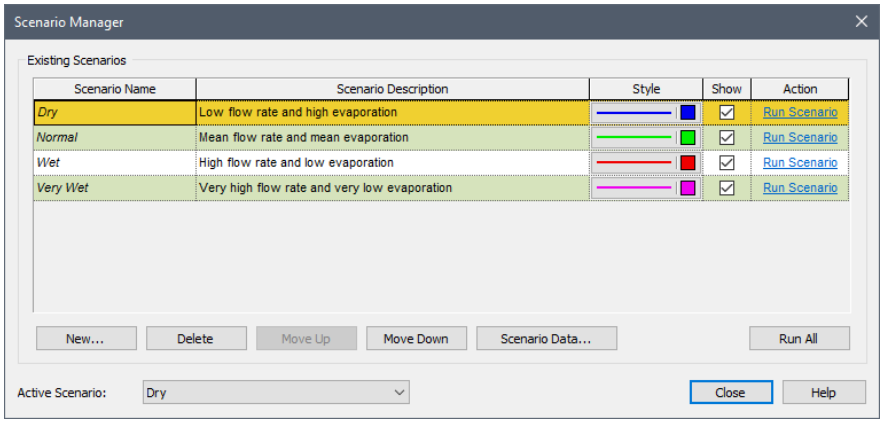
- Scenario results can only be compared when the model is in Scenario Mode. Scenario Mode is a special model state (that is different from Result Mode) that allows scenario results to be displayed and compared.

  Read more: Understanding Simulation Modes (page 517).

- When in Scenario Mode, scenario results can only be viewed in Time History Result elements, Distribution Result elements and Final Value Result elements. *No other results are available.* Hence, if your model does not contain any Time History, Distribution or Final Value Result elements, you will not be able to compare scenario results.

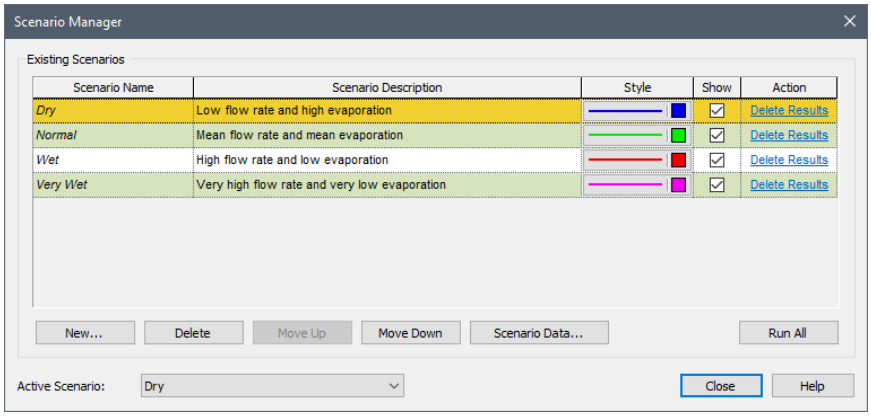
  Read more: Creating and Using Result Elements (page 593).

The most straightforward way to run a scenario and place your model in Scenario Mode is through the Scenario Manager:



You will note that from this dialog, you can run a single scenario (via one of the **Run Scenario** buttons) or run all scenarios (via the **Run All** button). In either case, GoldSim will run the model for the single scenario (or all scenarios), and place the model in Scenario Mode.

Here is the same dialog after pressing the **Run All** button:



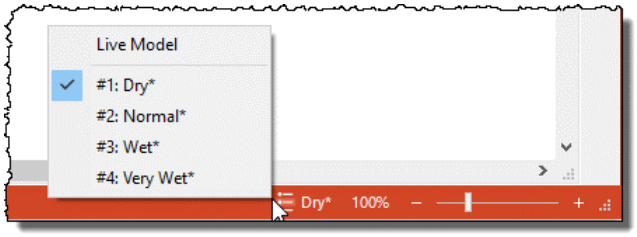
Doing so actually runs the model four times in this case (once for each scenario). The dialog indicates that all four scenarios now contain scenario results (the Action column provides the option to **Delete Results**, which would delete the scenario results for that scenario).

Warning: Warning messages are not displayed when running scenarios via the Scenario Manager (although fatal error messages are). To see any warning messages for a scenario, you would need to run it separately (outside of the Scenario Manager) by selecting it as the Active Scenario and pressing **F5** or the **Run** button.

Read more: Viewing Detailed Scenario Outputs in Result Mode (page 546).

After running these scenarios, the status bar changes to orange and indicates that the model is in Scenario Mode (the cursor also becomes orange):

Clicking on the right portion of the status bar shows all four scenarios (and the Live Model):



Note that all the scenarios have an asterisk (*) next to them. An asterisk indicates that the scenario has scenario results available to be viewed.

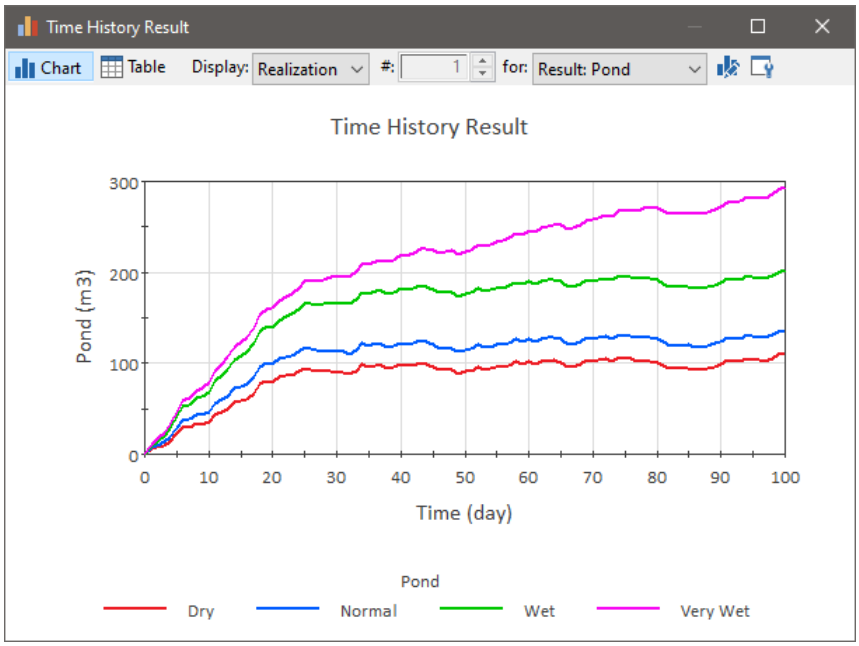
If you were then to browse the model, you would note the following:

- If you browse to a Scenario Data element, it will display the value for the Active Scenario.
- There is no option to right-click on an element and view its results. Elements do not store results in Scenario Mode.
- If you double-click on a Final Value Result element, what is displayed is a function of how the Result element is configured (it could display

results for all scenarios for which scenario results have been generated or for only the Active Scenario).

- If you double-click on a Time History Result element or a Distribution Result element, GoldSim will display results for all scenarios for which scenario results have been generated (as indicated by the asterisk mentioned above).

For example, a Time History Result would look like this:



Each scenario is shown and indicated in the legend.

Note: If the simulation is probabilistic, then when displaying a Time History of scenarios, GoldSim displays a specified statistic for each scenario (e.g., the mean), as defined in the Monte Carlo Result Options dialog.

Read more: Controlling Monte Carlo Result Options (page 500).

If you press **F4** you can return to Edit Mode (by deleting all scenario results), or you can choose to only delete the scenario results for the Active Scenario (while keeping the others). In this latter case, you will remain in Scenario Mode.

- Pressing **F5** will run the Active Scenario and place the model in Result Mode. This allows you to view detailed results for a particular scenario, as all results for the Active Scenario will be available to view. Note that while in Result Mode, you cannot compare scenarios (e.g., Result elements will only show results for the Active Scenario).

Read more: Viewing Detailed Scenario Outputs in Result Mode (page 546).

Note: All scenario results are deleted when you return to Edit Mode. However, any scenario results that exist prior to entering Result Mode are retained while in Result Mode (and can be viewed again if you return to Scenario Mode).

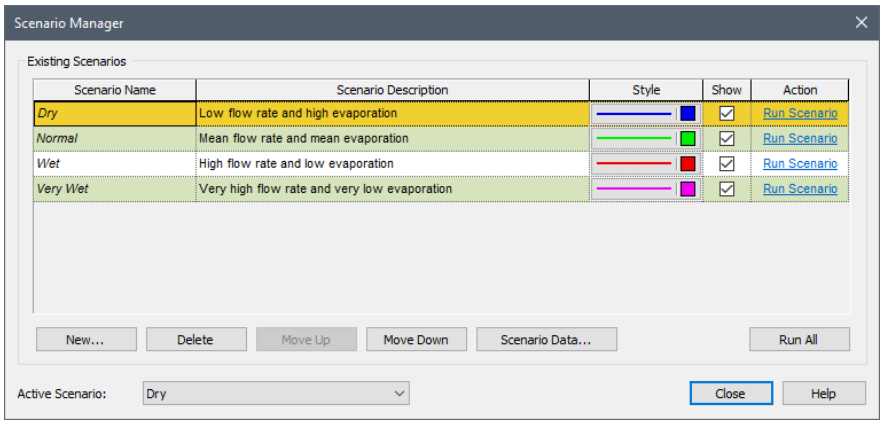
Creating and Editing Scenarios Using the Scenario Manager

A scenario is a specific set of input data (and corresponding outputs) for a model. *In particular, different scenarios have different values for one or more Data elements.* GoldSim's scenario modeling capability allows you to directly compare results generated by different sets of input parameters. In effect, when you use this capability, your model can store (and subsequently compare) multiple sets of results (and inputs).

Warning: Because scenario modeling is somewhat complex (as your model will be storing multiple sets of inputs and results), it is strongly recommended that you read the introductory section "Introduction to Scenarios"before using this feature. It provides an overview of how the scenario modeling capability works, and should be considered required reading prior to using this capability.

Read more: Introduction to Scenarios (page 525).

The Scenario Manager provides the primary mechanism for managing the scenarios in your model. The Scenario Manager can be accessed from the main menu (**Run | Scenario Manager…**) or by pressing **F7**, and looks like this:



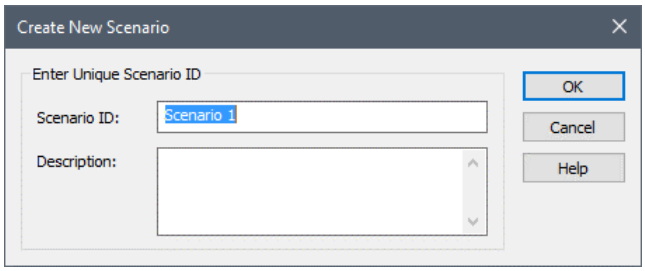
Using this dialog, you can create new scenarios, and delete existing ones. In the example shown above, four scenarios have been defined.

Of course, simply creating and naming a scenario is of no value if you do not specify the Scenario Data for each scenario (i.e., the specific Data elements that differentiate the scenarios). This can also be done via the Scenario Manager.

The sections below discuss the Scenario Manager in detail.

Adding Scenarios Using the Scenario Manager

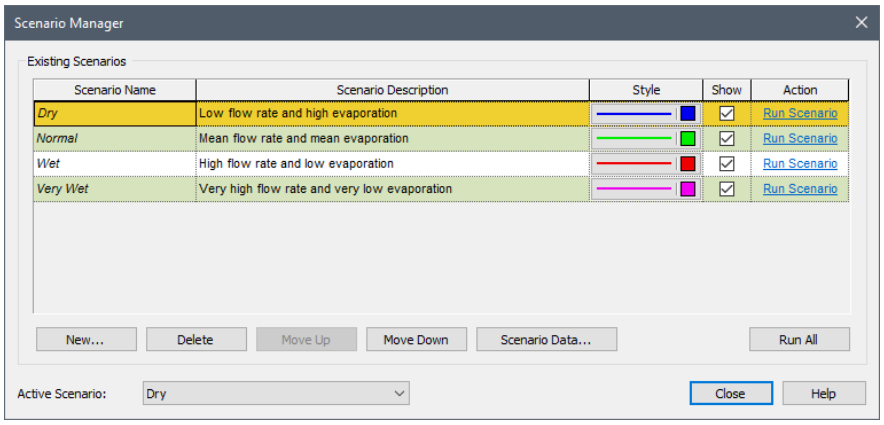
From within the Scenario Manager (accessed from the main menu (**Run | Scenario Manager…**) or by pressing **F7**) you can add a new scenario by pressing the **New…** button. When you do so, you are prompted for a Scenario Name and Description:



Note: By default, the scenario Description is the **Analysis description** specified in the **Information** tab of the Simulation Settings dialog (which by default is blank).

Read more: Viewing and Editing Model Summary Information (page 505).

After entering a Scenario ID and Description, this information is displayed in the Scenario Manager:



Note: After creating a scenario, you can edit its Name and/or Description by simply clicking in the field.

You can delete existing scenarios using the **Delete** button, and move the scenarios up and down in the list using the **Move Up** and **Move Down** buttons. (Holding the **Ctrl** key down switches the **Delete** button to a **Delete All** button which can be then used to delete all scenarios).

Of course, simply creating and naming a scenario is of no value if you do not specify the Scenario Data for each scenario (i.e., the specific Data elements that differentiate the scenarios). As discussed below,this can also be done via the Scenario Manager.

Note: In addition to using the Scenario Manager to create scenarios, once you are experienced with modeling scenarios, you will likely also create scenarios "on the fly" outside of the Scenario Manager using other methods provided by GoldSim. You can even create scenarios via a Dashboard.

Read more: Creating and Editing Scenarios in Dashboards (page 548).

The **Style** and **Show** columns control how e.g., the color) and whether a scenario's results are displayed in charts.

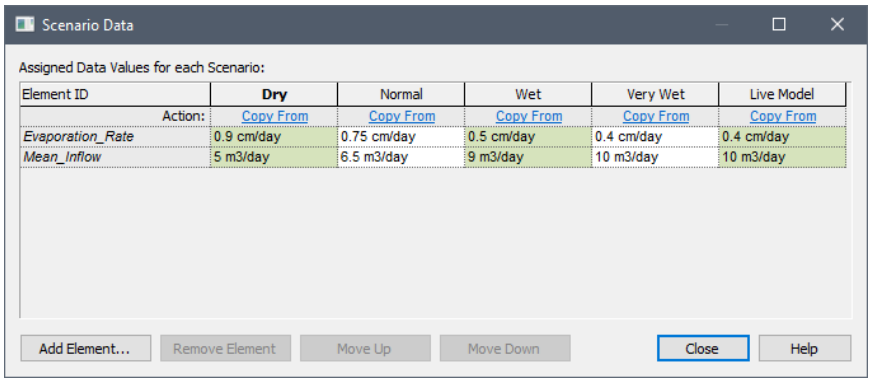
Read more: Using and Managing the Color Palette (page 437).

The **Action** column is used to run scenarios (or delete scenario results).

Read more: Running Scenarios and Displaying Scenario Results (page 540).

Creating and Editing Scenario Data Using the Scenario Manager

Scenario Data are the Data elements that differentiate the various scenarios in your model. Although GoldSim provides several ways to specify Scenario Data, the most straightforward way to do so is to use the Scenario Manager (accessed from the main menu by selecting **Run | Scenario Manager…** or by pressing **F7**). Within this dialog, you will find a button labeled **Scenario Data…**. Pressing this button displays the following dialog:



Each row in this dialog represents a Scenario Data element. Each column represents a scenario. You can add new Scenario Data using the **Add Element…** button. When you do so, GoldSim will display a browser showing all Data elements in the model. After selecting one, it will add it to the list.

Note: Cloned Data elements cannot be specified as Scenario Data.

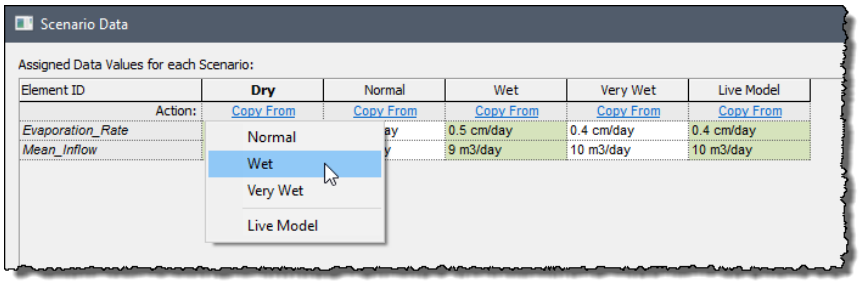
Read more: Cloning Elements (page 1026).

You can edit the value for any Scenario Data element in any defined scenario directly in this table. You cannot enter links into this table (entries must be values, expressions containing only values, or, if the Data is a Condition, True or False).

You can remove a Data element from the list of Scenario Data using the **Remove Element** button. The **Move Up** and **Move Down** buttons allow you to change the order of the Scenario Data elements in the list (simply for the purpose of better organizing the data; the order has no impact on how the data is used).

This table is very convenient because it displays all Scenario Data values for all defined scenarios side-by-side.

Each column in the table (i.e., each scenario) has a **Copy From** button at the top. Pressing this button displays a drop-list of all the other scenarios (as well as the Live Model):



Selecting one of these options copies all of the Data values from the selected scenario to the selected column. This provides a convenient way to rapidly change the values for a scenario (e.g., if you want to define a new scenario in which many of the values are the same as in an existing scenario, with a small number of differences).

Note: The **Copy From** button is only available if the scenario defined by that column does not have scenario results. If scenario results have been generated for that scenario, a **Delete Results** button is available.

Read more: Running Scenarios and Displaying Scenario Results (page 540).

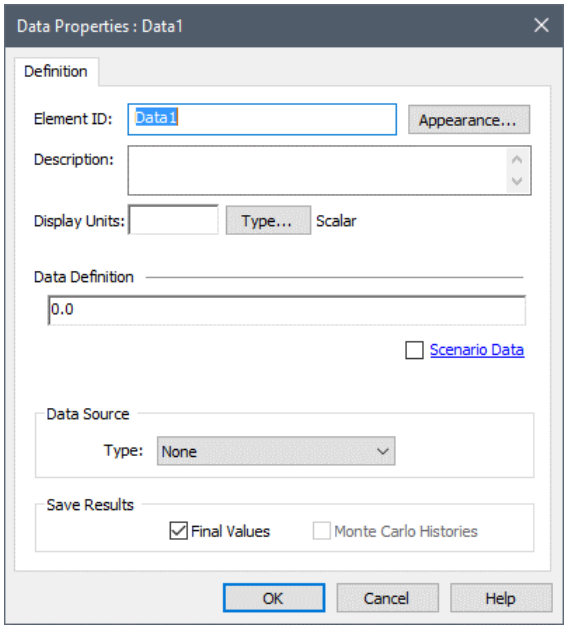
As discussed below, you can also browse into the model and edit Scenario Data directly. Moreover, you can also link Scenario Data elements to Dashboard controls and edit (and create) Scenarios via a Dashboard.

Read more: Creating and Editing Scenarios in Dashboards (page 548).

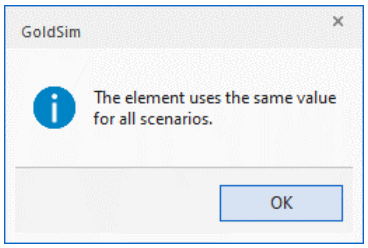
Browsing and Editing the Active Scenario

After you have defined scenarios in your model, you can browse the model and edit existing Data elements that have been defined as Scenario Data, or specify additional Data elements as being Scenario Data.

In particular, once you have defined at least one Scenario in your model, the dialog for Data elements is modified slightly. Specifically, the dialog provides an option to define a Data element as a Scenario Data element:



In this particular example, we are viewing a Data element that has not yet been defined as being Scenario Data (and hence it has the same value for all Scenarios). As can be seen, a **Scenario Data** checkbox is available (and in this case, unchecked). In fact, if you click on **Scenario Data** (the label, not the checkbox itself) a dialog will be displayed to indicate that this Data element provides the same value for all scenarios:

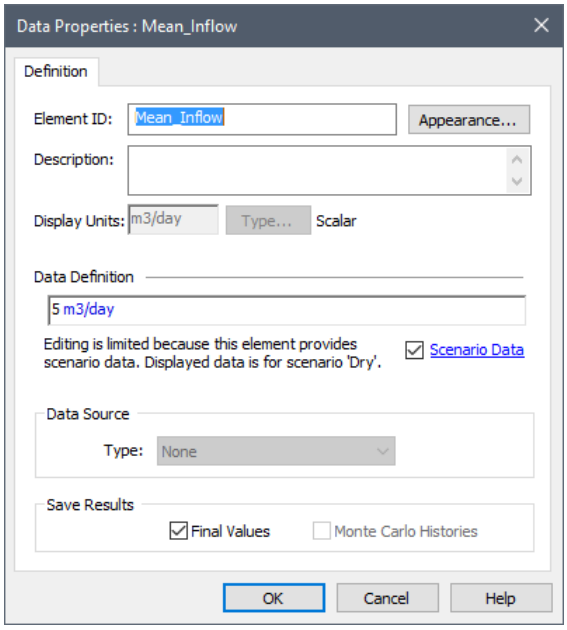


Checking the **Scenario Data** box would add this to the list of Scenario Data elements displayed in the Scenario Data dialog accessed via the Scenario Manager.

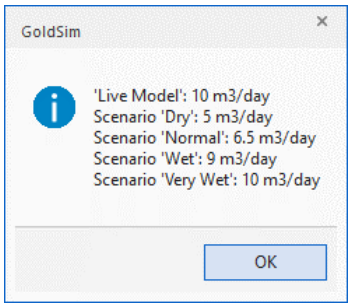
Note: Cloned Data elements cannot provide Scenario Data (i.e., you cannot check the **Scenario Data** box for a cloned element).

Read more: Cloning Elements (page 1026).

Here is the dialog for a Data element that has already been defined as Scenario Data (i.e., the **Scenario Data** box is checked):



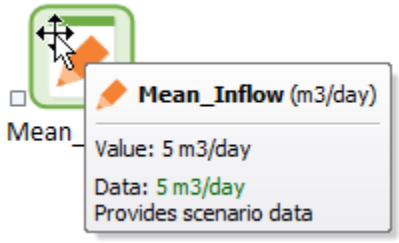
If you click on **Scenario Data** (the label, not the checkbox itself) a dialog will be displayed indicating the values used for each scenario:



To highlight those Data elements that are Scenario Data, they have different symbols in the graphics pane:

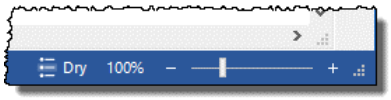
For Scenario Data, the pencil is orange instead of green.

Moreover, if you hold your cursor over a Scenario Data element, it indicates that it provides scenario data:

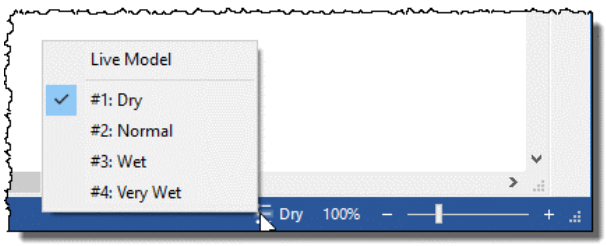


Like all Data elements, within the Data Definition field, a Scenario Data element displays a single value. That is, it cannot display the value for all scenarios; it can only show you the value for one scenario at a time. The dialog indicates which scenario is being displayed (in the example above, the "Dry" scenario is being displayed).

In this case, the "Dry" scenario is referred to as the Active Scenario. The Active Scenario is the scenario that is being viewed when you are browsing a model (and hence is only applicable if the model has scenarios defined). That is, whenever a model has scenarios, one of the scenarios is the Active Scenario. The Active Scenario is indicated in the right side of the GoldSim status bar:

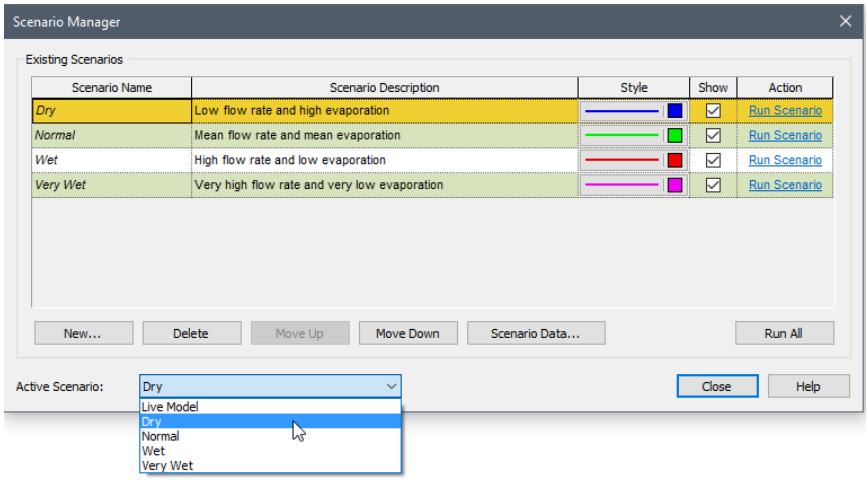


If you click on this portion of the status bar, GoldSim will display all of the scenarios (and you can select one to become the Active Scenario):



If you change the Active Scenario and then view a Scenario Data element, it will display the value for the selected scenario. Note that one of the options here is always the "Live Model". Live Model can be thought of as a "scratch" model, or a temporary placeholder model where you can experiment before saving something as a scenario.

You can also select the Active Scenario directly from within the Scenario Manager:



In addition, when viewing Scenario Data via the Scenario Manager (by pressing the **Scenario Data…** button), the Active Scenario will be marked in bold.

When viewing a Scenario Data element, you will note that some of the editing is locked (e.g., you cannot change the Type or dimensions). However, in Edit Mode you can change the value itself. You cannot, however, enter links (entries must be values, expressions containing only values, or, if the Data is a Condition, True or False).

If you were to change the value, it would change the value of this Data element *only for the Active Scenario*.

Note: You can also change the value of a Scenario Data element while in Scenario Mode if and only if the Active Scenario has no scenario results.

Read more: Running Scenarios and Displaying Scenario Results (page 540).

Running Scenarios and Displaying Scenario Results

The real power of GoldSim's scenarios capability is being able to run and view the results of different scenarios in a single plot or table. In order to do this, after defining scenarios, you need to run the different scenarios and compare their results.

The details of how to run and compare scenarios are presented in the sections below.

Understanding the Difference Between Result Mode and Scenario Mode

In models in which scenarios are not being used, there are three modes that the model can be in: Edit Mode, Run Mode, and Result Mode. The model is in Edit Mode while it is being edited, the model is in Run Mode while the simulation is actually running, and the model is placed in Result Mode after results have been generated.

Read more: Understanding Simulation Modes (page 517).

When using scenarios in GoldSim, a fourth mode is introduced: Scenario Mode. Scenario Mode is a special model state that allows scenario results to be displayed and compared. *Scenario results can only be compared when the model is in Scenario Mode.*

Although Scenario Mode is similar in some respects to Result Mode (in that both modes are used to view results), there are several key differences:

- When in Scenario Mode, scenario results can only be viewed in Time History Result elements, Distribution Result elements and Final Value Result elements. *No other results are available.* Hence, if your model does not contain any Time History, Distribution or Final Value Result elements, you will not be able to compare scenario results.

  Read more: Creating and Using Result Elements (page 593).

- When viewing results in Scenario Mode in Final Value or Distribution Result elements, you cannot view results at Capture Times. Only the Final Result can be viewed.

  Read more: Viewing Results at Capture Times (page 592).

- A model in Scenario Mode has *at least one* scenario with results. However, when in Scenario Mode, not all scenarios necessarily have results (since the scenarios can be run independently).

- Models cannot be edited in Result Mode. However, in Scenario Mode, you can edit Scenario Data elements for scenarios that do not have scenario results (i.e., if the Active Scenario does not have results, Scenario Data for that scenario can be edited).

Note: Although you can edit Scenario Data elements for an Active Scenario that does not have results while in Scenario Mode, you can never edit non-Data elements in Scenario Mode, since these are common to all scenarios, and doing so would invalidate scenario results that existed for other scenarios.

There are two ways to place a model into Scenario Mode:

- Using the Scenario Manager to run one or more scenarios.

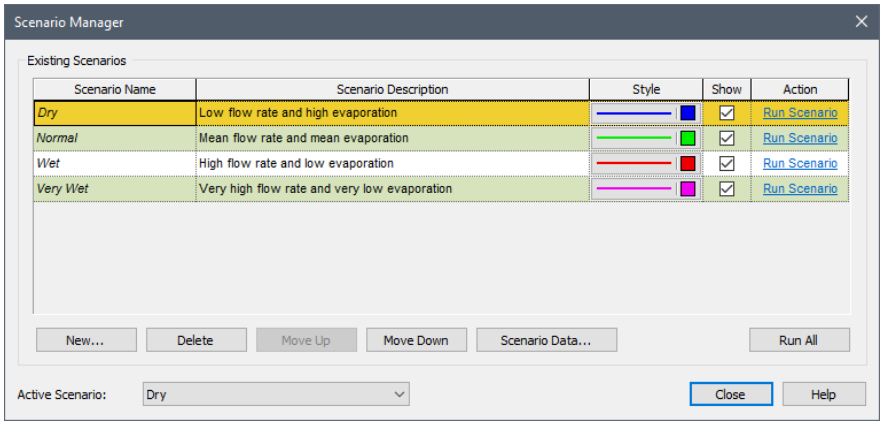
  Read more: Generating and Deleting Scenario Results Using the Scenario Manager (page 542).

- Transitioning directly from Result Mode to Scenario Mode.

  Read more: Transitioning Directly from Result Mode to Scenario Mode (page 547).

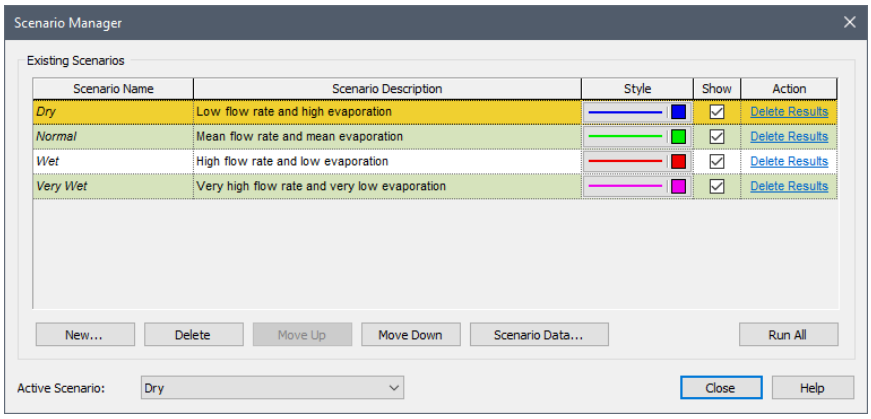
Generating and Deleting Scenario Results Using the Scenario Manager

The most straightforward way to run a scenario and place your model in Scenario Mode is through the Scenario Manager:



From this dialog, you can run a single scenario by pressing one of the **Run Scenario** buttons, or run all scenarios via the **Run All** button. In either case, GoldSim will run the model for the single scenario (or all scenarios), and place the model in Scenario Mode.

Here is the same dialog after pressing the **Run All** button:

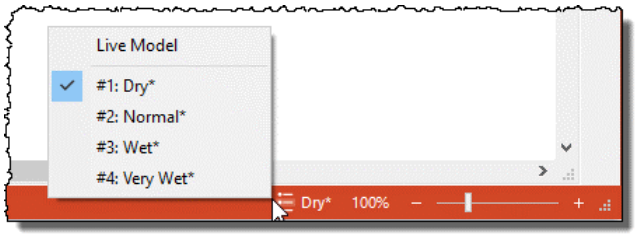


In this case, pressing the button actually ran the model four times (once for each scenario). The dialog indicates that all four scenarios contain scenario results (the Action column provides the option to **Delete Results**, which would delete the scenario results for that scenario).

Warning: Warning messages are not displayed when running scenarios via the Scenario Manager (although fatal error messages are). To see any warning messages for a scenario, you would need to run it separately (outside of the Scenario Manager) by selecting it as the Active Scenario and pressing **F5** or the **Run** button.

After running these scenarios, the status bar changes to orange and indicates that the model is in Scenario Mode:

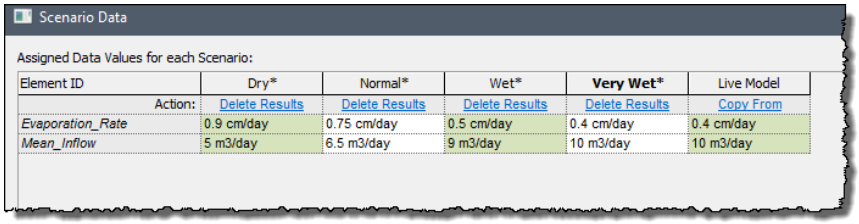
Clicking on the right portion of the status bar shows all four scenarios (and the Live Model):



Note that all the scenarios have an asterisk (*) next to them. An asterisk indicates that the scenario has scenario results available to be viewed.

Note: A model in Scenario Mode has *at least one* scenario with results. However, when in Scenario Mode, not all scenarios necessarily have results (since the scenarios can be run and results can be deleted independently). Only those scenarios with results are marked with an asterisk (*).

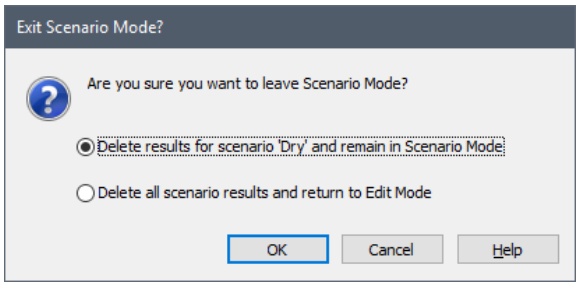
Once you have generated scenario results, there are a number of ways to delete them. From the Scenario Manager dialog itself, you can delete individual scenario results (using the **Delete Results** button for a particular scenario). In addition, when viewing Scenario Data from within the Scenario Manager (via the **Scenario Data…** button), a **Delete Results** button is available for each scenario:



Element ID	Dry*	Normal*	Wet*	**Very Wet***	Live Model
Action:	Delete Results	Delete Results	Delete Results	Delete Results	Copy From
Evaporation_Rate	0.9 cm/day	0.75 cm/day	0.5 cm/day	0.4 cm/day	0.4 cm/day
Mean_Inflow	5 m3/day	6.5 m3/day	9 m3/day	10 m3/day	10 m3/day

Note: Because, by definition, a model in Scenario Mode has *at least one* scenario with results, if you delete all scenario results from the Scenario Manager, the model will immediately return to Edit Mode.

Finally, if you press **F4** while in Scenario Mode (and the Active Scenario and at least one other scenario have results), you will be presented with this dialog:



The default option is to delete the results for the Active Scenario, but remain in Scenario Mode. Otherwise, you can return directly to Edit Mode (and all scenario results are deleted).

If you press **F4** in Scenario Mode (and the Active Scenario and at least one other scenario *do not* have results), the only option presented is to delete all results and return to Edit Mode.

You can also exit Scenario Mode by running the Active Scenario and going directly to Result Mode. In this case, all existing scenario results are retained.

Read more: Viewing Detailed Scenario Outputs in Result Mode (page 546).

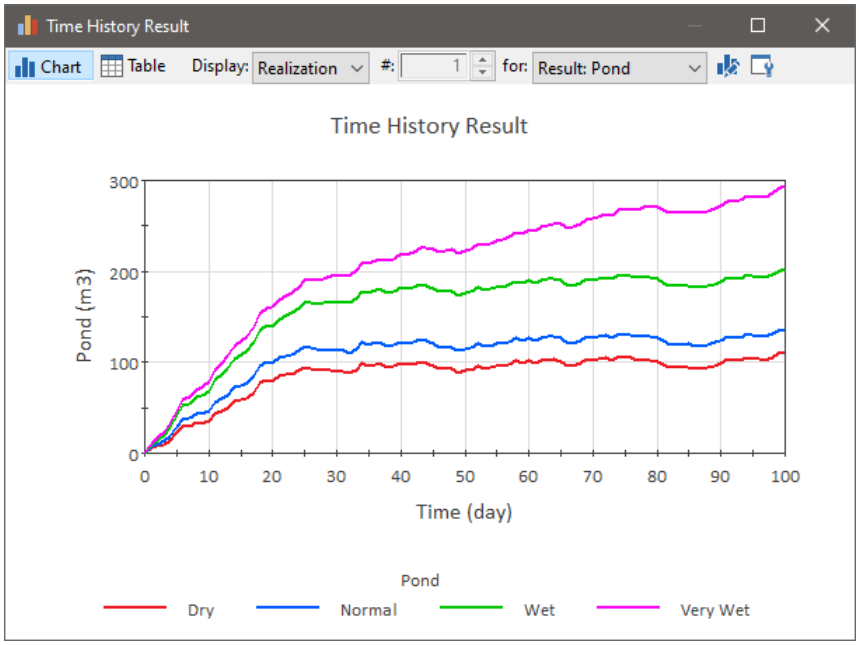
Comparing Scenario Results in Scenario Mode

Once a model is in Scenario Mode, if you were to browse the model, you would note the following:

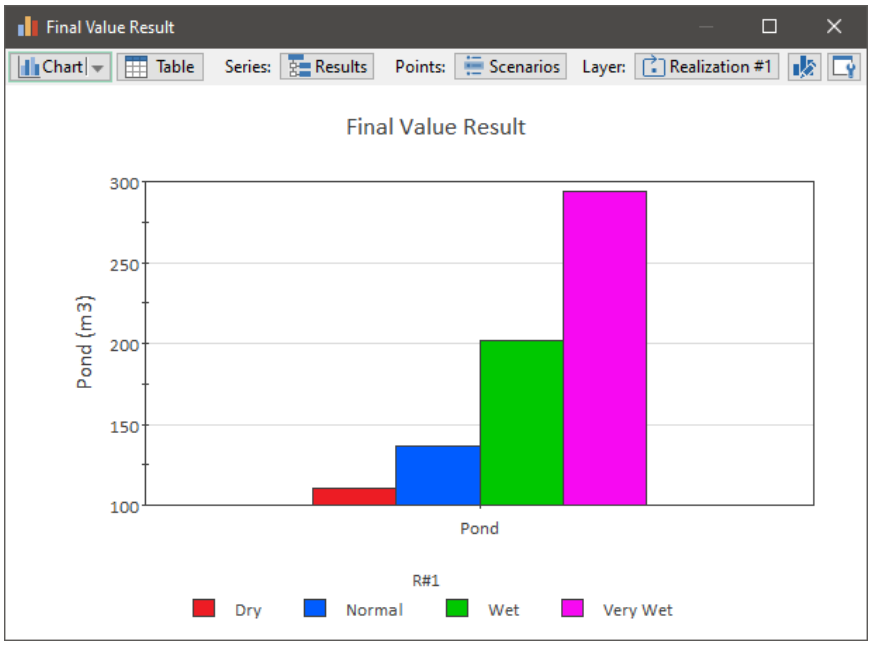
- If you browse to a Scenario Data element, it will display the value for the Active Scenario.
- There is no option to right-click on an element and view its results. Elements do not store results in Scenario Mode.
- If you double-click on a Final Value Result element, what is displayed is a function of how the Result element is configured. It could display results for all scenarios for which scenario results have been generated (and the **Show** button has been checked) or for only the Active Scenario.
- If you double-click on a Time History Result element or a Distribution Result element, GoldSim displays results for all scenarios for which scenario results have been generated (and the **Show** button has been checked).

Read more: Displaying Scenarios in Final Value Result Elements (page 717); Viewing Scenario Results in Time History Result Elements (page 645); Viewing Scenario Results in Distribution Result Elements (page 688).

For example, a Time History Result would look like this:

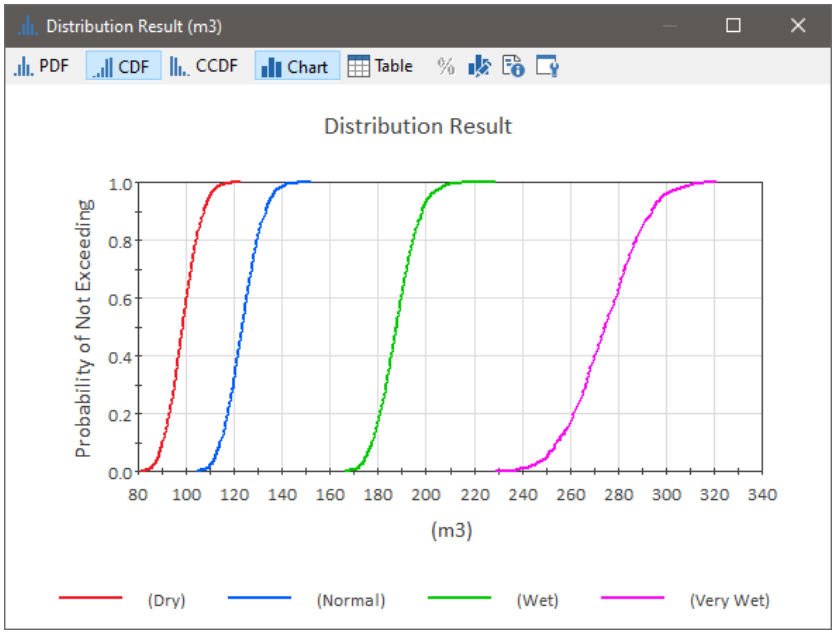


One of the possible displays for a Final Value Result would look like this:

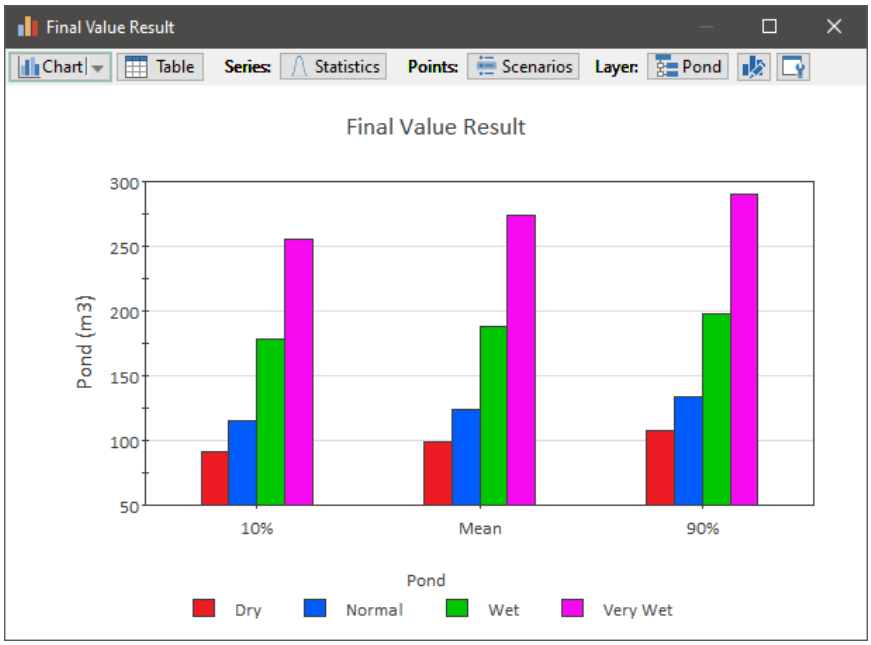


Each scenario is shown and indicated in the legend.

If the simulation is probabilistic, a Distribution Result will look like this, displaying the probability distribution for each scenario:



One of the possible displays for a Final Value Result for a probabilistic simulation allows you to view various statistics for each scenario and would look like this:



Note: Only Time History, Distribution and Final Value Result elements display scenario results. Scenario results cannot be displayed for other types of Result elements.

If you press **F4** you can return to Edit Mode (by deleting all scenario results), or you can choose to only delete the scenario results for the Active Scenario (while keeping the others). In this latter case, you will remain in Scenario Mode.

Pressing **F5** will run the Active Scenario and place the model in Result Mode. As discussed below,this allows you to view detailed results for a particular scenario.

Read more: Carrying Out a Simulation (Run Mode) (page 519); Viewing Results (Result Mode) (page 524).

Note: All scenario results are deleted when you return to Edit Mode. However, any scenario results that exist prior to entering Result Mode are retained in Result Mode (and can be viewed again if you return to Scenario Mode).

Viewing Detailed Scenario Outputs in Result Mode

- In order to compare scenario results, you must be in Scenario Mode. Moreover, when in Scenario Mode, scenario results can only be viewed in Time History Result elements, Distribution Result elements and Final Value Result elements (and Dashboard controls). *No other results are available.*
- Often, however, in addition to comparing scenario results, you will want to look at the detailed results for a single scenario. To do so, you must select the scenario of interest as the Active Scenario, and then run the model in the standard way (e.g., by pressing **F5**). This places the

model in Result Mode for the Active Scenario. All results are available to view.

Read more: Carrying Out a Simulation (Run Mode) (page 519); Viewing Results (Result Mode) (page 524).

- Note that while in Result Mode, you cannot compare scenarios (e.g., Result elements will only show results for the Active Scenario).

However, any scenario results that existed *prior* to entering Result Mode are still saved in the file (they are not deleted if you transitioned from Scenario Mode to Result Mode). You can view these again by returning to Scenario Mode. In particular, when you press **F4** from Result Mode, you will be presented with an option to return to Scenario Mode (where you will have access to all scenario results), or return to Edit Mode (which will delete all scenario results).

Read more: Transitioning Directly from Result Mode to Scenario Mode (page 547).

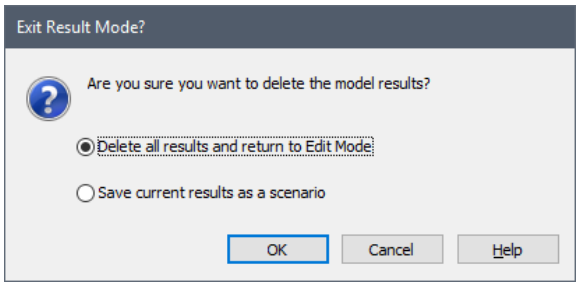
Transitioning Directly from Result Mode to Scenario Mode

When you are in Result Mode, you can press **F4** to delete the detailed output results and return to Edit Mode.

Read more: Understanding Simulation Modes (page 517).

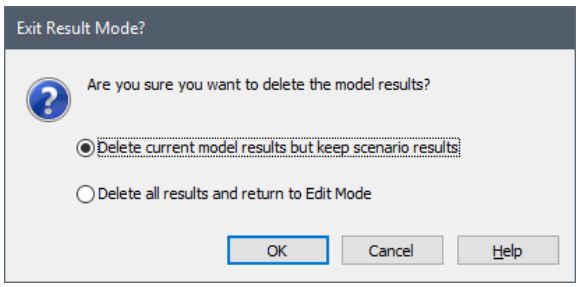
Note, however, that when you press **F4**, you will also be offered the opportunity to enter Scenario Mode. The options available are a function of whether any scenarios have been previously defined, whether the Active Scenario is the Live Model, and whether any scenario results already exist.

If no scenarios have been previously defined (or if the Active Scenario is the Live Model and no scenario results exist for other scenarios), the following dialog will be displayed when you press **F4**:



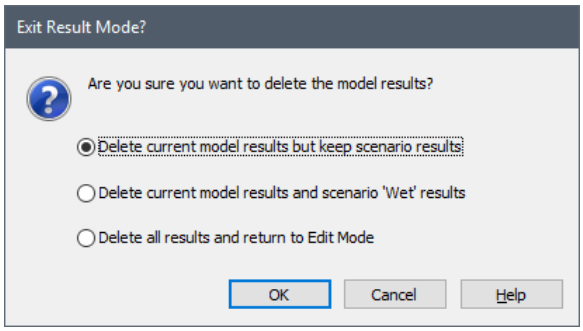
The first option is to delete all results and return to Edit Mode. If you select the second option, you will be prompted for a scenario name (and description), and the model will be placed in Scenario Mode. Although detailed outputs are deleted, the scenario results are saved.

If scenarios have been defined, no scenario results exist, and the Active Scenario is not the Live Model, the dialog displayed is somewhat different when you press **F4**:



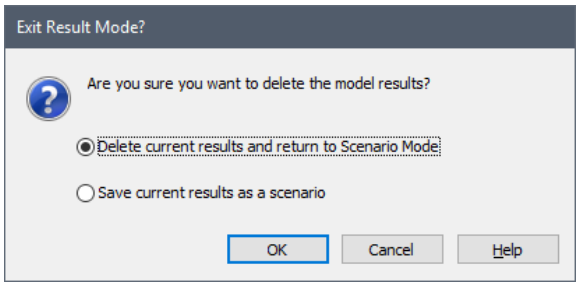
The default option is to delete the full results, but enter Scenario Mode (and keep the scenario results). The second option is to delete all results and return to Edit Mode.

If scenario results already exist in your model, and the Active Scenario is not the Live Model, the dialog displayed when you press **F4** provides three options:



The default option is to delete the full results, but enter Scenario Mode (and keep the scenario results). The second option is to delete the full results, as well as the scenario results for the Active Scenario, and enter Scenario Mode. The final option is to delete all results and return to Edit Mode.

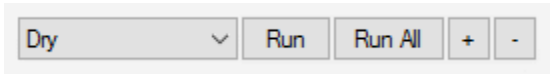
Finally, if scenario results already exist in your model, and the Active Scenario is the Live Model, the dialog displayed when you press **F4** provides two options:



The first option is to delete all results, and switch to Scenario Mode. If you select the second option, you will be prompted for a scenario name (and description), and the model will also be placed in Scenario Mode. Although detailed outputs are deleted, the scenario results are saved. If you wish to return all the way to Edit Mode, you must first return to Scenario Mode, and then press **F4** again.

Creating and Editing Scenarios in Dashboards

You can create, edit and run scenarios from a Dashboard. In particular, Dashboards provide a Scenario control that can be added that allows you to: 1) select the Active Scenario, 2) run the scenario; and 3) add and delete scenarios:



When a Scenario control is added to a Dashboard, you can enter Scenario Mode and compare scenario results directly from the Dashboard.

Dashboards and the Scenario control are discussed in detail in the **GoldSim Dashboard Authoring Module User's Guide**.

Running an Optimization

GoldSim provides the ability to carry out a special type of run to facilitate optimization of your model. For this type of run, you specify an objective

function (a specific result that you would like to minimize or maximize), an optional constraint (a condition that must be met), and one or more optimization variables (variables in your model that you have control over).

GoldSim then runs the model multiple times, systematically selecting combinations of values for each of the optimization variables. By doing so, GoldSim can determine the values of the optimization variables that optimize (minimize or maximize) the objective function while meeting the specified constraint.

Typical uses of optimization include:

- Finding the best input data values for a model, in order to match observed historical data (i.e., calibration).
- Selecting the "best" option from among alternatives. "Best" could mean safest, cheapest, most reliable, or another appropriate measure.
- Optimizing the timing of actions or policy changes during the course of a simulation.

The details of how to set up and run an optimization are presented in the sections below.

Two optimization examples can be found in the General Examples/Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu): 1) a very simple example file which illustrates the use of optimization for the purpose of calibration (CalibrationOptimization.gsm); and 2) a fairly complex example that illustrates the use of optimization to optimize a design (DesignOptimization.gsm).

Overview of Optimization

In order to run an optimization in GoldSim, you first need to select an objective function that is to be maximized or minimized. The objective function can be any output in your model. The optimization is carried out based on the *final value* (the value at the end of the realization) of the objective function.

The objective function can be a simple computed measure (e.g., impact, cost) or a complex expression (e.g. "stakeholder satisfaction" or "risk-weighted net present value"). In most cases, it will represent either a cumulative value (e.g., total accumulated cost), a peak value (e.g., the highest water level observed during the simulation), or a valley (e.g., the minimum amount of money in an account during the simulation). Cumulative values can be computed using Integrators, Reservoirs and Pools in GoldSim, while peaks and valleys can be computed using Extrema elements. As a result, the objective function is often a function of one or more of these types of elements.

Read more: Integrator Elements (page 233); Reservoir Elements (page 240); Pool Elements (page 258); Extrema Elements (page 282).

After you have defined the objective function, you need to identify one or more optimization variables (Data or Stochastic elements in your model) that can be adjusted by GoldSim to optimize the objective function. Optimization variables often represent "decision variables" in your model – variables that you have direct control over (e.g., how much money to spend, when to implement something, the properties of a facility that you are simulating). GoldSim requires you to specify an initial value (an initial guess) for each variable, as well as an upper and lower bound between which the variable will be allowed to range. You can also specify whether the variable is to be limited to integer values.

Obviously, the objective function should be dependent (either directly or indirectly) on all of the optimization variables.

You can also define a constraint that must be met when selecting optimization variables (such as not exceeding a regulatory limit, staying within a financial budget, or never having a combination of optimization variables that would be unacceptable for some reason). GoldSim will seek the optimal value of the objective function by varying the optimization variables within their bounds and will dismiss any solutions which do not meet the specified constraint condition.

Once the objective function and optimization variables have been defined, and any required constraints specified, the optimizer can be run. The optimization is based on Box's complex method.

Note: Box's complex method is described in: Box, M.J. (1965). "A new method of constrained optimization and a comparison with other methods," *The Computer Journal*, Volume 8, Issue 1, pp. 42-52.

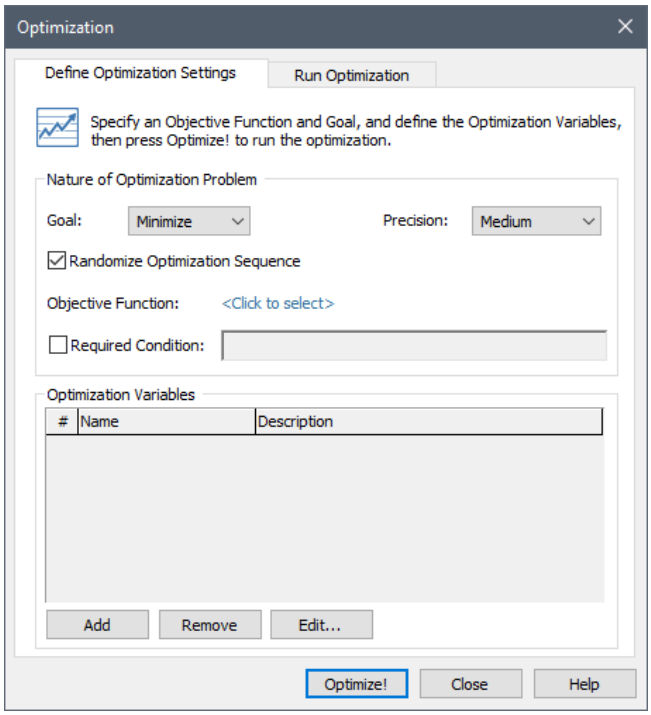
Box's complex method begins by developing an initial "complex," which is a set of valid solutions that meet all of the requirements specified by the user. This complex contains twice as many valid solutions as the number of optimization variables. Once the initial complex has been developed, the algorithm searches the solution space iteratively, replacing the least optimal members of the complex with more optimal ones until the solution converges or GoldSim determines that convergence cannot be achieved (in which case a warning message will be displayed).

Read more: Setting the Optimization Precision (page 555); Understanding Optimization Warning Messages (page 558).

When you complete an optimization run, GoldSim provides options for copying the optimal values of the optimization variables to the element definitions before carrying out any further simulations.

Defining the Optimization Settings

To prepare to carry out an optimization, select **Run | Optimization…** from the main menu (there is also an **Optimization** button in the **Advanced** toolbar). The following dialog will be displayed:



Note: You can only run an optimization from Edit Mode. You cannot run an optimization if the model is in Result Mode.

Defining the optimization settings requires three steps:

- Specifying the objective function and any constraints;
- Specifying the optimization variables; and
- Setting the optimization precision.

These three steps are described in the sections below.

Specifying the Objective Function and Constraints

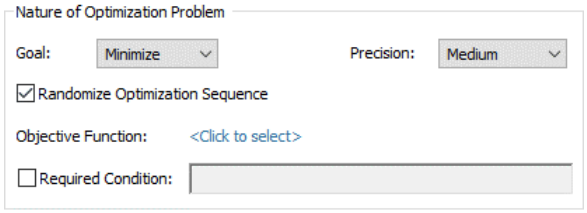
The first step in preparing to carry out an optimization is to define an objective function that is to be maximized or minimized. The objective function can be any output in your model. The optimization is carried out based on the *final value* (the value at the end of the realization) of the objective function.

In most cases, the objective function will represent either a cumulative value (e.g., total accumulated cost), a peak (e.g., the highest water level observed during the simulation), or a valley (e.g., the minimum amount of money in an account during the simulation). Cumulative values can be computed using Integrators and Reservoirs in GoldSim, while peaks and valleys can be computed using Extrema elements. As a result, the objective function is often a function of one or more of these types of elements.

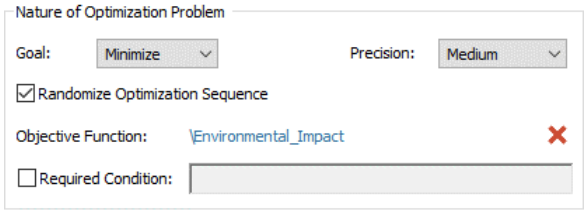
Read more: Integrator Elements (page 233); Reservoir Elements (page 240); Extrema Elements (page 282).

You can also define a constraint that must be satisfied by the solution. GoldSim will seek the optimal value of the objective function by varying the optimization variables within their bounds and will dismiss any solutions which do not meet the specified constraint condition.

The "Nature of Optimization Problem" section of the **Define Optimization Settings** tab is used to specify the objective function and any constraints:



To select the **Objective Function** you must click on "<Click to select>". A browser dialog for selecting an output will be displayed. After you select the output and press **OK**, the selected output is then shown in the dialog:



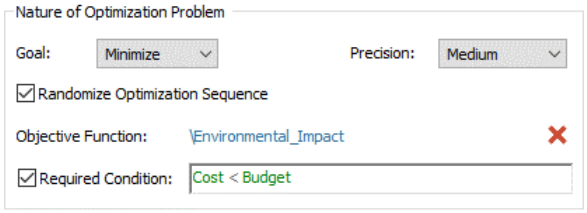
You can delete the selected output by pressing the red X to the right, or you can click on the item and select a different output.

The **Objective Function** must be a scalar value.

The **Goal** drop-list allows you to select whether you want to maximize or minimize the objective function. The **Precision** drop-list allows you to control the precision of the optimization algorithm.

Read more: Setting the Optimization Precision (page 555).

You can specify a constraint by checking the **Required Condition** checkbox and specifying a condition that must be true in order for a solution (i.e., a combination of values of the optimization variables) to be valid. The constraint must be a condition output or a conditional expression, and can be a function of the objective function, the optimization variables, and/or any other outputs in your model:



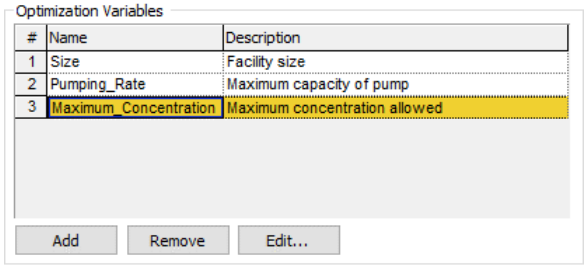
The **Required Condition** is evaluated at the end of each realization. Solutions that do not meet the specified condition will be dismissed, and no solutions that violate this constraint will ever be included in the complex that is developed by the optimizer.

Specifying the Optimization Variables

After you have defined the objective function, you need to identify one or more optimization variables that can be adjusted by GoldSim as it seeks to optimize the objective function. Optimization variables often represent "decision variables" in your model – variables that you have direct control over (e.g., how much money to spend, when to implement something, the properties of a facility that you are simulating) GoldSim requires you to specify an initial value (an initial guess) for each variable, as well as an upper and lower bound between which the variable will be allowed to range.

Obviously, the objective function should be dependent (either directly or indirectly) on all of the optimization variables.

The bottom half of the **Define Optimization Settings** tab allows you to specify an arbitrary number of optimization variables:



You can add optimization variables by pressing the **Add…** button.

When you do so, a browser dialog will be displayed for selecting an output. Optimization variables must be scalar Stochastic elements or Data elements. They can be values or conditions.

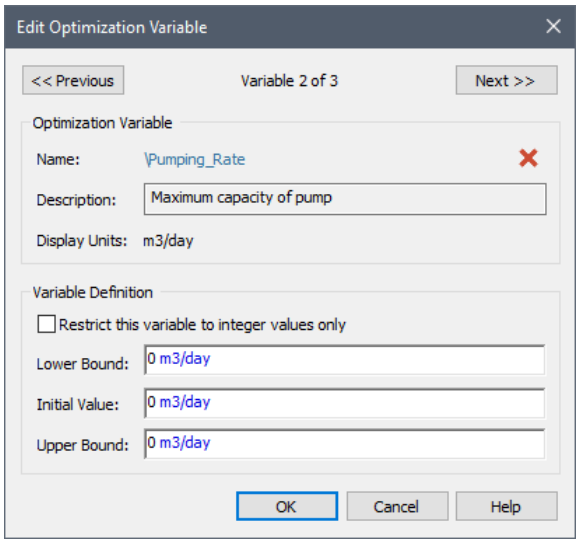
The dialog will only list Stochastic elements and Data elements (no element types other than Stochastics and Data elements will be listed). It will list Data and Stochastic elements that are arrays, but if you select one, it will display an error message.

Note: A clone can be selected as an optimization variable, but two "sister" clones (clones of each other) cannot both be selected. If you try to do so, GoldSim will display an error message.

Note: Only scalars can be specified as optimization variables. If you wish to optimize a member or members of a vector or matrix, you can do so by creating individual scalar Data elements that define the members of the vector or matrix.

Note: If a Stochastic is selected as an optimization variable, the Probability_Density and Cumulative_Probability outputs for the element in the model will always evaluate to 0 during the optimization runs.

After selecting an element as an optimization variable, the following dialog will be displayed:



The **Name**, **Description**, **Display Units** and **Type** are automatically transferred from the linked element (and cannot be edited here). If you've selected the wrong element, you can reopen the browser for selecting optimization variables by clicking on the Name.

For each optimization variable, you must specify the range over which the variable will be varied during the optimization by defining a **Lower Bound** and an **Upper Bound**. The bounds must be numbers and cannot be links to other elements in the model.

You are also required to specify an **Initial Value** for each optimization variable. This should be your "initial guess" for the optimal value of each variable. The Initial Value is not critical, but if it is chosen well (i.e., if it is relatively close to the true optimum), it could speed up the optimization. The Initial Value must be a number and cannot be a link to other elements in the model.

If you check the **Restrict this variable to integer values only**, during the optimization process, GoldSim will only use integer values for the variable.

Note: During the optimization process, GoldSim completely overrides the values of the elements chosen as optimization variables. That is, the manner in which they are defined (e.g., the distribution type for a Stochastic optimization variable) has no impact on the optimization.

Note: During the optimization process, each run is treated as a deterministic simulation. Hence, all Stochastic elements not defined as optimization variables use their deterministic value.

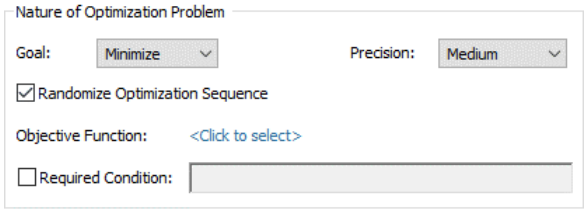
Once you have specified bounds and an initial value, you can click **Prev** or **Next** to view the other optimization variables, but the new optimization variable will not be added until you click the **OK** button.

Optimization variables can be removed by highlighting them in the dialog and pressing the **Remove** button.

You can edit the settings for an existing optimization variable by double clicking on the optimization variable in the dialog, or by highlighting the optimization variable and pressing the **Edit…** button.

Setting the Optimization Precision

The optimization algorithm can be controlled via the **Precision** setting in the **Define Optimization Settings** tab:



You can set the **Precision** to Maximum, High, Medium or Low (the default setting is Medium). The precision setting has two effects:

1. it determines the number of valid points used to generate the initial complex of solutions; and
2. it determines the convergence criterion GoldSim uses to decide whether or not it has obtained an "optimal" solution.

Box's complex method begins by developing an initial "complex," which is a set of valid solutions that meet all of the requirements specified by the user. This complex contains twice as many valid solutions as the number of optimization variables. Once the initial complex has been developed, the algorithm searches the solution space iteratively, replacing the least optimal members of the complex with more optimal ones until the solution converges or GoldSim determines that convergence cannot be achieved (in which case a warning message will be displayed).

The way in which the initial complex is generated depends on the **Precision** specified by the user:

- For Low Precision, GoldSim generates only the minimum number of valid solutions required to create the complex (i.e., two times the number of optimization variables).
- For Medium Precision, GoldSim generates twice as many valid solutions as it needs (i.e., it generates 4N valid solutions, where N is the number of optimization variables). It then uses the 2N most optimal solutions to form the initial complex.
- For High or Maximum Precision, GoldSim generates five times as many valid solutions as it needs (i.e., it generates 10N valid solutions, where N is the number of optimization variables). It then uses the 2N most optimal solutions to form the initial complex.

Hence, the higher the **Precision** setting, the better the initial complex spans the variable space (and the higher the likelihood that a global optimum, rather than a local optimum, will be found).

GoldSim determines whether or not it has achieved an optimal solution by comparing the range of objective function values in the current complex with the range of objective function values in the initial complex. The convergence criterion is also determined by the **Precision** specified by the user:

- For Low Precision, convergence requires the range in objective function values to be less than 0.01 of the initial range or 100 solutions have been tried.

- For Medium Precision, convergence requires the range in objective function values to be less than 0.001 of the initial range or 1000 solutions have been tried.
- For High Precision, convergence requires the range in objective function values to be less than 0.00001 of the initial range or 1E4 solutions have been tried.
- For Maximum Precision, the optimizer will continue until it can no longer improve the result, or 1E6 solutions have been tried.

In some cases, the optimization may not be able to converge within the allowed number of iterations. In this case, GoldSim will display a warning message.

Read more: Understanding Optimization Warning Messages (page 558).

The **Randomize Optimization Sequence** checkbox (which is checked by default), can be used to ensure that the initial complex is randomized every time it is created. This can be used to help ensure that GoldSim finds a global optimum by running the optimization more than once.

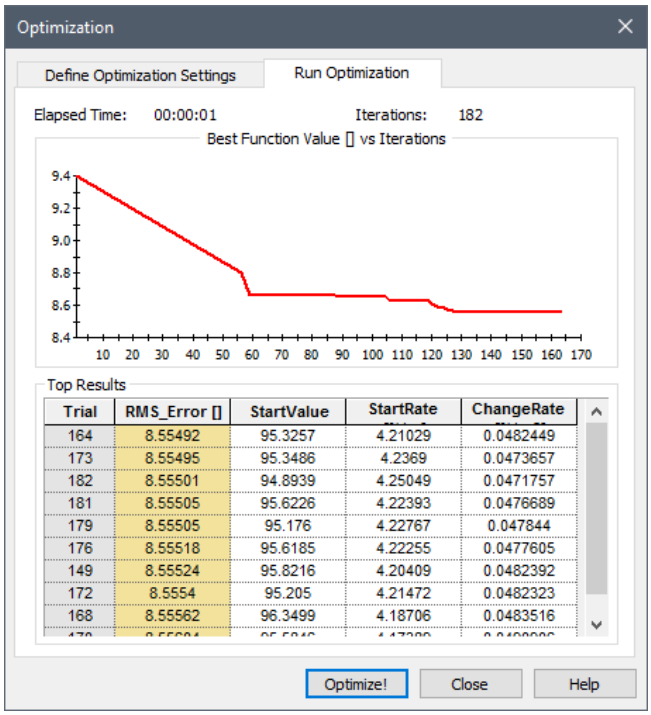
Read more: Finding a Global Optimum in Complex Models with Multiple Optima (page 558).

Running the Optimization

Once you have specified the objective function, constraints and optimization variables, the optimization can be run. To run the optimization, simply click the **Optimize!** button at the bottom of the Optimization dialog.

Note: During the optimization process, each run is treated as a deterministic simulation. You cannot run an optimization if your Monte Carlo settings are specified to run multiple realizations. The settings must be specified to either run a deterministic simulation or a single probabilistic simulation (in which case it will automatically be treated as a deterministic simulation).

Clicking the **Optimize!** button will immediately take you to the other tab in the optimization dialog (**Run Optimization**) and begin the optimization. The **Run Optimization** tab tracks the progress of the optimization:



The **Run Optimization** tab is divided into two sections:

Best Function Value vs. Iterations: This section of the dialog provides a graph that plots the most optimal value of the objective function (on the y-axis) versus the number of iterations that have been completed (on the x-axis).

Top Results: This section displays the objective function and optimization variable values from the ten most optimal iterations.

This tab is continuously updated during the course of an optimization.

While the optimization is running, a **Pause** button will be available. Pressing it will temporarily stop the optimization (and switch the **Pause** button into a **Resume** button, which can be clicked to restart the simulation). There is also an **Abort** button, which immediately ends the optimization.

After the optimization is completed, the **Pause** and **Abort** buttons will switch back to **Optimize!** and **Close** buttons.

When the optimization completes, a message will be displayed indicating that the optimization has completed. The first row in the Top Ten Results section will display the optimal values of the optimization variables and the optimized value of the objective function. When you press **Close** to exit the optimization, you will be presented with a dialog with options for saving these results.

Read more: Saving Optimization Settings and Results (page 559).

In some cases, the optimization may not converge. In this case, GoldSim will provide a warning message.

Read more: Understanding Optimization Warning Messages (page 558).

Some types of models may have multiple local optima. In such a case, GoldSim may not necessarily find the global optimum. There are, however, some steps you can take to increase the likelihood of finding the global optimum.

Read more: Finding a Global Optimum in Complex Models with Multiple Optima (page 558).

Warning: Warning messages are not displayed when running an optimization (although fatal error messages are).

Warning: When running an optimization, Interrupt messages are never displayed. Moreover, unless the **Specify Action When Message is off or cannot be shown** field in the Interrupt is set to "Continue" or "Skip remainder of current Realization and Continue" (or the Interrupt is disabled), any triggered Interrupts will result in a fatal error.

Read more: Interrupting a Simulation (page 423).

Finding a Global Optimum in Complex Models with Multiple Optima

For a well-behaved problem with a single optimum solution, GoldSim can be counted on to locate the optimum. For more complex problems with multiple local optima, however, the solution found by GoldSim may not necessarily be the true optimum (it could be a local optimum).

For complex models with local optima, the choice of bounds and initial values for the optimization variables can be important, and can determine whether GoldSim converges to a local optimum, rather than to the global optimum.

The best way to convince yourself that you have found a global, rather than a local, optimum, is to run the optimization multiple times with different initial complexes.

In order to ensure that GoldSim creates a different initial complex every time it starts an optimization, the **Randomize optimization sequence** checkbox should be checked (which is the default). If you then run multiple optimizations (by pressing the **Optimize!** button repeatedly), GoldSim will rerun the optimization with a different initial complex each time.

Note: If the **Randomize optimization sequence** checkbox is cleared, each optimization will use the same initial complex and hence will converge to the same solution.

Although it is impossible to be sure that you have found a global optimum, if you repeat the optimization multiple times (randomizing the initial complex) and converge to the same solution, your confidence that you have found a global optimum will certainly be increased.

Understanding Optimization Warning Messages

In some cases, an optimization may not converge. In this case, GoldSim will provide one of three warning messages:

Unable to create valid initial complex. Optimization failed. In order to start the optimization, GoldSim must find 2N valid solutions, where N is the number of optimization variables. This error indicates that GoldSim could not find 2N valid solutions. This probably indicates that your problem is over-constrained. That is, GoldSim could not find any combination of optimization variables (within the bounds specified) that met the specified constraint (the Required Condition).

Cannot improve on best solution, but failed to converge. Optimization is probably successful. This indicates that the optimization has found a number of valid solutions, but is "stuck" and cannot find any better solutions (while still failing to meet the convergence criterion). In this case, the solution is likely a good one, and it simply indicates that the convergence criterion was too strict. You should carefully examine the Top Results to determine if the optimal values are still significantly changing.

Solution still slowly improving, but failed to converge. Optimization is probably successful. This indicates that the optimization has found a number of valid solutions, and continues to slowly improve the solution, but has not converged after a large number of iterations (100 for low, 1000 for medium, 10,000 for high precision). In this case, the solution is likely a good one, and it simply indicates that the convergence criterion was too strict. You should carefully examine the Top Results to determine if the optimal values are still significantly changing.

Optimizing a Probabilistic Model

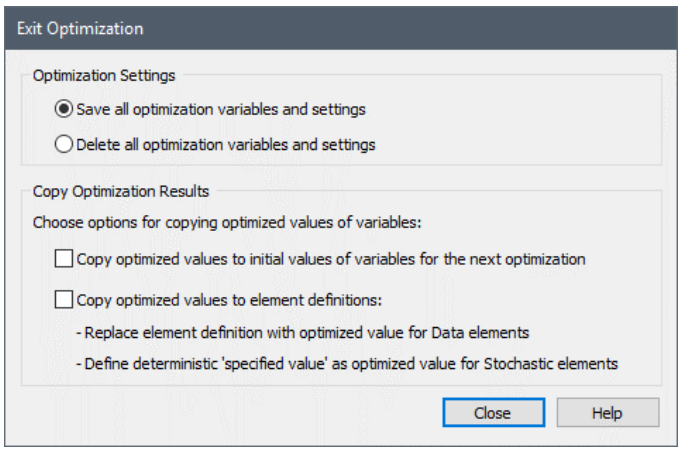
If you wish to optimize a probabilistic (uncertain) system, the objective function to be optimized cannot be a single deterministic output. Rather, it must be a statistic. That is, if X was an output of a probabilistic model (and hence was output as a probability distribution), optimizing X itself would be meaningless. Rather, you would need to optimize a particular statistic (e.g., the mean or 50th percentile) of the output X.

In order to do this within GoldSim, you must use SubModels. In particular, you must embed a SubModel within an outer model. The SubModel would be a fully dynamic Monte Carlo simulation, and the outer model would be a static optimization. The optimization variables for the outer model would be statistics that have been exposed on the output interface of the SubModel.

Read more: Using SubModels to Embed Models Within Models (page 1047).

Saving Optimization Settings and Results

When you close the Optimization dialog, you will see a dialog with a number of options:



At the top of the dialog are two radio buttons that determine whether the optimization settings (i.e., all of the settings on the **Define Optimization Settings** tab) are saved. If the first radio button is selected (**Save all optimization variables and settings**), all of these settings are saved. If the second radio button is selected, all of these settings are deleted (and hence will not be available the next time you want to run an optimization).

Even if you save the optimization settings, the optimization results in the **Run Optimization** tab will be deleted and will not be available the next time you run an optimization (you will need to re-run the optimization). Hence, before

exiting the Optimization dialog, you should record the optimal values of the optimization variables and the optimized value of the objective function displayed in the Top Ten Results section of the **Run Optimization** tab.

Note: GoldSim provides an easy way to extract and save the Top Results. Left-click on a column and then drag the cursor to select the other columns you wish to export. Alternatively, press **Ctrl+A** to select the entire Top Results table. Pressing **Ctrl+C** copies it to the clipboard (with the column headers). It can then be pasted into another application.

This information (the optimization results) can also be copied directly to other parts of the model. The bottom portion of the dialog provides two options for doing so (you can do neither, one or both).

The options are as follows:

Copy optimized values to initial values of variables for next optimization: This option replaces the Initial Values that you specified for each optimization variable with the values that resulted in the most optimal value of the objective function. This is useful, for example, if you plan to modify the model in the future, and think that the optimal values from the original model would be a good initial guess for the modified model. Note that this option is grayed out if optimization settings and variables are not saved.

Copy optimized values to element definitions: This option replaces the values of the optimization variable elements in the GoldSim model with the values that resulted in the most optimal value of the objective function. For optimization variables that are Data elements, the element definition is replaced with the optimized value. For optimization variables that are Stochastic elements, the "specified value" for deterministic simulations is replaced with the optimized value.

Read more: Specifying a Deterministic Value for a Stochastic (page 186).

Running Sensitivity Analyses

GoldSim provides the ability to carry out a special type of run to facilitate sensitivity analyses. For this type of run, you specify the result you are interested in, and one or more variables that you want to analyze (which must be Stochastics or Data elements).

GoldSim then runs the model multiple times, systematically sampling each variable over a specified range, while holding all of the other variables constant. This then allows GoldSim to produce sensitivity plots (i.e., a tornado chart and X-Y function charts) to assist you in graphically identifying the variables in your model to which the results is most sensitive.

Note: The sensitivity analyses discussed here produce graphical (and tabular) outputs created by changing one variable at a time, while holding all other variables constant. GoldSim also provides a second type of sensitivity analysis in which statistical sensitivity measures are computed by analyzing the results of multiple realizations of the model where all of the Stochastic variables are simultaneously sampled each realization.

Read more: Viewing a Sensitivity Analysis Table (page 746).

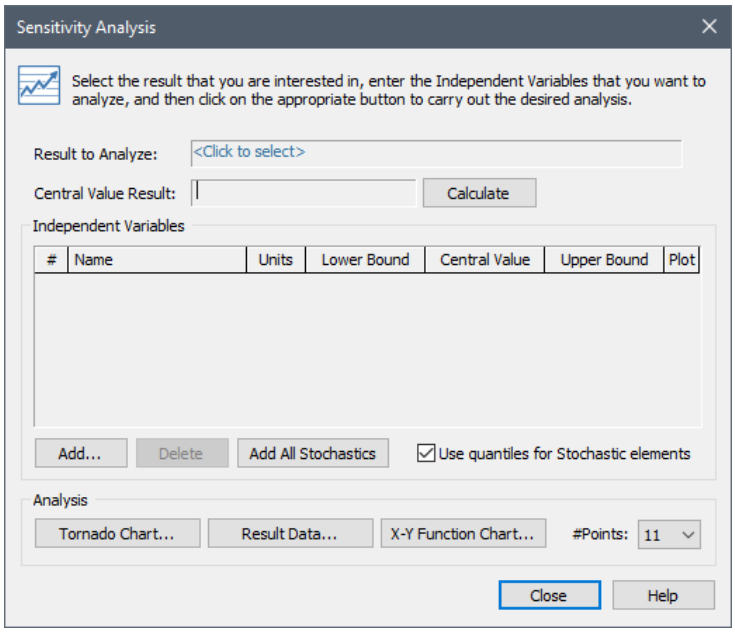
Note: During the sensitivity analysis, each run is treated as a deterministic simulation. Hence, all Stochastic elements not defined as independent variables use their deterministic value.

The details of how to set up, run and view such a sensitivity analysis are presented in the sections below.

A simple example file which illustrates the use of sensitivity analysis (Sensitivity.gsm) can be found in the General Examples/Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Selecting the Result and Independent Variables for a Sensitivity Analysis

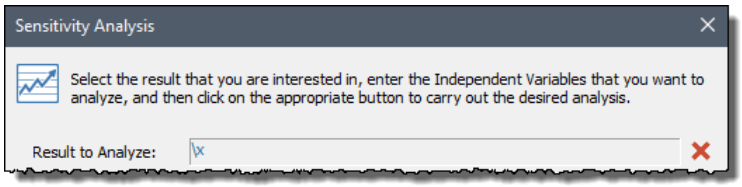
To prepare to carry out a sensitivity analysis, select **Run | Sensitivity Analysis…** from the main menu (there is also a **Sensitivity Analysis** button in the **Advanced** toolbar). The following dialog will be displayed:



Note: You can only run a sensitivity analysis from Edit Mode. You cannot run a sensitivity analysis if the model is in Result Mode.

The first step required to set up a sensitivity analysis is to define which output (i.e., result) you would like to analyze for sensitivity. The sensitivity analysis will be used to determine the degree to which other variables impact this result. You select this result by pressing "<Click to select>" immediately to the right of **Result to Analyze**.

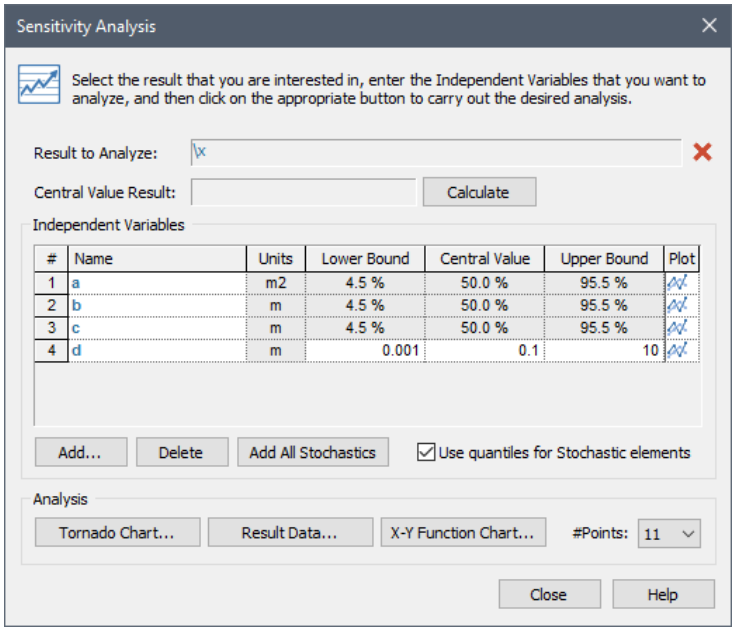
When you do so, a browser dialog will be displayed for selecting an output. You can select any scalar, value output in your model (you cannot select arrays or conditions). After you select the output and press **OK**, the selected output is then shown in the dialog:



You can delete the selected output by pressing the red X to the right, or you can click on the item and select a different output.

After selecting the result to analyze, you must then select the variables that will be varied to determine the degree to which they impact the result. You add these variables by pressing the **Add…** button.

When you do so, a browser dialog will be displayed for selecting an element. The dialog will only list Stochastic elements and Data elements (no other element types will be listed). You can select any Stochastic or Data element with a scalar, value output (you cannot select arrays or conditions). Each selected independent variable will then be listed in the dialog:



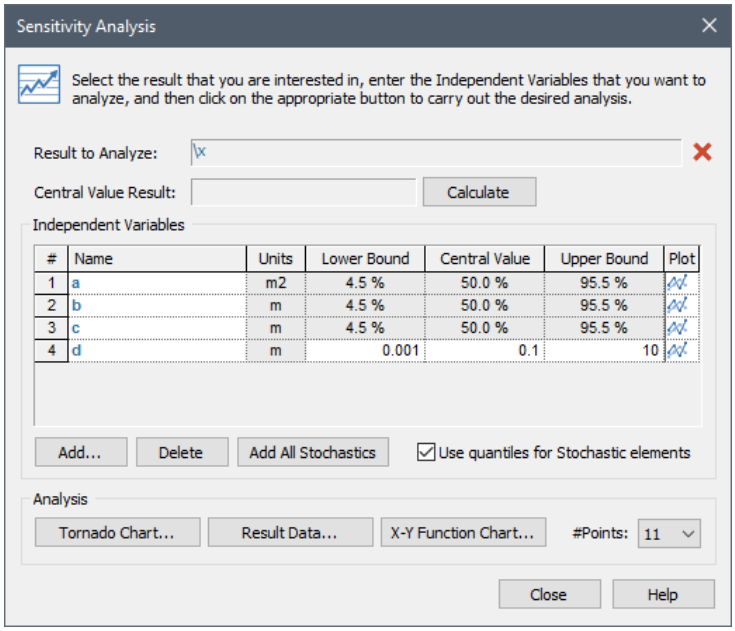
You can delete a variable that you have already added by selecting the variable in the list and pressing the **Delete** button. Pressing the **Add All Stochastics** button adds all valid Stochastic elements (i.e., Stochastics that are scalar values) in your model to the variable list.

Note: If a Stochastic is selected as an independent variable for a sensitivity analysis, the Probability_Density and Cumulative_Probability outputs for the element in the model will always evaluate to 0 during the sensitivity analysis runs.

You can also delete one variable and replace it with another by selecting the variable name. When you do so, a browser dialog will be displayed for selecting a new element.

Defining the Independent Variable Ranges for a Sensitivity Analysis

Once you have specified a result and added one or more independent variables, the Sensitivity Analysis dialog will look similar to this:



When GoldSim carries out a sensitivity analysis, it does so by running a series of deterministic simulations, varying one independent variable at a time through a range of values. You select the range of values using the **Lower Bound**, **Central Value** and **Upper Bound** fields in this dialog.

Read more: Deterministic Simulation Options (page 501).

For each simulation, GoldSim must select single values for all of the other independent variables (that are not currently being varied), and for any other Stochastic elements in the model. The manner in which these single values are selected is as follows:

- For Stochastics that are identified as one of the independent variables, GoldSim uses the specified **Central Value** for the single value.
- For Stochastics that are not listed as one of the independent variables, GoldSim uses the same value it would use if it were carrying out a deterministic simulation.
- For Data elements that are identified as one of the independent variables, GoldSim uses the specified **Central Value** for the single value.
- For Data elements that are not listed as one of the independent variables, GoldSim uses its defined value.

In order to carry out a sensitivity analysis, you must specify the range for each variable, as well as the number of points to sample within each range.

The number of points sampled for each variable is specified in the **#Points** field. This field defaults to 11, and must be an odd number.

For Data variables, you must always specify the **Lower Bound**, **Central Value** and **Upper Bound** directly. You enter numbers (without units). The units are displayed to the left of these three fields.

For Stochastic variables, you have a choice of how to define the range. If **Use quantiles for Stochastic elements** is checked (the default), GoldSim defines the bounds and the Central Value by using quantiles of the distribution. The Central Value is always the 50th percentile. The Lower and Upper Bounds are determined by the #Points using the following equations:

$$\text{Lower Bound} = \frac{100\%}{(\#\,\text{Points})(2)}$$

Upper Bound = 100% - Lower Bound

For example, with 11 points, the Lower Bound is approximately 4.5% and the Upper Bound is approximately 95.5%.

If **Use quantiles for Stochastic elements** is cleared, you must always specify the **Lower Bound**, **Central Value** and **Upper Bound** directly for Stochastics, just as you would for Data elements.

Warning: When defining the **Lower Bound**, **Central Value** and **Upper Bound** directly for Stochastics or Data elements, these values do not have to be related in any way to the actual definition for the elements. For example, you could specify a **Lower Bound**, **Central Value** and/or an **Upper Bound** that were outside the range of the actual defined distribution for a Stochastic. Similarly, a Data element could be defined such that its actual defined value was different from its **Central Value** when running Sensitivity Analyses. In general, this is likely to lead to confusion, and it is strongly recommended that when defining the ranges for your independent variables, the values should be consistent with the actual defined values for the elements that are used when not running a Sensitivity Analysis.

Viewing Sensitivity Analysis Results

Once you have specified a result, added one or more independent variables, and defined the ranges for the independent variables, you can carry out several different types of sensitivity analysis.

GoldSim provides four types of analysis and display:

- Central Value Result;
- Tornado Chart;
- X-Y Function Chart; and
- Result Data Display.

These are discussed in the sections below.

Note: The sensitivity analyses discussed here produce graphical and tabular outputs created by changing one variable at a time, while holding all other variables constant. GoldSim also provides a second type of sensitivity analysis in which statistical sensitivity measures are computed by analyzing the results of multiple realizations of the model where all of the Stochastic variables are simultaneously sampled each realization.

Read more: Viewing a Sensitivity Analysis Table (page 746).

Note: During the sensitivity analysis, each run is treated as a deterministic simulation. You cannot run a sensitivity analysis if your Monte Carlo settings are specified to run multiple realizations. The settings must be specified to either run a deterministic simulation or a single probabilistic simulation (in which case it will automatically be treated as a deterministic simulation).

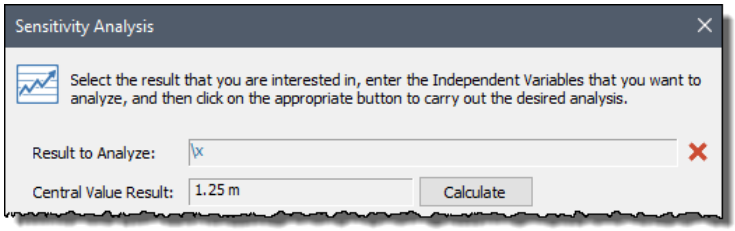
Warning: Warning messages are not displayed when running a sensitivity analysis (although fatal error messages are).

Warning: When running a sensitivity analysis, Interrupt messages are never displayed. Moreover, unless the **Specify Action When Message is off or cannot be shown** field in the Interrupt is set to "Continue" or "Skip remainder of current Realization and Continue" (or the Interrupt is disabled), any triggered Interrupts will result in a fatal error.

Read more: Interrupting a Simulation (page 423).

Sensitivity Analysis: Central Value Result

The simplest type of sensitivity analysis within the Sensitivity Analysis dialog is to compute the **Central Value Result**. This is a single deterministic simulation in which the specified **Central Value** is used for all defined independent variables. Pressing the **Calculate** button causes GoldSim to run a single deterministic simulation, and display the value of the selected result in the **Central Value Result** field:



This can be a useful way to quickly run a series of "what if" deterministic analyses, by manually changing the Central Values for one or more of the independent variables.

Sensitivity Analysis: Tornado Chart

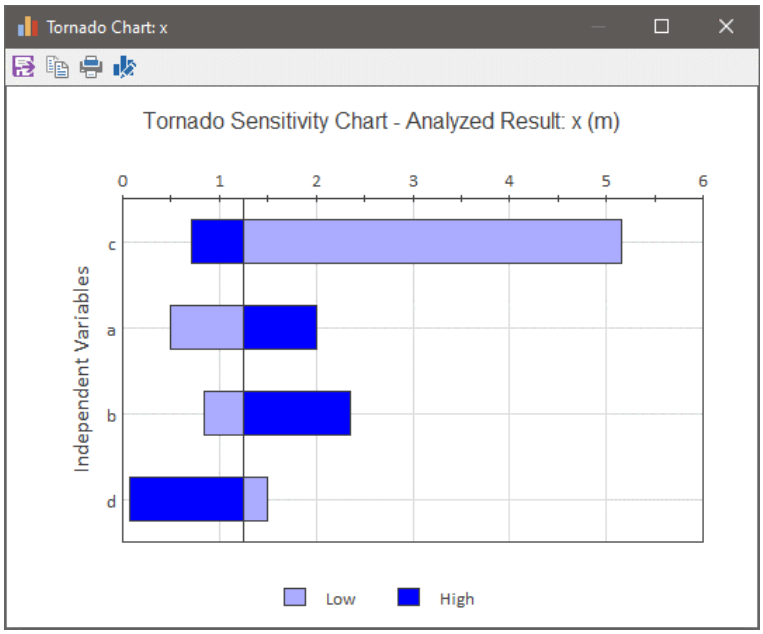
A tornado chart is a type of sensitivity analysis that provides a graphical representation of the degree to which the Result is sensitive to the specified Independent Variables.

A tornado chart can be produced by pressing the **Tornado Chart…** button in the Sensitivity Analysis dialog. When you do so, GoldSim runs a series of deterministic simulations, varying one independent variable at a time through a range of values. In particular, it does the following:

1. While holding all other Independent Variables at their Central Value and all other Stochastics (not identified as Independent Variables) at their deterministic values, GoldSim runs 3 deterministic simulations with three different values for the first dependent variable: the **Lower Bound**, the **Central Value**, and the **Upper Boun**d.
2. The process is repeated for each Independent Variable.

For example, if there were 10 Independent Variables specified, GoldSim would carry out 30 deterministic simulations to produce the tornado chart.

Once it carries out these simulations, it uses the results to construct a tornado chart such as this:



The x-axis of a tornado chart represents the values of the Result for different values of the independent variables.

Each bar represents the range of Result values produced when each independent variable is set to Lower Bound, Central Value, and Upper Bound (with the other variables being held constant). A light blue bar indicates that the value was produced by the Lower Bound (Low), and a dark blue bar indicates that the value was produced by the Upper Bound (High). For example, this particular chart indicates that the variable d produced a Result equal to about 1.25 when d was at its Lower Bound, and a Result of about 0.2 when d was at its Upper Bound.

The variables are organized from top to bottom according to the total range of Results produced. That is, the variable that produces the largest range of the Result between it Lower and Upper Bound is at the top of the chart. Hence, bars become smaller toward the bottom of the chart, and the overall effect is to take on the appearance of a "tornado".

The solid vertical line represents the value of the Result when the Central Values are used for all independent variables. In this example, the Result using the Central Values is 1.3.

Note: If you have more than 20 independent variables, GoldSim will only plot the top 20 variables in the tornado chart.

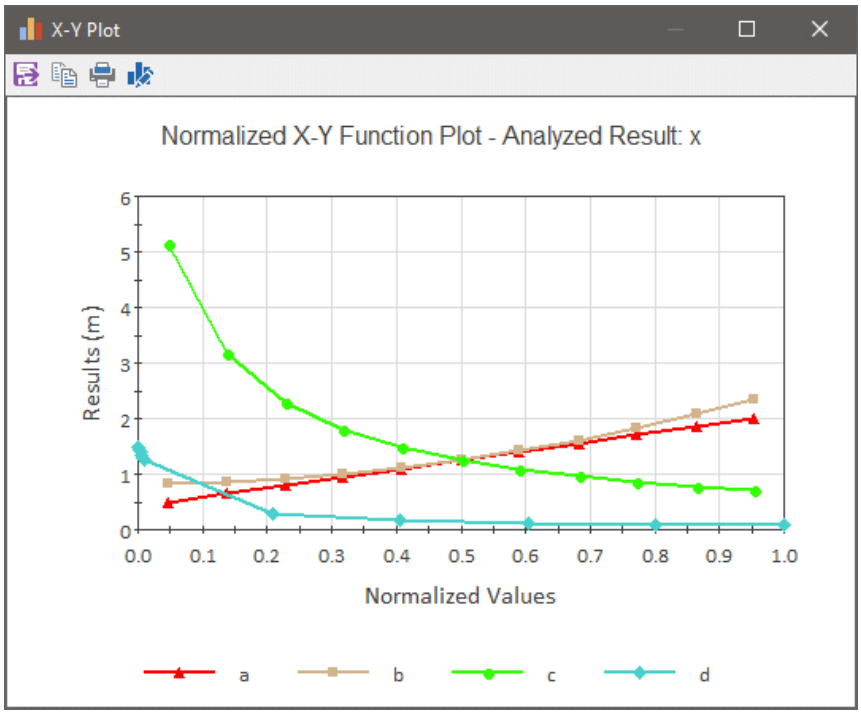
Sensitivity Analysis: X-Y Function Chart

An X-Y function chart is a type of sensitivity analysis that provides a graphical representation of the degree to which the Result is sensitive to the specified Independent Variables.

An X-Y function chart can be produced by pressing the **X-Y Function Chart…** button in the Sensitivity Analysis dialog. When you do so, GoldSim runs a series of deterministic simulations, varying one independent variable at a time through its range of values. In particular, it does the following:

1. While holding all other Independent Variables at their Central Value and all other Stochastics (not identified as Independent Variables) at their deterministic values, GoldSim runs n deterministic simulations, where n is the number specified by **#Points**. For each simulation, the first Independent Variable is varied from its **Lower Bound** to its **Upper Bound**.
2. The process is repeated for each Independent Variable.

Once it carries out these simulations, it uses the results to construct an X-Y function chart such as this:



The y-axis of an X-Y function chart represents the values of the Result for different values of the independent variables.

There is one line for each variable. Each line illustrates how the Result changes when that independent variable is varied from its Lower Bound to its Upper Bound (with the other variables being held constant). The number of points used to create each line is determined by the **#Points** field.

Note: One of the points is always the Central Value. Half of the remaining points are spaced evenly (linearly) between the Lower Bound and Central Value, and the other half of the remaining points are spaced evenly (linearly) between the Central Value and the Upper Bound.

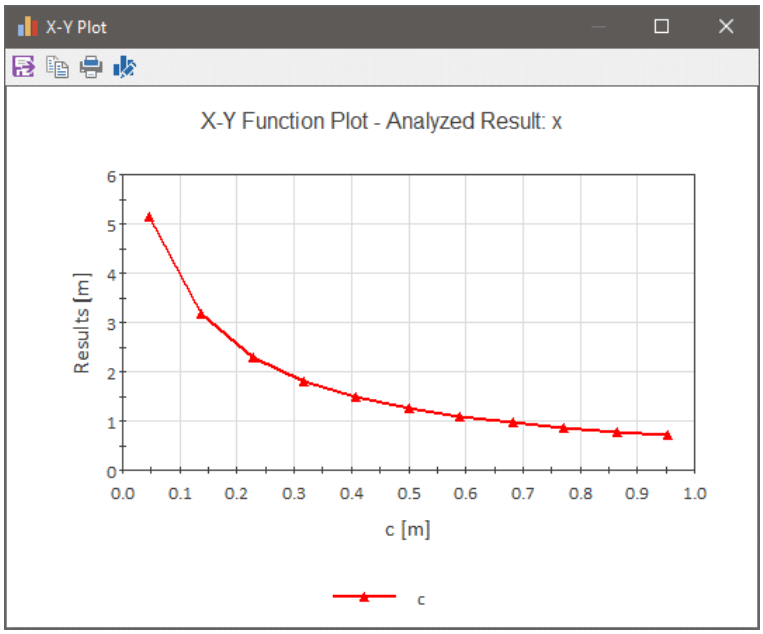
Because each variable likely will have different units and a different range, the x-axis does not represent actual values; rather it represents normalized values

(and hence they all range from 0 to 1). The normalization differs depending on whether the range of the independent variable was specified as quantiles or was specified directly.

For Stochastic independent variables whose Bounds have been entered as quantiles, the x-axis represents the actual quantile of each point. For Data elements (and Stochastics) whose Bounds have been specified directly (as Lower Bound, Central Value and Upper Bound), the x-axis represents the following:

$$\text{Normalized Value} = \frac{(\text{Value} - \text{Lower Bound})}{(\text{Upper Bound} - \text{Lower Bound})}$$

If you would like to plot a single independent variable (on the x-axis) against the result (on the y-axis), using the actual value of the independent variable rather than the normalized value, you can do so by pressing the appropriate button in the column labeled **Plot** in the Independent Variable table. A chart like this will be displayed:



In some cases, you may simply want to view the raw data used to produce the X-Y function chart. You can do so by pressing the **Result Data…** button in the Sensitivity Analysis dialog. When you do so, a table like this is displayed:

Sensitivity Analysis Result Data

	a		b		c		d	
	Variable Value (m2)	Result Value (m)	Variable Value (m)	Result Value (m)	Variable Value (m)	Result Value (m)	Variable Value (m)	Result Value (m)
Lower	0.045	0.492	0.045	0.837	0.045	5.156	0.001	1.497
Point 2	0.136	0.644	0.136	0.864	0.136	3.173	0.021	1.440
Point 3	0.227	0.795	0.227	0.919	0.227	2.292	0.041	1.387
Point 4	0.318	0.947	0.318	1.002	0.318	1.793	0.060	1.338
Point 5	0.409	1.098	0.409	1.112	0.409	1.473	0.080	1.293
Central	0.500	1.250	0.500	1.250	0.500	1.250	0.100	1.250
Point 7	0.591	1.402	0.591	1.415	0.591	1.086	2.080	0.291
Point 8	0.682	1.553	0.682	1.608	0.682	0.959	4.060	0.164
Point 9	0.773	1.705	0.773	1.829	0.773	0.859	6.040	0.115
Point 10	0.864	1.856	0.864	2.076	0.864	0.778	8.020	0.088
Upper	0.955	2.008	0.955	2.352	0.955	0.711	10.000	0.071

This table shows the actual value for the independent variables (rather than the normalized values).

Note: You can copy the contents of this table to the clipboard. To do so, you must first select the entire table (by double-clicking on the empty cell in the upper left-hand corner of the table, or by pressing **Ctrl+A**). After you do so, you can copy the table to the clipboard by **Ctrl+C**). You can subsequently paste the table into another application (such as a spreadsheet).

The Run Log

Whenever you run a GoldSim model, a Run Log is produced. The Run Log contains basic statistics regarding the simulation (e.g., the version of the program, the date, the simulation length), and any warning or error messages that were generated.

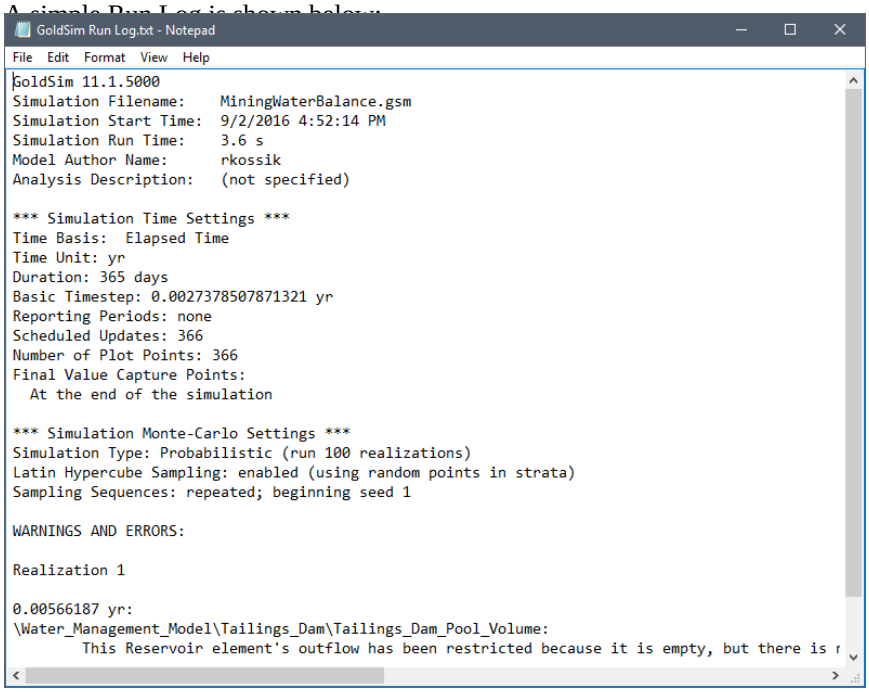
If your simulation generates any warning messages during the run, you will immediately be prompted to view the Run Log when the simulation completes. The Run Log can also be viewed at any time after a simulation is completed by selecting **Run|View Run Log** in the main menu.

Note: The Run Log is not produced when running scenarios, sensitivity analysis or optimization.

The Run Log is automatically viewed by whatever application is associated with ".txt" files (typically Notepad or WordPad).

Note: The Run Log only becomes available after a model has been run. In Result Mode, the Run Log contains information describing the current run. If a model is in Edit Mode, the Run Log contains information describing the *most recent* run (the results of which are no longer available).

A simple Run Log is shown below:



Note: Although the Run Log is viewed in a text editor, it is saved internally within the GoldSim file and cannot be edited. If you edit the Run Log using the text editor, the changes will not be saved in the GoldSim file.

When you view a Run Log, GoldSim creates a text file from the information in the GoldSim file. By default, this file is saved in the same location as the model file. If it cannot be saved there (due to access issues), GoldSim will save it to the user's temporary folder (and provide the location of the file in a message).

By default, the name of the Run Log file is "GoldSim Run Log.txt".

Note: On rare occasions, you may want to instruct GoldSim to insert the model filename into the name of the Run Log filename. To do this, you must edit the Windows Registry. In particular, add a DWORD registry key under HKEY_CURRENT_USER\Software\GTG\Settings named *RunLogEmbedModelName* and set it to a non-zero value. If you do so, the name of the Run Log file will be "ModelFilename _Run Log.txt. For example, if the model filename was called "Example.gsm", the Run Log file would be named "Example_RunLog.txt".

The Run Log contains the following information:

- General simulation information, such as the GoldSim version number, the filename, the time the simulation was begun (in effect, a timestamp for the run), the total simulation time, and the Analysis Description.
- All of the key simulation settings, summarizing exactly how the simulation was carried out.

- Any warning and error messages associated with the run. If the run has been aborted, this will also be indicated.
- Whether (and when) any elements have been downloaded from a database prior to running the model.

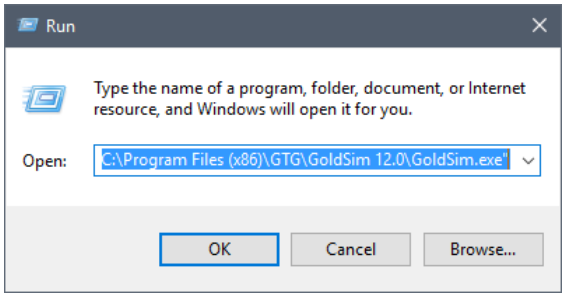
Read more: Linking Elements to a Database (page 1107).

The Run Log is important because it provides an internal, uneditable "audit trail" for the run. By looking at the Run Log, you can immediately see key information like when the model was run, what version of GoldSim was used, and whether there were any warning messages.

Running GoldSim from the Command Line

In some cases, it may be useful to bypass GoldSim user interface and run GoldSim directly from the command line.

This, for example, could be done by selecting **Run** from the Windows **Start** menu, which displays the following dialog:



You must enter the full path to the GoldSim executable (which may, of course, be different than that shown above), followed by the GoldSim file that you want to open. If no filename is specified, GoldSim opens a new file.

Note: If no path is specified for a filename, GoldSim looks in the last directory from which a GoldSim file was opened. Hence, it is highly recommended that you provide a full path for the filename.

The primary reason for running GoldSim from the command line is to take advantage of a number of command line parameters that cause GoldSim to execute in a specific manner.

The command line parameters are summarized in the following table. Note that the parameters are entered *after* the executable and *before* the model file name.

Parameter	Description	Comments
-show *name*	Opens GoldSim and jumps to the specified Container or Dashboard	Used if you want a GoldSim model to simply open immediately and display the contents of a specific Container or Dashboard. If this parameter is used to reference a Container name that is used multiple times within a model (within localized Containers), GoldSim opens the first Container with the specified name found while searching downward through the containment hierarchy.
-r -run	Opens the GoldSim file and immediately runs the simulation.	In this situation, GoldSim automatically skips the "Ready" state and starts the simulation.
-getdb *[date]*	Executes a global database download for all elements linked to databases.	The date is only required for Extended GoldSim databases. The date must be specified in local format and be enclosed in quotes (e.g., "7 March 2013").
-x	Closes GoldSim after all other options have been executed.	Note that unless auto-save is enabled (in the Options dialog), or the –sv parameter was used, the GoldSim model file will NOT be saved when the application is closed.
-sv *[filename]* -save *[filename]*	Saves the model file using either the optionally provided output filename, or the input filename (if an output file is not provided).	This option can be used to run and save a model, or to open a model and save it in a newer version of GoldSim.
-dpclient	Opens GoldSim in Client Mode.	Used when running models on multiple processors using GoldSim's distributed processing features (GoldSim Distributed Processing Module). This command cannot be used with any other parameters.

Parameter	Description	Comments
-d "*element.input=expression"* -data "*element.input=expression"*	Inserts the provided *expression* into the specified *input* for the specified *element*.	This parameter allows you to change the contents of an input field for any element in GoldSim using the command line. The *input* can be omitted (only the element name needs to be specified) if the input name is "Definition" (e.g., for Data and Expression elements). This parameter is particularly useful if you want to stack a number of runs in a batch file, with each run changing one or more element definitions.
-starttime "*date[time]*"	Resets the Start Time	The time is optional. The date/time string can take on any of the following formats: "25 January 1996" "January 25, 1996 8:30:00" "8:30:00 Jan. 25, 1996" "1/25/1996 8:30:00" Time can be specified in military (24 hour time) or 12 hour time using PM and AM.
-endtime "*date[time]*"	Resets the End Time	-endtime and -duration are mutually exclusive (only one can be set). The -endtime flag must be used in conjunction with the -starttime flag. The time is optional. The date/time string can take on any of the following formats: "25 January 1996" "January 25, 1996 8:30:00" "8:30:00 Jan. 25, 1996" "1/25/1996 8:30:00" Time can be specified in military (24 hour time) or 12 hour time using PM and AM.
-duration "*time expression*"	Resets the Duration using the provided expression	-endtime and -duration are mutually exclusive (only one can be set). Time expression should use GoldSim's built-in units, and must have dimensions of Time.

Examples of how some of these parameters would commonly be used are provided below. Note that these parameter strings would follow the name (and path) of the GoldSim executable (goldsim.exe).

Command line	Comments
-x –sv test1.gsm	Opens test1.gsm, saves it, and closes GoldSim. Useful, for example, if you want to convert test1.gsm to the latest GoldSim version.
-x –sv test2.gsm test1.gsm	Opens test1.gsm, saves it as test2.gsm, and closes GoldSim. Only the destination model (test2 in this case) is saved. Useful, for example, if you want to convert test1.gsm to the latest GoldSim version, but preserve the original file.
-r test1.gsm	Opens test1.gsm, executes pre-run checks and starts the simulation. GoldSim remains open after the simulation. The model file is only saved if auto-save is enabled in the Options dialog.
-r –sv test1.gsm	Opens test1.gsm, executes pre-run checks and starts the simulation. At the end of the simulation, the model file is saved. GoldSim remains open after the simulation.
-r –sv –x test1.gsm	Opens test1.gsm, executes pre-run checks and starts the simulation. At the end of the simulation, the model file is saved. GoldSim is then closed.
-r –sv test1res.gsm test1.gsm	Opens test1.gsm, executes pre-run checks and starts the simulation. At the end of the simulation, the model file is saved to test1res.gsm. GoldSim remains open after the simulation.
-dpclient	Starts GoldSim in Client mode. This command cannot be used with any other parameters.

Several points should be noted regarding the use of the –d (-data) command:

- The argument to this command must be enclosed in quotes.
- Units must be specified if the input has dimensions.
- More than one input can be defined in a command line. Note, however, that Windows limits the length of a command string (to 8191 characters).
- If a Data element is connected to a Dashboard control, the Dashboard will always take precedence. As a result, if you want to control an element via a command line, it should not be connected to a Dashboard control.
- The –d parameter will only find global elements. If an element is located within a localized Container, it will not be found.

Examples of the use of the –data command are provided below:

Command line	Comments
-d “Data1=5m3”	Puts the value of 5 m3 into the input of element Data1. This would only be valid if Data1 had an input named Definition (e.g., if it was a Data element or Expression element).

Command line	Comments
-d “Pond.Initial Value = 10m3”	Puts the value of 10 m3 into the Initial Value input of element Pond (in this case, a Reservoir).
-d “X = if(etime>5day,1,2)”	Puts the expression *if(etime>5day,1,2)* into the input of element X. This would only be valid if X had an input named Definition (e.g., if it was a Data element or Expression element).
-d “Data1=5m3” –d “Data2=5sec”	Puts the value of 5 m3 into the input of element Data1, and 5 sec into the input of element Data2. This would only be valid if Data1 and Data2 had an input named Definition (e.g., if they were Data or Expression elements).

Several points should be noted regarding the use of the –starttime, -endtime and -duration commands:

- The arguments to these commands must be enclosed in quotes.
- Units must be specified if the input has dimensions.
- The commands can only be used in the following combinations:
  - -starttime only (Elapsed Time, Calendar Time or Static models)
  - -starttime and -duration (Elapsed Time or Calendar Time models)
  - -starttime and -endtime (Calendar Time models only)
  - -duration only (Elapsed Time or Calendar Time models)

Examples of the use of the –starttime, -endtime and -duration commands are provided below:

Command line	Comments
-starttime “1/1/2021”	Sets the Start Time to 1 January 2021
-starttime "25 January 2021 18:30:00"	Sets the Start Time to 25 January 2021 at 6:30 PM
-starttime "25 January 2021 6:30:00 PM"	Sets the Start Time to 25 January 2021 at 6:30 PM
-starttime “1/1/2021” -duration “100 days”	Sets the Start Time to 1 January 2021and the Duration to 100 days
-starttime “1/1/2021” -endtime “1/1/2022”	Sets the Start Time to 1 January 2021 and the End Time to 1 January 2022
-duration “100 days”	Set the Duration to 100 days (using the defined Start Time and replacing the End Time

In most cases, it is likely that you will want to “stack” a number of GoldSim runs by creating a batch file that you run from the command line. However, if you simply stack command lines and then run a batch file, all GoldSim calls would be launched in parallel (e.g., if you had 10 command lines that ran GoldSim, 10 instances of GoldSim would open and run simultaneously).

To avoid this problem and force the commands to run in series, you can use the Start/Wait command provided by Windows. An example batch file that utilizes this is shown below:

```
CD c:\Program Files (x86)\GTG\GoldSim 11.1
Start /wait GoldSim.exe -r -sv r1.gsm -d "InputA=10m" -x  “c:\runs\input.gsm”
Start /wait GoldSim.exe -r -sv r2.gsm -d "InputA=20m" -x  “input.gsm”
Start /wait GoldSim.exe -r -sv r3.gsm -d "InputA=30m" -x  “input.gsm”
Start /wait GoldSim.exe -r -sv r4.gsm -d "InputA=40m" -x  “input.gsm”
```

The first line simply sets the directory to the location of the GoldSim executable. The next line opens a GoldSim model called input.gsm. By specifying the path here, this sets the path for all input and output files in the remainder of the batch file. GoldSim changes the value of InputA to 10m, runs the model and saves it as r1.gsm. GoldSim then closes. After closing, the next GoldSim command is implemented (open input.gsm again, change InputA to 20m, run and save the model to r2.gsm). This continues until all four GoldSim runs are complete.

Chapter 8: Displaying Results in GoldSim

Often the most effective way to describe, explore, and summarize a set of numbers - even a very large set - is to look at pictures of those numbers.

Edward Tufte, *The Visual Display of Quantitative Information*

Chapter Overview

GoldSim has powerful charting and display functions that allow you to view your simulation results in a variety of ways. You can plot time histories of your data, view probability distributions, create scatter plots and bar charts, and view tables of results. You can also combine multiple results on a single plot, and view multiple plots simultaneously. To facilitate the creation of report quality graphics, you can modify and save *chart styles*, which allow you to customize (and reuse) the style (i.e., appearance) for each type of chart.

This chapter describes how you can create and view the results of your simulations.

In this Chapter

The following topics are discussed in this chapter:

- Displaying Results: An Overview
- Viewing Time History Results
- Viewing Distribution Results
- Viewing Final Value Results
- Viewing Multi-Variate Results
- Viewing Final Values for Arrays
- Editing the Appearance of a Chart
- Creating and Using Chart Styles
- Exporting Results
- Copying and Exporting Result Displays

Displaying Results: An Overview

The sections below provide the basic information you need to understand the types of result displays you can produce in GoldSim. They also provide references to topics that describe these various result display features in greater detail.

Understanding Result Mode

A GoldSim model file is always in one of four modes (or states): Edit Mode, Run Mode, Result Mode, or Scenario Mode.

The mode that the model is in is clearly identified in the status bar (in the lower left-hand corner of the GoldSim window). In addition, the status bar takes on a different color in each mode:

This model is in Edit Mode. The status bar is blue.

This model is in Run Mode. The status bar is pink.

This model is in Run Mode, but is paused. The status bar is rust brown.

This model is in Result Mode. The status bar is green.

This model is in Scenario Mode. The status bar is orange.

Read more: Understanding Simulation Modes (page 517).

Results can be viewed in two modes: Result Mode and Scenario Mode. Result Mode is the most common way that you will view results. Scenario Mode only exists if you are using GoldSim's scenario feature. Viewing results in Scenario Mode is similar to viewing results in Result Mode, with a number of key limitations.

Read more: Viewing Scenario Results (page 600).

After you run your model (e.g., by pressing **F5**), it will automatically be placed in Result Mode. When in Result Mode, elements with outputs that have been saved are identified in two ways: 1) the elements (and their outputs) are **bold** in the browser (and output interfaces); and 2) the element output ports in the graphics pane are green.

When a model is in Result Mode, you can navigate it, open property dialogs, and view result plots. You can also move elements around within the graphics pane, add graphics (e.g., text, images), and add and edit Result elements.

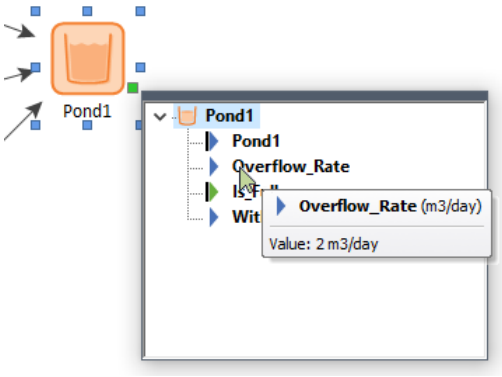
You cannot, however, edit the model in any way that would change it's behavior (e.g., you cannot change values in property dialogs or add or delete elements). GoldSim enforces this rule to ensure that the results and inputs to a model do not become inconsistent.

If you press **F4**, choose **Run|Return to Edit Mode** from the file menu, or press the Edit Mode button in the standard toolbar, the results will be discarded and the model will be returned to Edit Mode.

Viewing "Last Value" Results in Tool-Tips

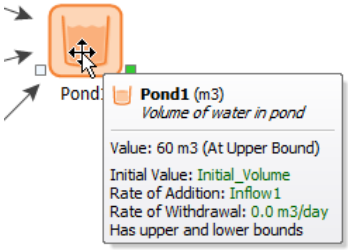
Although GoldSim provides a variety of powerful ways in which you can display simulation results in the form or charts and tables, the simplest way to view basic results is via tool-tips.

In Result Mode, an output's last Value (the value at the end of the last realization) will be displayed in a tool-tip when the cursor is held over it in a browser (or output interface).



Read more: Using Tool-Tips (page 111).

If the output is the primary output of an element, the last Value will also be shown in the tool-tip displayed when the cursor is held over the element itself.



Tool-tips are always displayed for scalar outputs. If you hold the cursor over a vector or a matrix, only a portion of the last Values may be displayed (if the array is large). Note, however, that if you expand the array in a browser or output interface and hold the cursor over a single item, the last Value for that item will be displayed.

Read more: Using Vectors and Matrices (page 848).

Note: The last Value for an output is displayed in tool-tips regardless of whether results (Time Histories or Final Values) have been saved for the output.

Read more: Saving Outputs as Results (page 514).

Note: You can control the number of significant figures displayed in tool-tips from the **Results** tab of the Options dialog (accessed via **Model |Options…** from the main menu).

Read more: The Results Tab of the Options Dialog (page 467).

Viewing the Five Basic Result Types

GoldSim provides five ways in which you can display results in graphical and tabular form:

Time History Results: Values at selected times for a particular output.

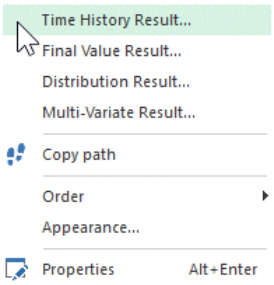
Distribution Results: Probability distributions of the final value (i.e., the value at the end of each realization) of an uncertain output.

Final Value Results: Comparisons of final value(s) in the form of bar, column and pie charts (and the associated tables of these displays).

Multi-Variate Results: Comparisons of final values of two or more outputs in the form of scatter plots, correlation tables, and sensitivity analyses; and

Array Results: Final values for vector and matrix outputs.

Right-clicking on an element with a primary output (in the graphics pane or browser) or on a specific output (in an output interface or a browser) which has been saved will provide a context menu for displaying these five types of results.



Depending on the output type and what kinds of results have been saved, different options will be available.

Note: Time History Results are only available if you have selected **Save Time Histories** for the output. Multi-Variate Results, Distribution Results and Final Value Results are only available if you have selected **Save Final Values** for the output. Array Results are only available if the output is a vector or a matrix *and* you have selected **Save Final Values** for the output.

Read more: Saving Outputs as Results (page 514).

All five result types can be viewed either as a *chart* or a *table* (and in some cases, there are multiple types of charts and/or tables that can be viewed for a particular type of result).

A chart or table accessed and viewed in this manner is referred to as an ***interactive result***. For each type of interactive result, there is a default display that is shown (a chart for all but the Distribution Result, which shows a summary page with both chart and tabular information). Once a result is displayed, you can subsequently switch back and forth between different chart and table views.

Charts or tables can also be viewed using specialized elements referred to as ***Result elements***. Result elements allow you to organize all of your key result charts or tables, and allow you to access those results via a simple double-click.

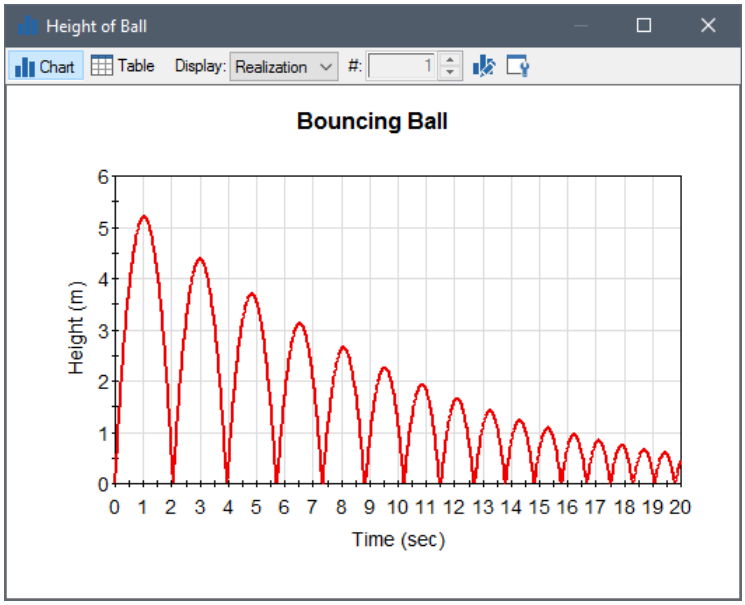
Read more: Creating and Using Result Elements (page 593).

Note: Interactive Time History Results for an output are not available for multi-realization runs unless the output is connected to a Result element.

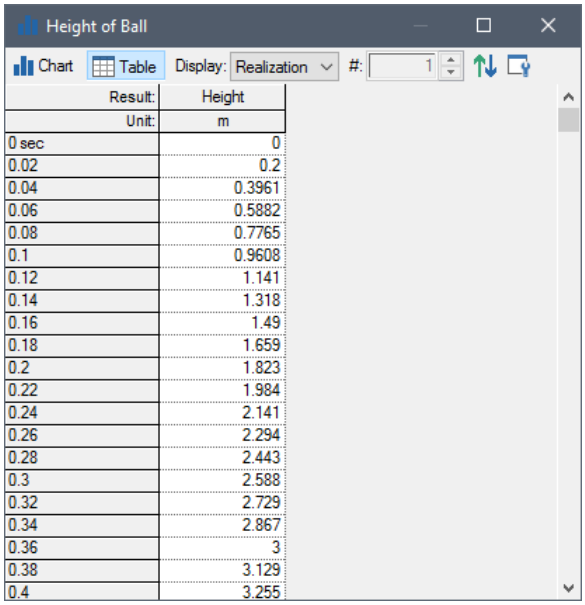
Examples of the five types of result displays are provided below. Details regarding the manner in which these result displays can be manipulated and customized are provided in subsequent sections.

Time History Results

Time History results show the "history" of a particular output as a function of time, and are probably the most common form of result display you will use. A time history chart looks like this:



The same information can also be viewed in table form, in which the time is shown in one column, and the output's value is shown in the other:



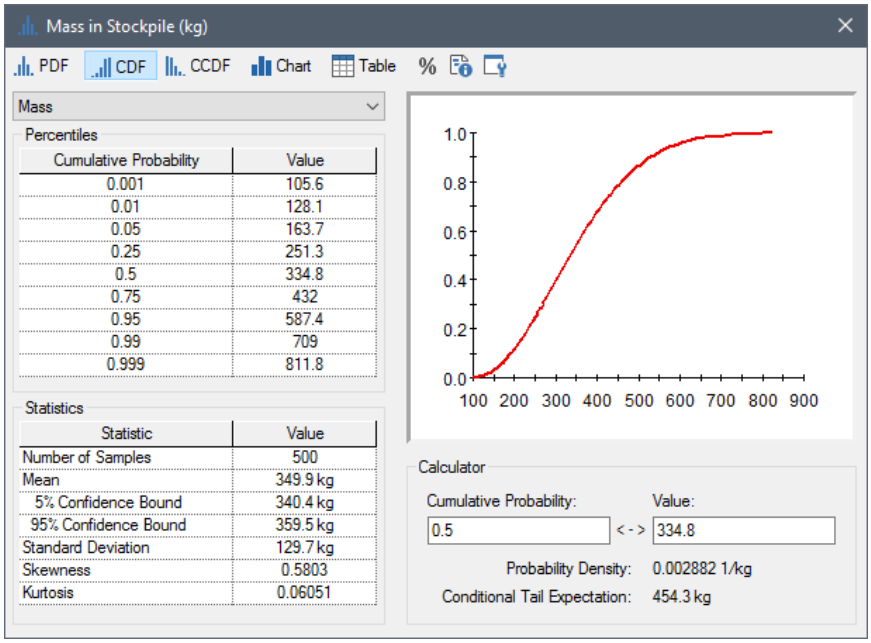
Result:	Height
Unit:	m
0 sec	0
0.02	0.2
0.04	0.3961
0.06	0.5882
0.08	0.7765
0.1	0.9608
0.12	1.141
0.14	1.318
0.16	1.49
0.18	1.659
0.2	1.823
0.22	1.984
0.24	2.141
0.26	2.294
0.28	2.443
0.3	2.588
0.32	2.729
0.34	2.867
0.36	3
0.38	3.129
0.4	3.255

Read more: Viewing Time History Results (page 604).

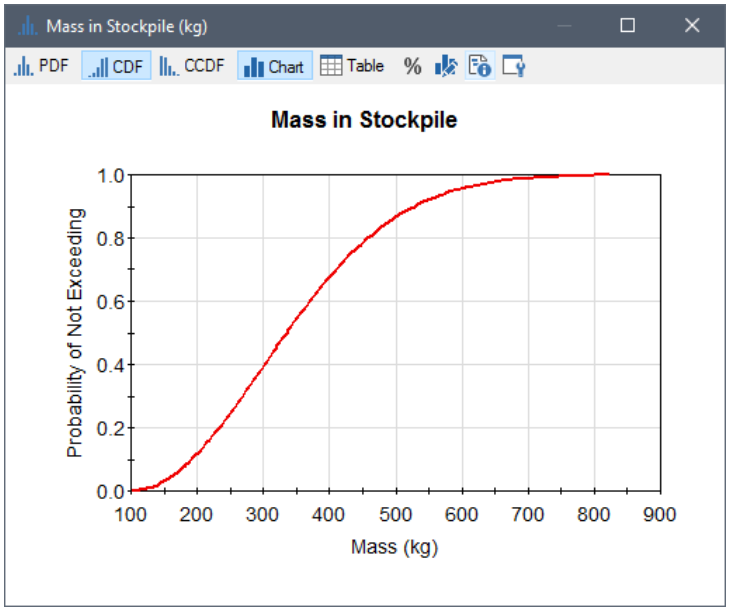
Distribution Results

In many systems, you may be uncertain about some of the input parameters. In such a case, GoldSim allows you to define these parameters as probability distributions. If at least one of the inputs to a model is a probability distribution, by definition, the outputs are probability distributions. (Basic concepts of probabilistic simulation are provided in Appendix A.) Distribution results provide a way to view the final values of uncertain (probabilistic) outputs.

The summary display for a distribution result (the default display for an interactive result) combines graphical and tabular information, and looks like this:

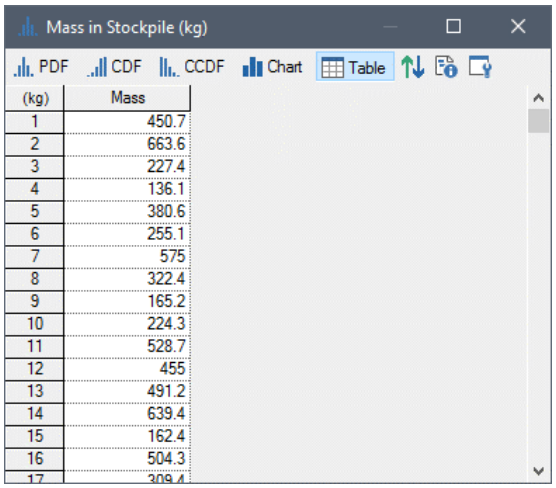


The chart display for a distribution expands the small chart provided in the upper right-hand corner of the summary display shown above.



Note that distribution charts can be viewed as probability density functions (PDFs), cumulative distribution functions (CDFs), or complementary cumulative distribution functions (CCDFs).

The table display for a distribution shows the final value for each realization:



(kg)	Mass
1	450.7
2	663.6
3	227.4
4	136.1
5	380.6
6	255.1
7	575
8	322.4
9	165.2
10	224.3
11	528.7
12	455
13	491.2
14	639.4
15	162.4
16	504.3
17	309.4

Read more: Viewing Distribution Results (page 662).

Final Value Results

Final Value results are used to carry out side-by-side comparisons of the final values of outputs for different types of simulations. In order to use them, you need to carefully specify what you wish to compare and how you want to display that comparison. Depending on how your model has been run (e.g., multiple realizations, multiple scenarios, multiple Capture Times) and the outputs you have specified to compare (e.g., one output, multiple outputs, vector results, matrix results), there can be a large variety of ways to display the comparison.

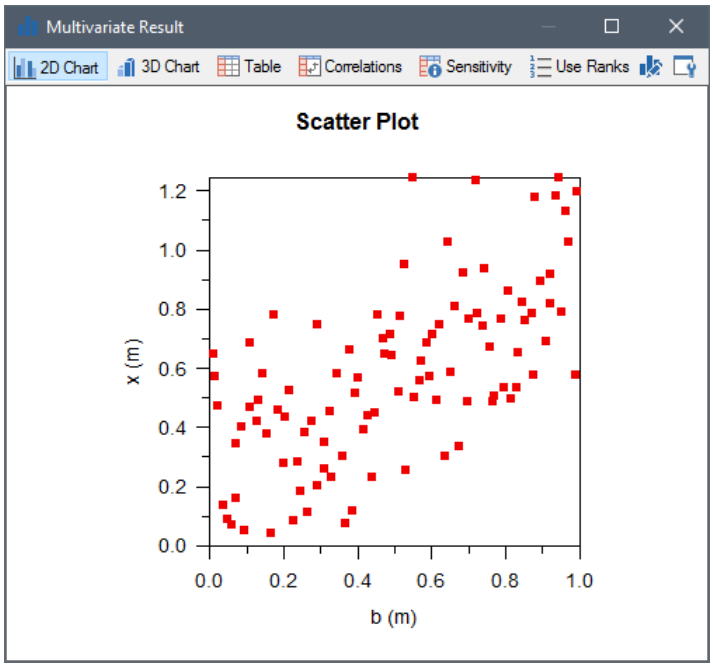
Read more: Viewing Final Value Results (page 694).

Multi-Variate Results

When evaluating the results of your simulations, you will sometimes want to view multi-variate results, in which multiple outputs are analyzed in graphical or tabular form.

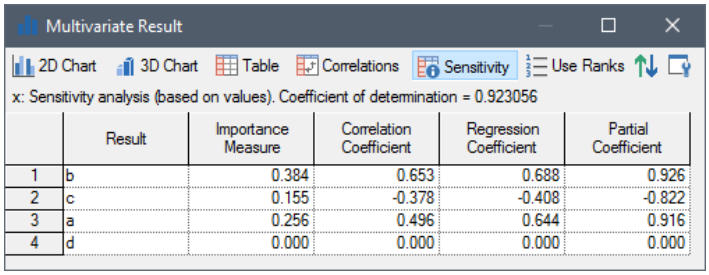
To view multi-variate results, you select a specific output that you are interested in, along with the input variables (which are typically Stochastics) that may have affected that result.

One example of this is the 2-D scatter plot, in which the final value of one output is plotted against the final value of another:



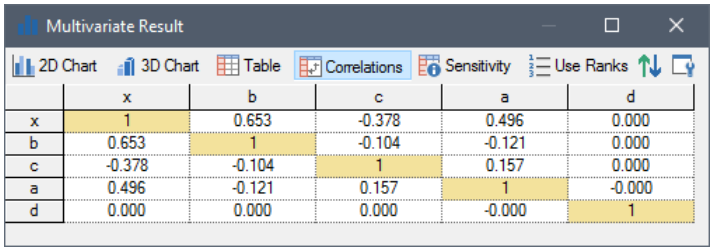
GoldSim also allows you to create a 3-D scatter plot, in which one output is plotted against two others.

GoldSim provides two very useful tabular multi-variate result outputs to support sensitivity and uncertainty analysis. One table provides a variety of statistical sensitivity analysis outputs (coefficient of determination, correlation coefficients, standardized regression coefficients, partial correlation coefficients, and importance measures):



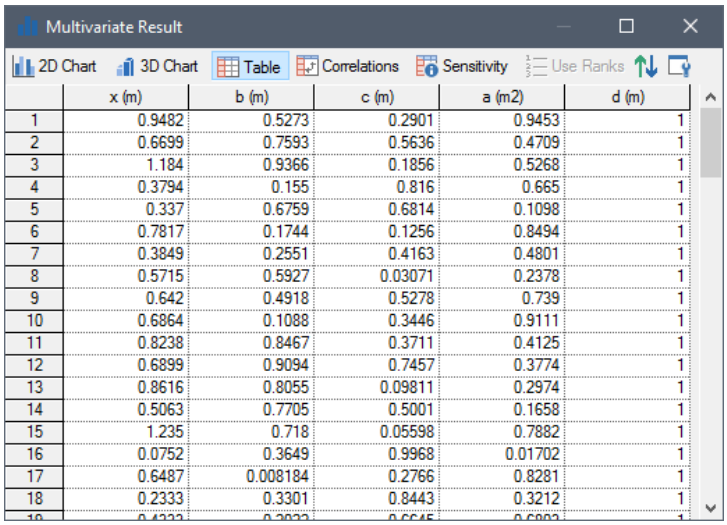
	Result	Importance Measure	Correlation Coefficient	Regression Coefficient	Partial Coefficient
1	b	0.384	0.653	0.688	0.926
2	c	0.155	-0.378	-0.408	-0.822
3	a	0.256	0.496	0.644	0.916
4	d	0.000	0.000	0.000	0.000

A second table displays a complete correlation matrix, which indicates the degree to which all selected variables are correlated to each other:



	x	b	c	a	d
x	1	0.653	-0.378	0.496	0.000
b	0.653	1	-0.104	-0.121	0.000
c	-0.378	-0.104	1	0.157	0.000
a	0.496	-0.121	0.157	1	-0.000
d	0.000	0.000	0.000	-0.000	1

You can also view the raw data display of multiple variables, showing the final values for each realization for each of a number of selected outputs:



	x (m)	b (m)	c (m)	a (m2)	d (m)
1	0.9482	0.5273	0.2901	0.9453	1
2	0.6699	0.7593	0.5636	0.4709	1
3	1.184	0.9366	0.1856	0.5268	1
4	0.3794	0.155	0.816	0.665	1
5	0.337	0.6759	0.6814	0.1098	1
6	0.7817	0.1744	0.1256	0.8494	1
7	0.3849	0.2551	0.4163	0.4801	1
8	0.5715	0.5927	0.03071	0.2378	1
9	0.642	0.4918	0.5278	0.739	1
10	0.6864	0.1088	0.3446	0.9111	1
11	0.8238	0.8467	0.3711	0.4125	1
12	0.6899	0.9094	0.7457	0.3774	1
13	0.8616	0.8055	0.09811	0.2974	1
14	0.5063	0.7705	0.5001	0.1658	1
15	1.235	0.718	0.05598	0.7882	1
16	0.0752	0.3649	0.9968	0.01702	1
17	0.6487	0.008184	0.2766	0.8281	1
18	0.2333	0.3301	0.8443	0.3212	1

Read more: Viewing Multi-Variate Results (page 737).

Array Results

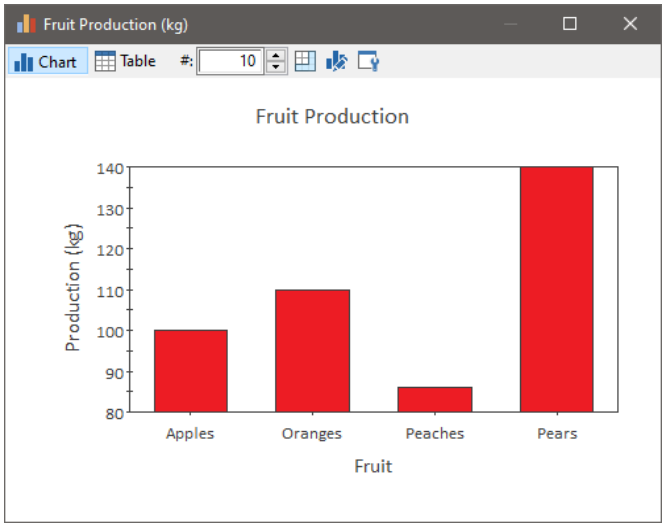
Many complex models will utilize vectors and matrices, collectively referred to as arrays. GoldSim allows you to view array results in both graphical and tabular form.

Read more: Using Vectors and Matrices (page 848).

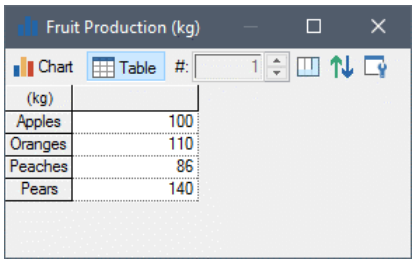
Note: Final Value results are more flexible for viewing arrays and for the most part make this result display redundant (i.e., this is a legacy feature). It does have two minor features not available in Final Value elements (the ability to sum rows and columns and the ability to produce 3D charts), but for most applications Final Value displays are much more powerful (e.g., they are available in Scenario Mode and can produce a wider variety of chart types).

Read more: Final Value Results (page 583).

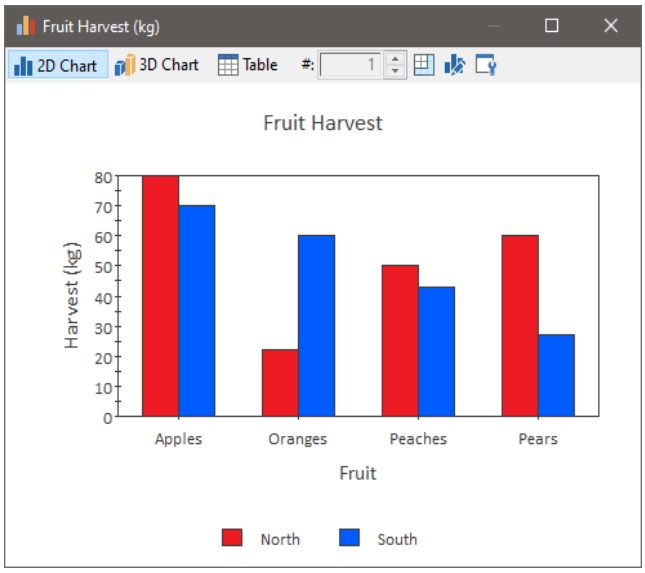
A chart display of a vector looks like this:



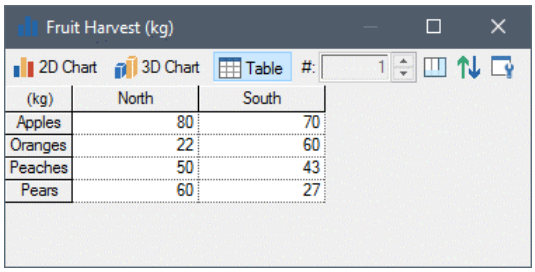
In tabular form, the vector looks like this:



One form of a chart display for a matrix looks like this:



In tabular form, the matrix is displayed as follows:



Read more: Viewing Array Results (page 754).

Using Result Display Windows

Although GoldSim allows you to view five different types of results (time histories, distributions, final values, multi-variate results, and array results), the result display windows for these result types share a number of common characteristics:

- All five results can be viewed either as a *chart* or a *table* (and in some cases, there are multiple types of charts and/or tables that can be viewed for a particular type of result). For interactive results, the default is to show a chart (except for the Distribution Result, which shows a summary page with both chart and tabular information). Once a result is displayed, you can subsequently switch back and forth between different chart and table views.
- Although you can resize and maximize an interactive chart or table result display window, it is always *modal*. That is, it cannot be minimized, and with the exception of viewing the result properties

dialog (which can be displayed simultaneously and share the focus with the result display window), it retains the focus while it is displayed. As a result, you must close the result display window before you can edit any other part of your GoldSim model.

Read more: Viewing and Editing Result Properties (page 587).

- GoldSim does, however, provide a mechanism (Result elements) by which you can display one or more *modeless* result display windows (which allow you to navigate and edit other parts of the GoldSim model while keeping the windows open).

  Read more: Creating and Using Result Elements (page 593).

- Chart and table result display windows for all fivw types of results have a number of common buttons which provide access to specialized dialogs and/or allow you to carry out specific actions.

- You can control the number of significant figures displayed in result displays from the **Results** tab of the Options dialog (accessed via **Model |Options…** from the main menu).

  Read more: Controlling Significant Figures and Scientific Notation in Result Displays (page 591).

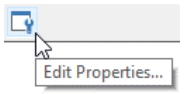
- Charts for all five result types provide a number of common functions, such as context-sensitive menus, data tips and the ability to zoom in on a section of the chart.

  Read more: Using Context Menus in Charts (page 588); Viewing Data Tips in Charts (page 589); Zooming in on a Chart (page 589).

Viewing and Editing Result Properties

For each type of interactive result, there is a default display that is shown (a chart for all but the Distribution Result, which shows a summary page with both chart and tabular information). Once a result is displayed, you can subsequently switch back and forth between different chart and table views.

Whenever you are viewing a result display, you can choose to view the *properties* for that particular result. All result display windows have a toolbar at the top. This toolbar contains buttons, a number of which are common to all result display windows. For all result display windows, the furthest button to the right is for displaying the Result Properties dialog:



Pressing this button displays the Result Properties dialog for the result. Note that when you press this button, it does not close the result display window you were displaying. Both windows are displayed simultaneously (although you can subsequently close one or the other). When viewing results, any changes you make to the Result Properties are immediately represented in the result display.

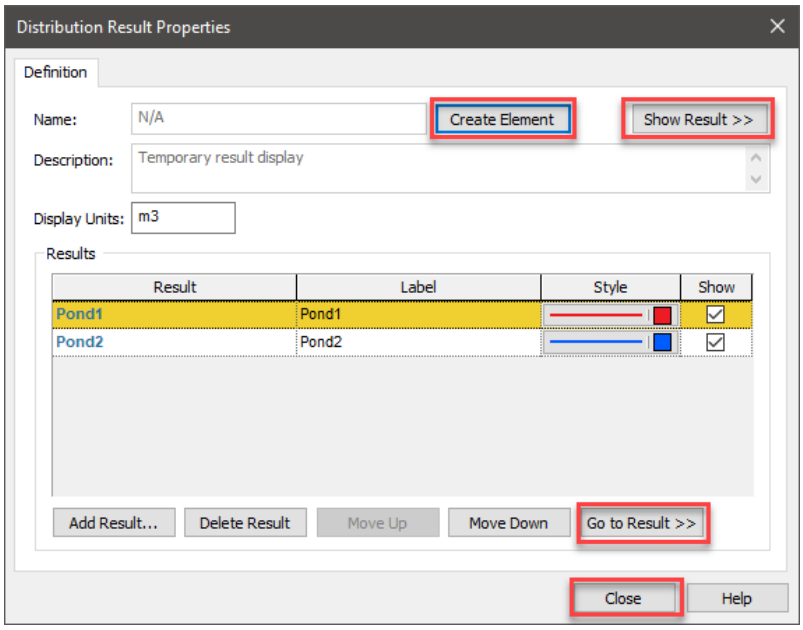
The Result Properties dialog is always modal. That is, it cannot be minimized, and with the exception of viewing the result display (which can be displayed simultaneously and share the focus with the Properties dialog), it retains the focus while it is displayed. As a result, you must close the Result Properties dialog before you can edit any other part of your GoldSim model.

Result Properties differ somewhat for each of the five basic result types.

Read more: Viewing the Properties of a Time History Result (page 605); Viewing the Properties of a Distribution Result (page 663); Viewing the

Properties of a Final Value Result (page 705); Viewing the Properties of a Multi-Variate Result (page 740); Viewing the Properties of an Array Result (page 756).

The Properties for a Distribution Result are shown below, and the attributes that are shared among all result types are highlighted:



The following attributes are common to Result Properties dialogs:

- At the top of the page is a button to **Create Element**. By pressing this button, a Result element is created. When you do so, the key change that will be noticeable is that the Name will now be editable. The Create Element button becomes an Appearance button (which is used to modify the appearance of the element itself).

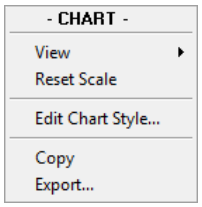
  Read more: Creating and Using Result Elements (page 593).

- The **Show Result** >> button opens a result display window (while keeping the Properties dialog simultaneously open).
- The **Go to Result** >> button closes the dialog and jumps to the selected result in the graphics pane.
- The **Close** button closes the Properties dialog.

In addition, all Result Properties dialogs (except for Arrays) allow you to add additional results to the display (i.e., multiple outputs) using the **Add Result…** button, and jump directly to the selected result using the **Go to Result** >> button. You can also modify the **Label** for each result (which can subsequently be displayed in legends and headers, footers and axes labels).

Using Context Menus in Charts

All result charts in GoldSim have context menus from which you can carry out a variety of actions. By right-clicking anywhere in a chart, the following context menu is available:



The options in this menu are as follows:

View: Expands to show three options (Show Header, Show Footer, Show Legend). This allows you to toggle these on and off.

Reset Scale: GoldSim allows you to zoom within a chart (by dragging your cursor from one point of the chart to another *while holding down the Ctrl key*). Reset Scale allows you to reset to the original scale.

Read more: Zooming in on a Chart (page 589).

Edit Chart Style… : This provides access to a dialog for editing the chart style.

Read more: Editing the Appearance of a Chart (page 768).

Copy: Copies the chart to the clipboard (from where it subsequently can be pasted into another application).

Read more: Copying a Chart or Table (page 800).

Export…: Exports the chart to a selected graphics format.

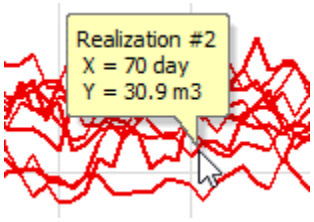
Read more: Exporting a Chart (page 801).

In addition to the Chart context menu, by right-clicking on a specific item (the Header, Footer or Legend), you can access a context menu that pertains just to that item:

These menus can be used to Hide the item, edit it directly (by going directly to the appropriate tab on the Chart Style dialog), or, in the case of Headers and Footers, paste text.

Viewing Data Tips in Charts

GoldSim allows you to view a "data tip" by holding the cursor over a data point in a chart. The example below shows a data tip for a point in a time history chart:



In this particular case, the data tip displays the realization number for the curve, and X and Y values of the data point. (For a time history chart, the X axis is always time).

Zooming in on a Chart

In some situations, you may want to zoom in on a portion of a chart that is of particular interest. You can, of course, edit the style of the chart and change the range of the axes which are displayed.

Read more: Editing the Appearance of a Chart (page 768).

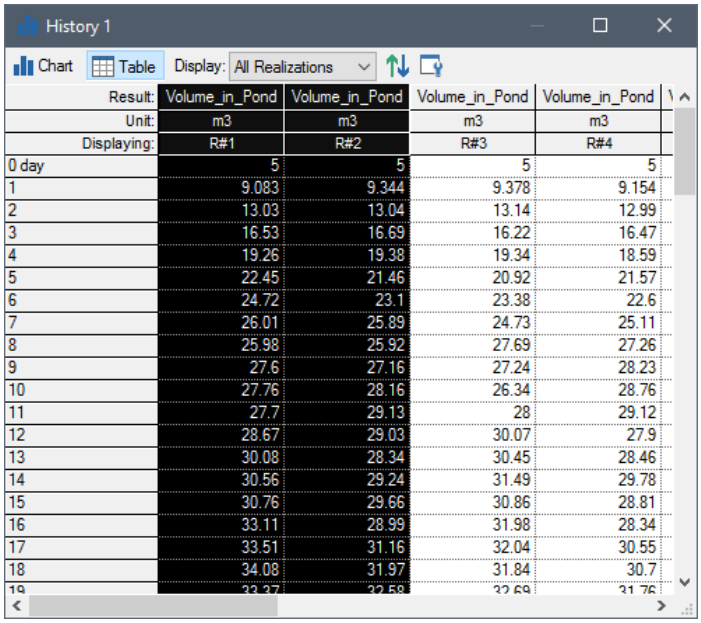
GoldSim also provides a more direct way to zoom in on a section of a chart. In particular, if you drag your cursor from one point of the chart to another *while holding down the Ctrl key* you will create a selection box.

Releasing the left mouse button zooms in on the selected portion of the chart. To return to the original scale, right-click on the chart, and select **Reset Scale** from the chart context menu, or press **Shft+R**.

Selecting Items and Copying Values in Result Tables

In some cases, you may want to select, copy and paste values from a result table into another application (e.g., a spreadsheet).

Selecting rows or columns in a result table is straightforward. You can select a row or column by left-clicking in any row or column label:



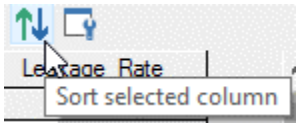
Result:	Volume_in_Pond	Volume_in_Pond	Volume_in_Pond	Volume_in_Pond
Unit:	m3	m3	m3	m3
Displaying:	R#1	R#2	R#3	R#4
0 day	5	5	5	5
1	9.083	9.344	9.378	9.154
2	13.03	13.04	13.14	12.99
3	16.53	16.69	16.22	16.47
4	19.26	19.38	19.34	18.59
5	22.45	21.46	20.92	21.57
6	24.72	23.1	23.38	22.6
7	26.01	25.89	24.73	25.11
8	25.98	25.92	27.69	27.26
9	27.6	27.16	27.24	28.23
10	27.76	28.16	26.34	28.76
11	27.7	29.13	28	29.12
12	28.67	29.03	30.07	27.9
13	30.08	28.34	30.45	28.46
14	30.56	29.24	31.49	29.78
15	30.76	29.66	30.86	28.81
16	33.11	28.99	31.98	28.34
17	33.51	31.16	32.04	30.55
18	34.08	31.97	31.84	30.7
19	33.37	32.58	32.69	31.76

Contiguous rows or columns can be selected by dragging the mouse while it is pressed. Non-contiguous rows or columns can be selected by holding the Ctrl key down while left-clicking. The entire table can be selected by clicking on the cell in the upper left-hand corner of the table.

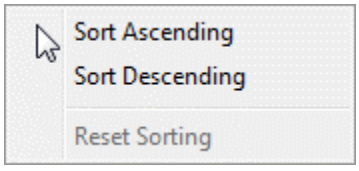
Once a selection has been made, it can be copied to the clipboard by pressing **Ctrl+C**.

Sorting Values in Result Tables

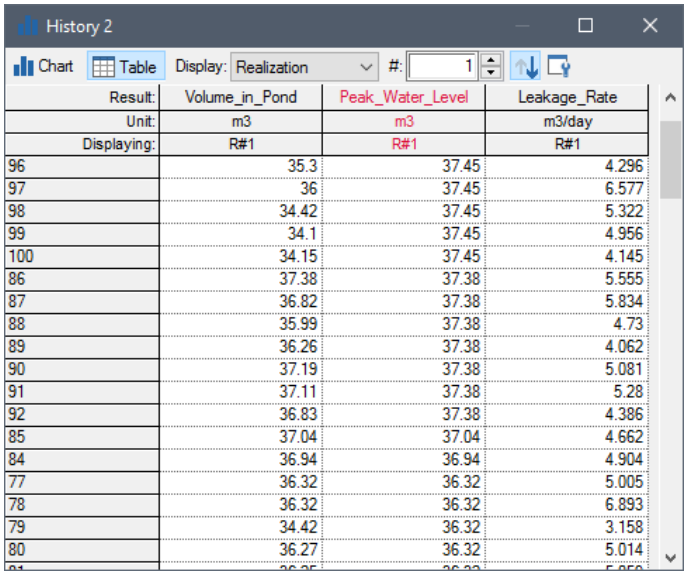
All result tables can be sorted in ascending or descending order. To sort a table, simply select a column (by clicking in it) and press the Sort button:



When you do so, a context menu will be displayed allowing you to sort in ascending or descending order:



After selecting one of these options, that column then becomes the sort key for the table (all columns are sorted based on that column). Whenever the data is sorted, the header of the sort key is shown in red:



Result:	Volume_in_Pond	Peak_Water_Level	Leakage_Rate
Unit:	m3	m3	m3/day
Displaying:	R#1	R#1	R#1
96	35.3	37.45	4.296
97	36	37.45	6.577
98	34.42	37.45	5.322
99	34.1	37.45	4.956
100	34.15	37.45	4.145
86	37.38	37.38	5.555
87	36.82	37.38	5.834
88	35.99	37.38	4.73
89	36.26	37.38	4.062
90	37.19	37.38	5.081
91	37.11	37.38	5.28
92	36.83	37.38	4.386
85	37.04	37.04	4.662
84	36.94	36.94	4.904
77	36.32	36.32	5.005
78	36.32	36.32	6.893
79	34.42	36.32	3.158
80	36.27	36.32	5.014

In this case, the second column is the sort key, and the header is shown in red. In addition, the Sort button changes to indicate the direction of the sort (in this case, descending).

You can choose a new sort key by simply clicking on a different column and pressing the **Sort** button again.

Note that the **Sort** button changes its appearance when sorting is on. The button appears depressed, and one of the two arrows appears larger, and points in the direction of decreasing values (i.e., if the sort is in descending order the larger arrow points down; if it is in ascending order, the larger arrow points up).

To turn sorting off, press the **Sort** button again and select **Reset Sorting**.

Controlling Significant Figures and Scientific Notation in Result Displays

GoldSim provides a number of options for controlling the way that Results are displayed. These include the minimum number of significant figures to use, whether or not scientific notation is used, how conditions are displayed and how currencies are displayed. These options are controlled via the **Results** tab of the Options dialog (accessed via **Model |Options…** from the main menu).

Read more: The Results Tab of the Options Dialog (page 467).

In addition, you can control the minimum number of significant figures to use and the magnitude above which scientific notation is used if directly from chart and table displays using accelerator keys:

Minimum number of significant figures to display: This setting can be changed dynamically from within most result displays using **Alt-Cursor Left** (i.e, **Alt-Left Arrow**) and **Alt-Cursor Right**. The default value is 4.

Use scientific notation if absolute value is >=: This setting can be changed dynamically from within most result displays using **Alt-Cursor Up** and **Alt-Cursor Down**. The default value is 6 ((and GoldSim will always use scientific notation if the magnitude of the value is less than 0.0001 or greater than 1e10).

Note: When labeling chart axes, GoldSim respects the specified scientific notation setting, but ignores the significant figures setting (significant figures in chart axes are determined automatically and cannot be user-controlled).

Size of Values Displayed

Although internal calculations are carried out using double precision numbers, results are only stored as single precision numbers (in order to reduce storage requirements). As a result, result values can only be relied upon to a maximum of 7 significant figures. For date outputs (e.g., outputs of the Milestone element), dates displayed in and around 2000 are only accurate to approximately 2 minutes.

This also means that when results are viewed in tables or charts, the range of values that can be displayed is between -1.2E-38 and 3.4E38.

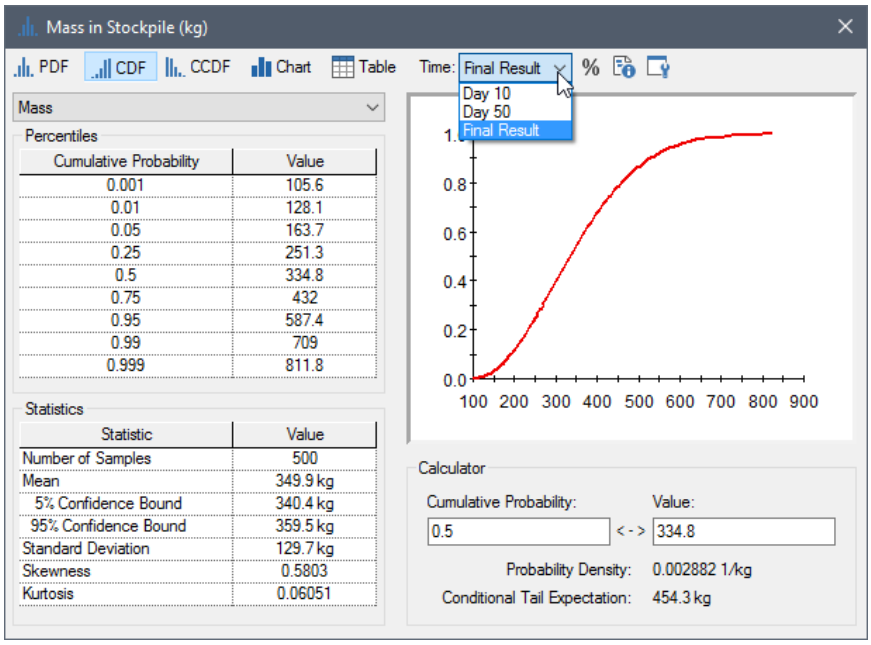
Viewing Results at Capture Times

Distributions, Multi-Variate results, Final Value results and Array results all operate on Final Values. That is, they allow you to view the value at the end of each realization.

In some cases, however, you may also want to capture these results at other times in the simulation (rather than just the end of the simulation). This can be useful, for example, if you wanted to view a result distribution for an output at various times during a simulation. GoldSim facilitates this by allowing you to create Capture Times at which these results are also made available.

Read more: Creating Capture Times for Results (page 488).

If you have created Capture Times, an additional drop-list (labeled "Time") is added to the result display windows for Final Value, Distribution, Multi-Variate, and Array results:



To view the results for a particular Capture Time, you simply select it from the drop-list.

Note: Capture Times cannot be viewed in Scenario Mode (i.e., only the Final Result can be viewed). That is, if you are running scenarios and viewing results (using Distribution or Final Value Result elements) you cannot view results for scenarios at specified Capture Times. You can only view scenario results in these elements for the Final Result.

Read more: Creating, Running and Comparing Scenarios (page 525).

A simple example file illustrating Capture Times (CaptureTimes.gsm) can be found in the can be found in the General Examples/ Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

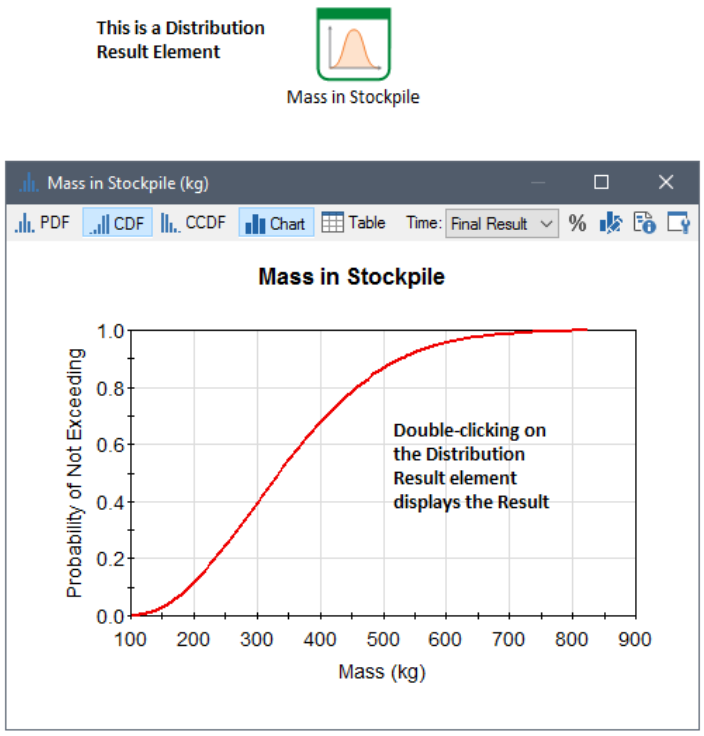
Note: Several elements (Stochastics, SubModels, Spreadsheet elements) produce a special type of complex output representing all the distribution information (Distribution output). This output can be viewed in a Distribution Result. However, when doing so, Capture Times are ignored (when viewing a Distribution output, Capture Times don't apply, since a Distribution output contains a single "snapshot" and cannot represent multiple "snapshots").

Creating and Using Result Elements

While the interactive result display procedure (in which you right-click on an element or an output and select a result display option from a context menu) is appropriate in many cases, it has several limitations:

- It requires several steps to actually view the result (expand an element's outputs, right-click on an output, select display options).
- The outputs you want to display may be scattered across various portions of your model, forcing you to navigate through the model to find and display the results.
- The result display is modal, meaning you can only view one display at a time.

To address these limitations, GoldSim allows you to create ***Result elements***. A Result element is a specialized element representing a particular result display. As such, there are five types of basic Result elements: Time History, Distribution, Final Value, Multi-Variate, and Array. When you double-click on a Result element, the result is directly displayed:



Result elements have several important advantages:

- They allow you to access results via a simple double-click.
- They allow you to make key results readily accessible by placing them in one or more convenient locations (e.g., in a single "results" Container) to facilitate presentations and use of the model by others.
- All the result characteristics are saved with the Result element, so that you can completely control and customize how the result will be displayed when it is subsequently viewed (e.g., in a presentation or by another user). Once you display the result, the last size and position of the result display is also saved with the Result element.
- Result elements can be opened prior to the start of a simulation, and are updated dynamically as the simulation progresses (e.g., as each realization is completed).
- The display windows for Result elements are modeless, meaning that you can view multiple display windows simultaneously.

In addition, in some cases, Result elements have special capabilities that do not exist for the corresponding interactive result.

Read more: Specialized Uses for Result Elements (page 599).

Adding Result Elements to Your Model

There are two ways to create a Result element: by converting an interactive result into a Result element, or by creating a Result element directly.

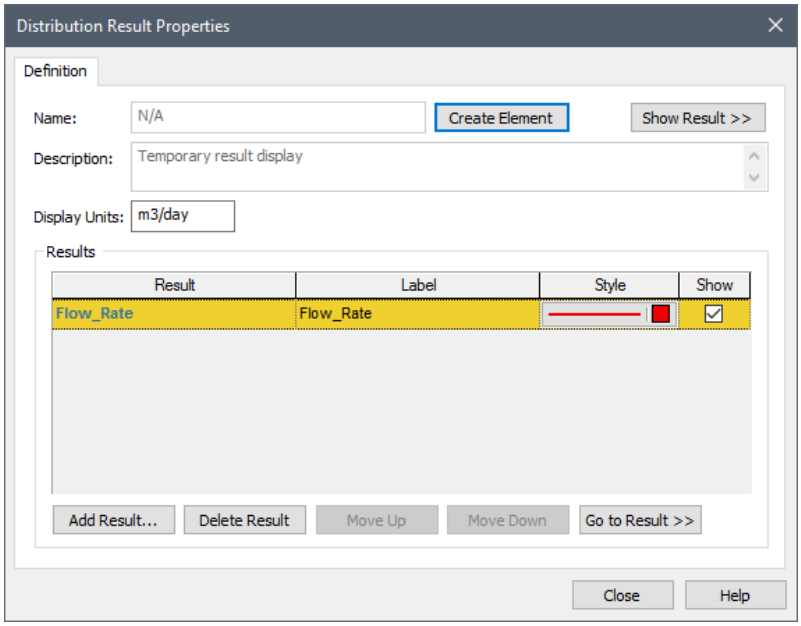
While viewing an interactive result display (in which you right-click on an element or an output and select a result display option from a context menu), you can convert it to a Result element.

You can do so from the Result Properties dialog for the result you are viewing.

Read more: Viewing and Editing Result Properties (page 587).

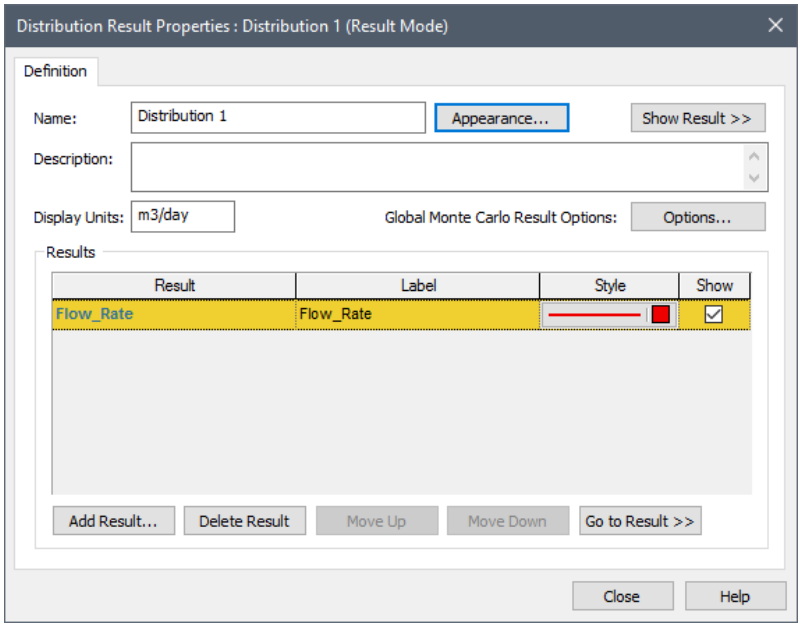
***Result Properties** button*

This dialog can be accessed by pressing the Result properties button while viewing the chart or table. This will display the Result Properties dialog:



This is the Result Properties dialog for a Distribution result. Dialogs for other result types are similar.

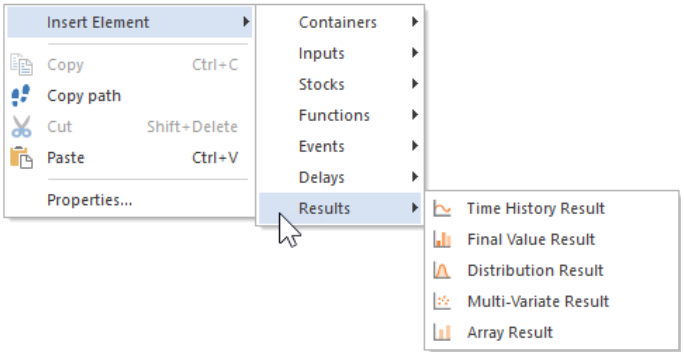
If you press the **Create Element** button, GoldSim will insert an element. The **Name** will also become editable (a default name will be automatically inserted that you can change). You will also note that the **Create Element** button changes to **Appearance**:



Note: With one exception, Result elements follow the same rules as other GoldSim elements regarding their names (e.g., can only include letters, numbers and the underscore character). Unlike other elements in GoldSim, however, the **Name** of a Result element can contain spaces.

For some result types, some additional fields may also become available when the Result element is created (in the example above, an **Options…** button becomes available).

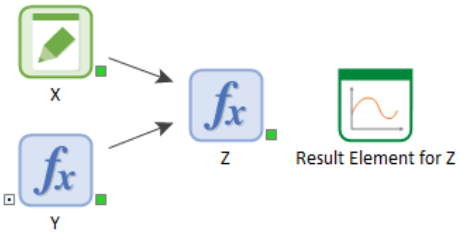
You can also insert a result element into your model directly just as you would insert any other kind of element, via the main menu or context menus:



Viewing a Result Element

Result elements are similar to other elements in GoldSim, in that you can move them, copy them and change their appearance. There are, however, several important differences:

- When you double-click on a result element in Result Mode, Run Mode or Scenario Mode, the result window is immediately displayed You can display the (empty) result window of a Result element directly in Edit Mode, by Ctrl-double-clicking it (double-clicking on a Result element in Edit Mode displays its properties dialog).
- Result elements do not have input or output ports (since they do not have any outputs). Although they do reference other elements (the results being displayed), these are not considered inputs. Hence, there are no influence lines drawn to Result elements:



A result element has the same result display and editing capabilities as an interactive result display. You can choose to view a table or chart form of the result, or view the Result Properties page (e.g., in order to add other outputs to the display). Result elements "remember" the last type of result format (i.e., table or chart), and display that format the next time they are viewed (double-clicked).

Like an interactive result, you can edit the appearance of the chart (e.g., headers, footers, etc.).

Read more: Editing the Appearance of a Chart (page 768).

Note, however, that whenever you change the appearance of the chart for a result element, *these changes are automatically saved with the* element.

One of the key features of result elements is that they can be opened prior to the start of a simulation (via a Ctrl+double-click), and then viewed during the simulation. The display is updated whenever the simulation is paused, and at the end of every realization. If you are running a single realization, Time History results are updated continuously as the simulation proceeds.

This can be particularly useful in helping you to debug a model (by pausing the simulation at specific points).

The dynamic display of result elements is facilitated by GoldSim's ability to slow down the speed of the simulation, step through a simulation one realization or timestep at a time, and pause and resume a simulation.

Read more: Pausing and Stepping through a Simulation (page 522).

Note that you cannot open a result element while a model is running. If you want to view a result element being dynamically updated, you must open it prior to starting the simulation, or while the simulation is paused. If you open a result element prior to starting the simulation and try to view a chart, the resizable result display window will open with a message that there is no data available.

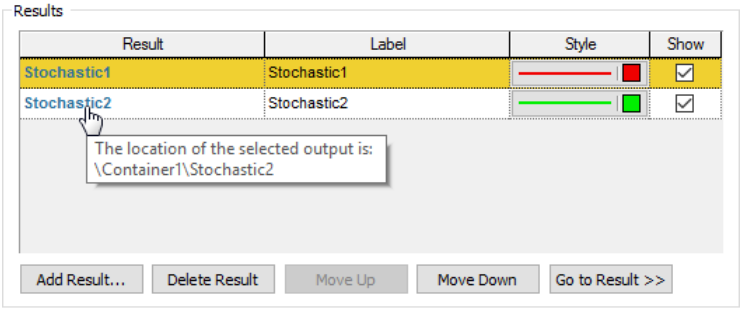
Browsing Between Result Elements and Referenced Outputs

Unlike other elements in GoldSim, when you reference an output of an element within a Result element, it is not treated as a "link". That is, the Result element is not considered to be a "function of" of the outputs that it references (since the Result element is not actually carrying out a calculation; it is simply serving as a mechanism to display a result). As a result, you will note that influences are not drawn between the element(s) being referenced and the Result element. Moreover, the Result element does not appear in the "Affects" list for the element being referenced.

Read more: Understanding Influences (page 99); Viewing Element Dependencies (page 114).

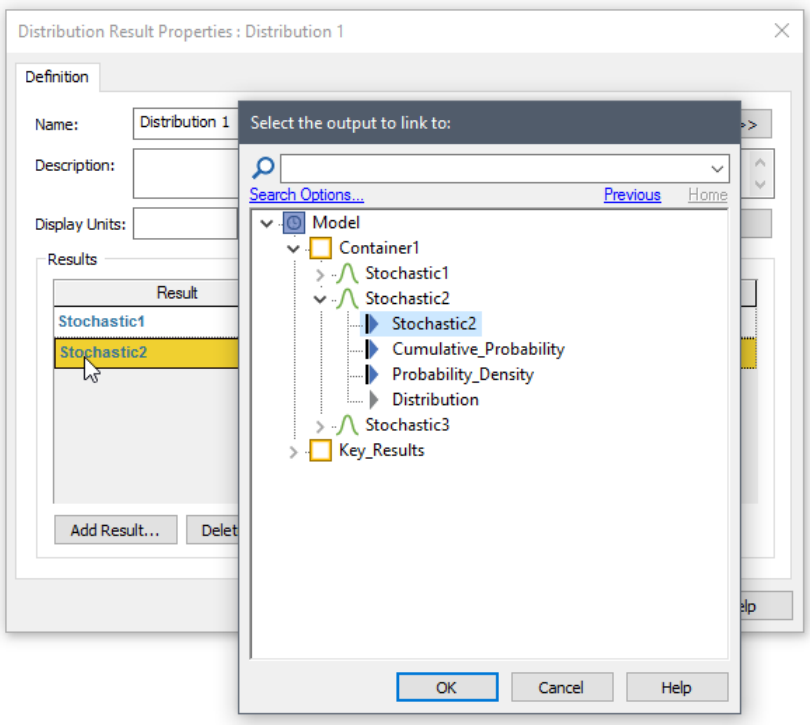
Nevertheless, it is often necessary to quickly find the elements being referenced by a Result element (and conversely, the Result element that references a particular element). To facilitate this, GoldSim provides a number of tools for browsing between Result elements and the outputs (and hence elements) that they reference:

- From within the Properties dialog for a Result element, if you select a result (i.e., an output), and then press the **Go to Result>>** button, the dialog will close and the output's element will be selected (i.e., GoldSim will jump directly to that location in the graphics pane). (Note that Array results do not have a **Go to Result>>** button, as this button is most valuable when a Result element contains multiple results).
- From within the Properties dialog for a Result element, if you place your cursor over the result, a tool-tip will be displayed showing the location of the element being referenced:

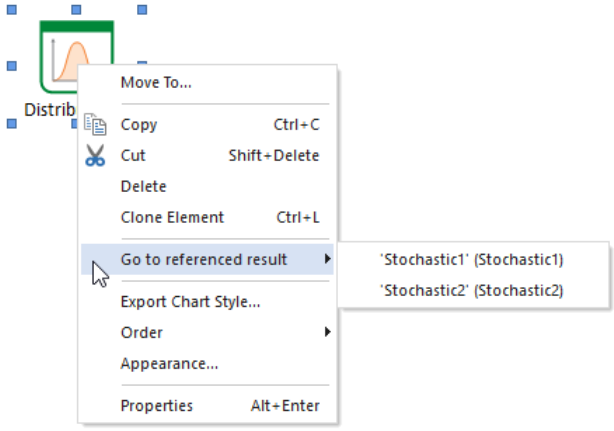


If you Ctrl+double-click on the result, the dialog will close and the output's element will be selected (i.e., GoldSim will jump directly to that location in the graphics pane).

If you double-click on the result, a browser will be shown illustrating the location of the element in the hierarchy:

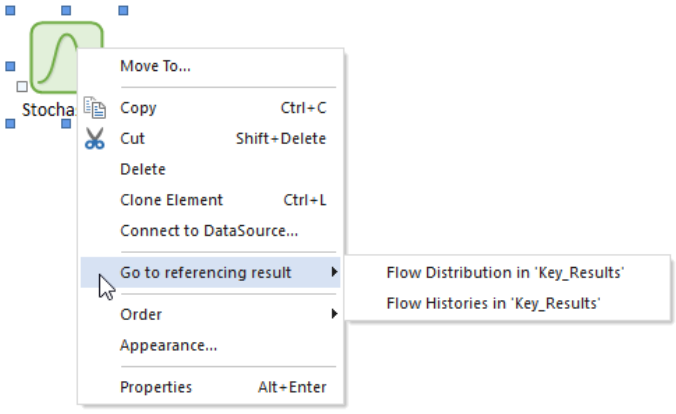


- If your right-click on a Result element in the graphics pane (or the browser), a context menu will be displayed listing all of the referenced outputs:



If you click on one of the outputs listed, the output's element will be selected (i.e., GoldSim will jump directly to that location in the graphics pane).

- If you right-click on a referenced element in the graphics pane (or the browser), a context menu will be displayed listing all of the Result elements that reference outputs from the element:



If you click on one of the Result elements listed, the Result element will be selected (i.e., GoldSim will jump directly to that location in the graphics pane).

Specialized Uses for Result Elements

Result elements have special capabilities that do not exist for the corresponding interactive result:

- Result elements can be opened (via a button) or embedded directly into Dashboards.

  Dashboards are discussed in detail in the **Dashboard Authoring Module User's Guide**.

- Time history results for simulations with multiple realizations can only be displayed for outputs that are referenced by Time History Result elements.

  Read more: Viewing Time Histories of Multiple Realizations (page 620); Saving Outputs as Results (page 514).

- Time History. Final Value and Distribution Result elements can be used to display Scenario results.

Read more: Viewing Scenario Results in Time History Result Elements (page 645); Viewing Scenario Results in Distribution Result Elements (page 688).

- Time History Result elements can be specified to export time history results (i.e., model outputs) to spreadsheets and text files automatically at the end of a simulation.

  Read more: Exporting from a Time History Result Element to a Spreadsheet (page 786); Exporting from a Time History Result Element to a Text File (page 794).

- Time History Result elements can be specified to plot results based on Reporting Periods.

  Read more: Viewing Reporting Period-Based Results in Time History Result Elements (page 631).

- Time History Result elements within a parent model can be used to display time history results from inside a SubModel.

  Read more: Viewing SubModel Results in Time History Result Elements (page 640).

- Distribution Result elements within a parent model can be used to display nested Monte Carlo simulation results generated using a SubModel.

  Read more: Carrying Out Nested Monte Carlo Simulation Using a SubModel (page 1067).

- Time History Result elements can be specified to display results at unscheduled update points.

  Read more: Viewing Unscheduled Updates in Time History Result Elements (page 652).

Viewing Scenario Results

GoldSim's scenario modeling capability allows you to directly compare results generated by different sets of input parameters. In effect, when you use this capability, your model can store (and subsequently compare) multiple sets of results (and inputs).

Read more: Creating, Running and Comparing Scenarios (page 525).

In particular, when a model is in Scenario Mode, if you were to browse the model, you would note the following:

- There is no option to right-click on an element and view its results. Elements do not store results in Scenario Mode.
- If you double-click on a Time History Result element or a Distribution Result element, GoldSim displays results for all scenarios for which scenario results have been generated (and for which the **Show** button has been checked from within the Scenario Manager). If you double-click on a Final Value Result element, what is displayed is a function of how the Result element is configured. It could display results for all scenarios for which scenario results have been generated (and the **Show** button has been checked) or for only the Active Scenario.

Read more: Viewing Scenario Results in Time History Result Elements (page 645); Viewing Scenario Results in Distribution Result Elements (page 688); Displaying Scenarios in Final Value Result Elements (page 717).

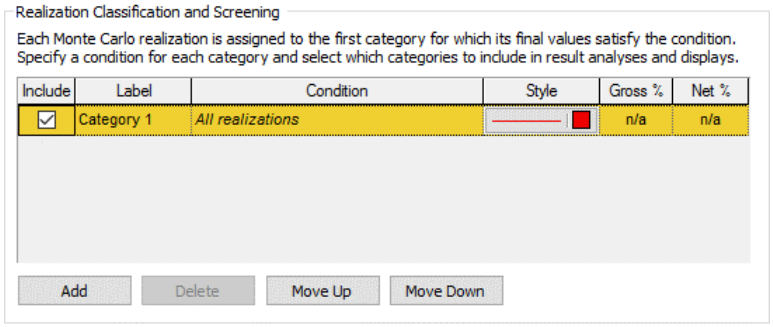
Classifying and Screening Realizations

When carrying out probabilistic simulations, you may often run hundreds or thousands of realizations. In order to analyze the results, it is often quite useful to classify the realizations into *categories*. A category is simply defined by a condition relating one or more outputs in the model (e.g., those realizations in which the discount rate was above 3.5%; those realizations in which the profit exceeded $1,000,000; those realizations in which the peak concentration was between 1 mg/l and 10 mg/l).

The power of categories is that once you have defined them, you can use them in two ways:

- Within certain kinds of result charts (e.g., scatter plots, time histories, distributions), realizations from each category can be displayed in a different color (and/or symbol).
- Within all result displays, you can choose to screen out one or more categories, so that the results that are shown (in charts and tables) only include those realizations in the categories which you have chosen to include.

Classification categories are defined at the bottom of the Monte Carlo Result Display Properties dialog:

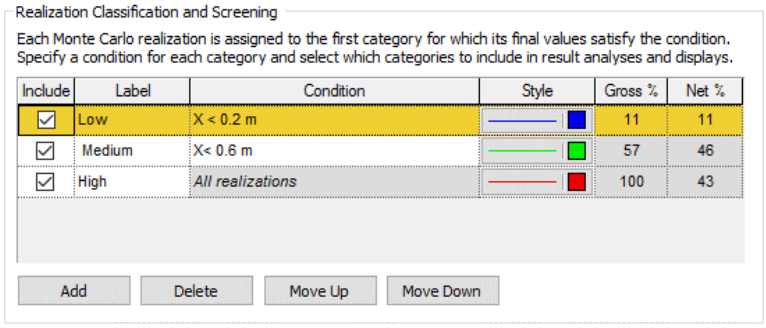


This dialog can be accessed from the Monte Carlo tab of the Simulation Settings dialog (via the **Result Options…** button), and is also accessible from result properties dialogs.

Read more: Viewing and Editing Result Properties (page 587).

By default, all results are placed in a single category (defined as "All realizations"). You can add categories by pressing the **Add** button. When you do so, it adds a row above the selected row. For each category that you add, you must define a **Label** and a **Condition**.

In this example, three categories have been defined:



It is critical to understand how the categories of realizations are created by GoldSim. ***In particular, the order of the Classification Conditions is***

important. If multiple Classification Conditions are true for a realization, the realization is assigned to the category with the first True Condition in the list. Hence, in the example shown above:

- The "Low" category consists of all realizations in which X < 0.2. As indicated by the **Net %** column, 11% of the realizations fall into this category.
- The "Medium" category consists of all realizations in which X >= 0.2 (and hence they do not fall into the "Low" category above it) AND X < 0.6. As indicated by the **Net %** column, 46% of the realizations fall into this category.
- The "High" category consists of all remaining realizations (all realizations in which the conditions in the first two categories are false). In this case, it implies that the category consists of all realizations in which X >= 0.6. As indicated by the **Net %** column, 43% of the realizations fall into this category.

As pointed out above, the **Net %** columns indicates the percentage of realizations falling into each category. The **Gross %** column shows the percentage of realizations falling into the selected category and all the categories above it.

Note: If you place your cursor over the **Net %** field, a tool-tip will display the actual realizations that fall into that category; if you place your cursor over the **Gross %** field, a tool-tip will display the actual realizations that fall into that category and all the categories above it.

Note: The **Gross %** and **Net %** are only shown when the model is in Result Mode (or when the model is paused).

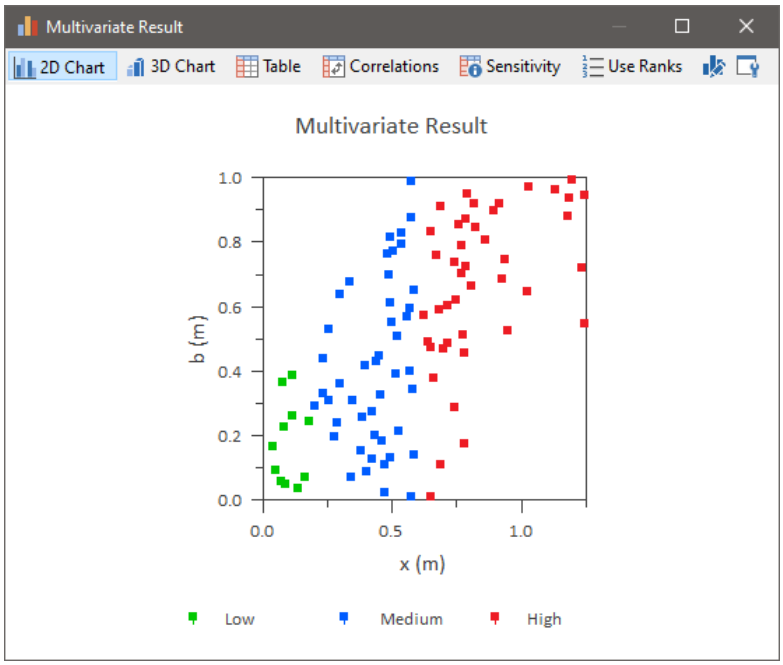
Read more: Understanding Result Mode (page 578).

You can use the **Move Up** and **Move Down** buttons to change the order of the Conditions (and hence the definition of the categories).

Several points should be noted regarding defining the categories:

- You cannot edit the Condition for (or move) the final category. It always represents "everything else". That is, it represents all realizations that do not fall into one of the previous categories.
- The Condition can be a complex expression, but it must be a scalar condition.
- You can edit the Conditions in Edit Mode, Result Mode or Run Mode (but not Scenario Mode). However, in Result Mode or Run Mode, you cannot reference an output for which Final Values have not been saved.

Categories are powerful because in Result Mode, within certain kinds of result charts (e.g., scatter plots, time histories, distributions), realizations from each category can be displayed in a different color (and/or symbol). For example, this Multi-Variate Result (a 2D scatter plot) breaks down the results by category:



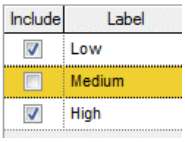
Note that for each category, you can select a **Style**. This is used to control things such as colore when plotting the results when you have created multiple categories.

Read more: Using and Managing the Color Palette (page 437).

The manner in which these Styles are used is a function of the type of result being plotted.

Read more: Using Result Classification and Screening in Time History Results (page 638); Using Result Classification and Screening in Distribution Results (page 681); Using Result Classification and Screening in Final Value Results (page 733); Using Result Classification and Screening in Multi-Variate Results (page 751); Using Result Screening in Array Results (page 765).

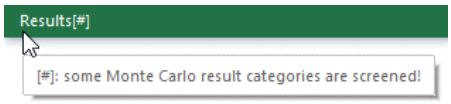
In addition, you can choose to screen out one or more categories of realizations by clearing the **Include** checkbox for a category:



When you do so, when showing results (in both charts and tables), only those realizations in the categories which you have chosen to include are displayed.

Note: You can edit the **Include** box in Edit Mode, Result Mode Scenario Mode or Run Mode.

Obviously, if you have screened out results in such a way, it is critical that this is made apparent that the results being shown are screened. Hence, when results are screened, this is indicated in the right-hand corner of the status bar. A hashtag (and a comment) are added after "Results":



Creating Chart Styles

GoldSim has powerful charting capabilities that allow you to customize the appearance of each chart (e.g., by adding headers and footers, changing axes scales and labels, etc.).

Read more: Editing the Appearance of a Chart (page 768).

In some cases, after modifying the appearance of a chart, you may want to save the particular set of properties you have created (e.g., label fonts, header, footer) so that you can apply them to another chart. To facilitate this, GoldSim allows you to save the set of properties as a named ***chart style***. The named chart style is saved as part of the model file, and can subsequently be applied to other results in your model. You can also export and import chart styles between models.

In order to facilitate the use of a single chart style for multiple results, GoldSim allows you to use ***keywords*** (delimited by the % symbol) when you create and use chart styles. For example, you could define a chart style in which the header was %rname%. This particular keyword inserts the name of the Result element you are displaying. Similarly, the keyword %curdate% inserts the current date.

When you view a result, it will initially take on a set of characteristics defined by the default chart style for that particular type of chart (e.g., time history, distribution, etc.). GoldSim automatically provides a set of default chart styles for all chart types (that utilize the keywords). If desired, however, for any type of chart, you can specify one of your own custom chart styles as the default chart.

Read more: Creating and Using Chart Styles (page 779).

Viewing Time History Results

Time History results show the "history" of a particular output as a function of time, and are probably the most common form of result display you will use.

A Time History result has two types of views:

- Chart View; and
- Table View.

If you have saved Time Histories for an output, you can display a Time History result by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Time History Result…** from the context menu. By default, a chart will be displayed.

The specific time points that are displayed in Time History results are determined by your simulation settings.

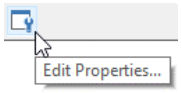
Read more: Specifying When Time History Results Will Be Saved (page 482).

Note: Time history results for simulations with multiple realizations can only be displayed for outputs that are referenced by Time History Result elements.

The topics below discuss the display and use of Time History results in detail.

Viewing the Properties of a Time History Result

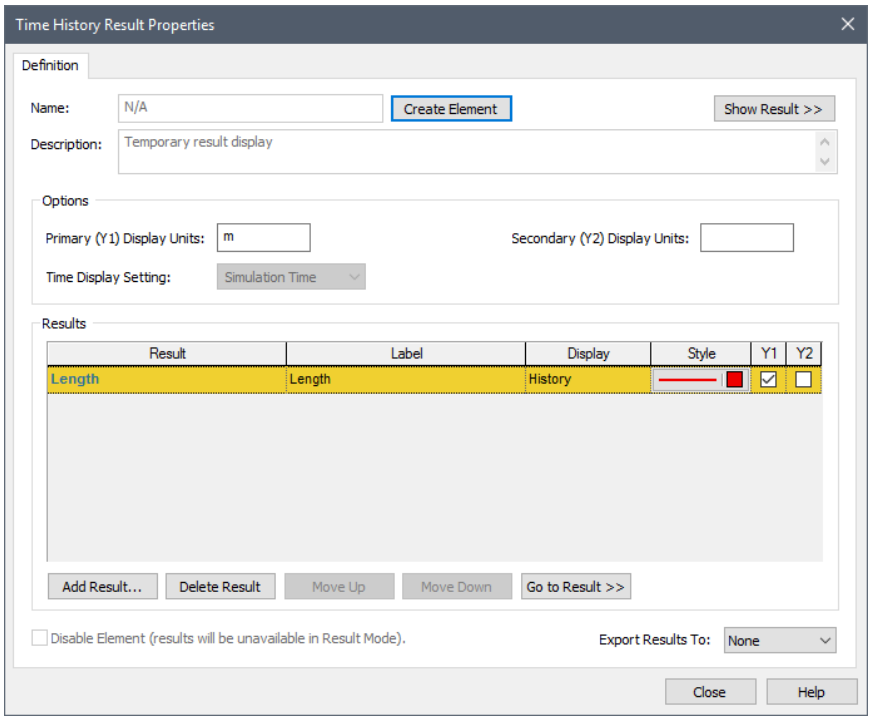
If you create a new Time History Result element in Edit Mode or you click on the Result Properties button when viewing a Time History Result chart or table, the Properties dialog for the result will be displayed. The Result Properties button is the furthest button to the right at the top of the display window:



Note that when you press this button while viewing results, it does not close the result display window you were displaying. Both windows are displayed simultaneously (although you can subsequently close one or the other). When viewing results, any changes you make to the Result Properties are immediately represented in the result display.

The Result Properties dialog is always modal. That is, it cannot be minimized, and with the exception of viewing the result display (which can be displayed simultaneously and share the focus with the Properties dialog), it retains the focus while it is displayed. As a result, you must close the Result Properties dialog before you can edit any other part of your GoldSim model.

The Result Properties dialog for an interactive (scalar) Time History result looks like this:



You can show the full path for a result (showing the containment hierarchy) by placing your cursor over the Result item to display a tool-tip.

At the top of the page is a button to **Create Element**. By pressing this button, a Result element is created. When you do so, the key change that will be noticeable is that the **Name** will now be editable. The **Create Element** button becomes an **Appearance** button (which is used to modify the appearance of the element itself).

Read more: Creating and Using Result Elements (page 593).

The **Show Result** >> button opens a result display window (while keeping the Properties dialog simultaneously open.

Read more: Viewing a Time History Chart (page 608); Viewing a Time History Table (page 610).

The **Add Result…** button allows you to add results to the chart. Results can be deleted with the **Delete Result** button. The order in which multiple results appear in the list can be changed using the **Move Up** and **Move Down** buttons. Pressing **Go to Result** >> closes the Properties dialog and selects the element associated with the result in the graphics pane.

Read more: Viewing Time Histories of Multiple Outputs (page 612).

For each result in the list, you specify a **Style** (used in charts), and the **Label** used in legends in charts and headers in tables.

Read more: Controlling the Chart Style in Time History Results (page 658).

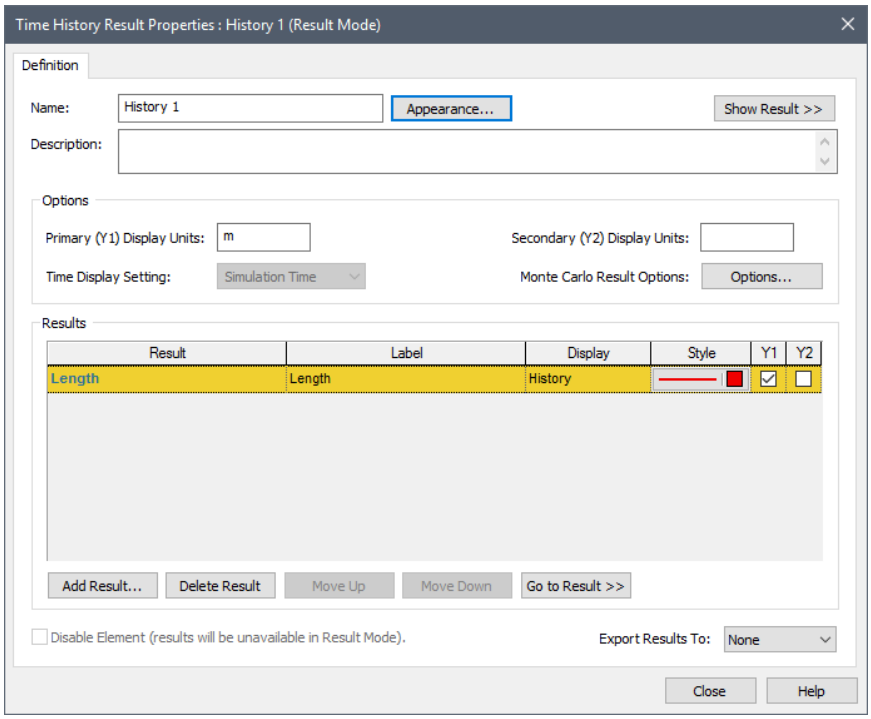
Note: The colors used for a Probability chart (which shows the percentiles for a multi-realization simulation) are not specified by the **Style** button. Rather, these are controlled via the Global Monte Carlo Result Options.

Read more: Viewing Probability Histories for Multiple Realizations (page 623).

The **Y1** and **Y2** checkboxes are used to determine which axis the result is plotted on. If you add a second output that has the same dimensions as the original output, it will automatically be placed on the primary (Y1) axis. If it has different dimensions, it will automatically be assigned to the secondary (Y2) axis. You can add as many outputs as desired to the list. If you add an output whose dimensions do not match those currently assigned to the Y1 or Y2 axes, it will be assigned to neither. As a result, it will not be displayed in the chart (but will be displayed in the table). If you specifically try to assign an unassigned output to an axis, any outputs assigned to that axis with different dimensions will be cleared and the axis will take on the new dimension.

You can also specify the **Display Units** for the Y1 and Y2 axis (which overrides the display units specified within the element's property dialog).

The Properties dialog for a Time History Result element has several differences:



- The **Create Element** button is replaced by an **Appearance** button (which is used to modify the appearance of the element itself).
- The **Name** (and **Description**) are editable (since this is an element).
- An **Options…** button is available that provides access to the Monte Carlo Result Display Properties.

  Read more: Controlling Monte Carlo Result Options (page 500).

- Time History Result elements also have two additional options at the bottom of the dialog: the ability to disable the element, and the ability to export results (to a spreadsheet or text file) at the end of a simulation.

  Read more: Disabling a Time History Result Element (page 658); Exporting From a Time History Result Element to a Spreadsheet (page 786); Exporting from a Time History Result Element to a Text File (page 794).

- The **Time Display Setting** can only be edited while in Edit Mode. It defaults to "Simulation Time", which is the appropriate setting for viewing standard time histories. However, two additional options are also available ("Reporting Periods" and "SubModel Time") which can be selected in order to view Reporting Period-based results and SubModel results, respectively, in Time History Result elements.

  Read more: Viewing Reporting Period-Based Results in Time History Result Elements (page 631); Viewing SubModel Results in Time History Result Elements (page 640).

If you have run multiple realizations, the Properties dialog for a Time History Result dialog has one additional field that is not available for single realization runs: you can specify a **Custom Statistic** for each output:

This can then be viewed in result displays.

Read more: Viewing Custom Statistics for Multiple Realizations (page 627).

Viewing a Time History Chart

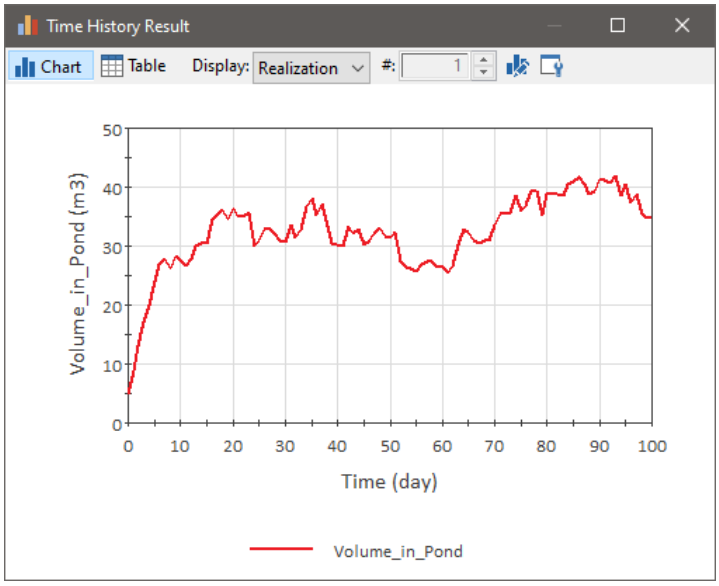
If you have saved Time Histories for an output, you can display a Time History chart by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Time History Result…** from the context menu. By default, a chart will be displayed.

Note: When viewing a Time History Result element, the element "remembers" the last type of view that was displayed, and displays that view when you double-click on it.

Note: Time history results for simulations with multiple realizations can only be displayed for outputs that are referenced by Time History Result elements.

If you are viewing a table rather than a chart, you can view a chart by pressing the **Chart** button at the top of the display.

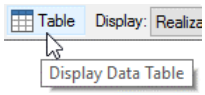
A Time History Chart looks like this:



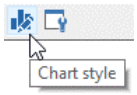
The Time History Chart has a variety of buttons and controls at the top of the window. Some items are always present, while others are only shown under certain circumstances (e.g., when viewing multiple realizations and/or multiple outputs).

The following buttons are always available:

Display Table: Selecting this button switches to a Time History Table view of the result. Note that when viewing a table, the Display Table button appears selected; when viewing a chart, the Display Chart button appears selected.

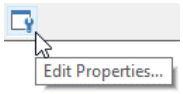


Edit Chart Style: This button provides access to a dialog for editing the chart style.



Read more: Controlling the Chart Style in Time History Results (page 658).

Edit Properties: This provides access to the Result Properties.



Read more: Viewing the Properties of a Time History Result (page 605).

In some situations, you may want to zoom in on a portion of a chart that is of particular interest. You can, of course, edit the style of the chart and change the range of the axes which are displayed. GoldSim also provides a keyboard short-cut to support this.

Read more: Zooming in on a Chart (page 589).

Condition outputs are either True or False and are typically used as state variables or flags in a simulation. As a result, in some situations, you may want to save and plot time histories of conditions. To facilitate this, when plotting a time history of a condition, GoldSim plots True as 1 and False as 0.

Like all result charts, you can also control various attributes of the chart via a context menu. This includes the ability to turn on and off a legend. The legend uses the **Label** for the result defined in the Result Properties page. When viewing multiple results on one chart, you will always want to display the legend.

Read more: Using Context Menus in Charts (page 588); Viewing Time Histories of Multiple Outputs (page 612).

You can control the number of significant figures displayed in result displays from the **Results** tab of the Options dialog (accessed via **Model |Options…** from the main menu).

Read more: Controlling Significant Figures and Scientific Notation in Result Displays (page 591).

You can copy the chart to the clipboard by right-clicking in the chart, and selecting **Copy** from the context menu. Alternatively, you can press **Ctrl+C** while viewing the chart. To export a chart, right-click in the chart, and select **Export…** from the context menu.

Read more: Copying a Chart or Table (page 800); Exporting a Chart (page 801).

Note: When viewing time history results from a SubModel within the parent model, the Chart display is modified somewhat, and in some cases provides slightly different options.

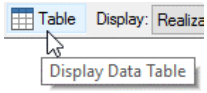
Read more: Viewing SubModel Results in Time History Result Elements (page 640); Carrying Out Nested Monte Carlo Simulation Using a SubModel (page 1067).

Viewing a Time History Table

When you display a Time History result by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Time History Result…** from the context menu., by default, a chart will be displayed.

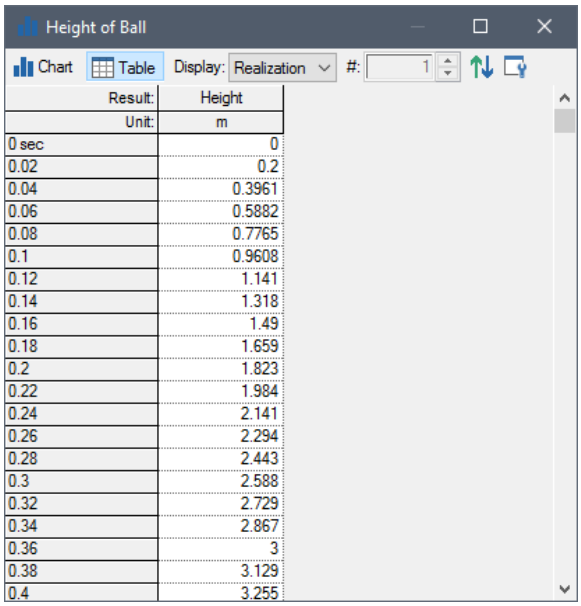
Read more: Viewing a Time History Chart (page 608).

You can view a Time History Table by pressing the **Display Table** button when viewing a chart.



Note: When viewing a Time History Result element, the element "remembers" the last type of view that was displayed, and displays that view when you double-click on it.

A Time History Table looks like this:



Result:	Height
Unit:	m
0 sec	0
0.02	0.2
0.04	0.3961
0.06	0.5882
0.08	0.7765
0.1	0.9608
0.12	1.141
0.14	1.318
0.16	1.49
0.18	1.659
0.2	1.823
0.22	1.984
0.24	2.141
0.26	2.294
0.28	2.443
0.3	2.588
0.32	2.729
0.34	2.867
0.36	3
0.38	3.129
0.4	3.255

For multi-realization runs, there are three header rows. The first shows the Label for the result; the second shows the unit; and the third identifies exactly what is being displayed (e.g., a realization or a specific statistic). For single realization runs, the third header row is not shown (as it is not applicable).

The first column then shows the plot points being used (i.e., scheduled timesteps at which point values are saved). Each row represents a separate plot point (a result value that was saved at a particular point).

What is displayed in the first column is a function of two things:

- Is the **Time Display Setting** (in the Properties dialog) set to "Simulation Time", "SubModel Time" or "Reporting Periods"? In the first two cases ("Simulation Time is the default and the only option for interactive results), the first column contains elapsed times or dates. In the last case, the first column contains Reporting Period names.

  Read more: Viewing Reporting Period-Based Results in Time History Result Elements (page 631).

- Is the **Time Basis** in the Simulation Settings dialog "Elapsed Time" or "Calendar Time"? In the former case, the first column displays elapsed times. In the latter case, the first column displays dates.

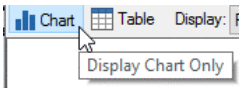
  Read more: Defining the Time Basis and Simulation Duration (page 471).

You can increase or decrease the width of a column by dragging the line separating columns to the right or to the left, respectively. If the column is too narrow to display the contents of a cell, holding the cursor over the cell displays a tool-tip with the contents.

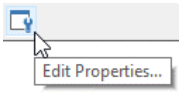
The Time History Table has a variety of buttons and controls at the top of the window. Some of items are always present, while others are only shown under certain circumstances (e.g., when viewing multiple realizations and/or multiple outputs).

The following three buttons are always available:

Display Chart: Selecting this button switches to a Time History Chart view of the result. Note that when viewing a table, the Display Table button appears selected; when viewing a chart, the Display Chart button appears selected.

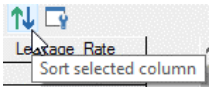


Edit Properties: This provides access to the Result Properties.



Read more: Viewing the Properties of a Time History Result (page 605).

Sort: This button allows you to sort the rows based on a selected column.



Read more: Sorting Values in Result Tables (page 590).

Several additional points should be noted regarding Time History Tables:

- Conditions are displayed in tables as either 1/0, true/false, True/False, TRUE/FALSE, on/off, or High/Low. You select which of these pairs to use on the **Results** tab of the Options dialog (accessed via **Model |Options…** from the main menu).

- You can control the number of significant figures displayed in tables from the **Results** tab of the Options dialog (accessed via **Model |Options…** from the main menu).

Read more: Controlling Significant Figures and Scientific Notation in Result Displays (page 591).

- You can copy the contents of a Time History Table to the clipboard by pressing **Ctrl+C**. You must first select the cells you wish to copy. You can do so by placing your cursor in one cell and dragging to another location. You can select the entire table by pressing the cell in the upper left-hand corner of the table. Cells that are not adjacent can be selected by pressing the **Ctrl** key when selecting. Selected items will be highlighted in black. You can subsequently paste the table into another application (such as a spreadsheet).

  Read more: Selecting Items and Copying Values in Result Tables (page 590).

Note: When viewing time history results from a SubModel within the parent model, the Table display is modified somewhat, and in some cases provides slightly different options.

Read more: Viewing SubModel Results in Time History Result Elements (page 640); Carrying Out Nested Monte Carlo Simulation Using a SubModel (page 1067).

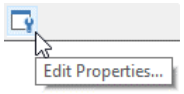
Viewing Time Histories of Multiple Outputs

It is often useful to plot the time histories of multiple outputs on a single plot. This allows you to compare and contrast different results, or to better understand how various parameters in your model affect each other. Therefore, GoldSim allows you to display multiple outputs on a single time history chart or table.

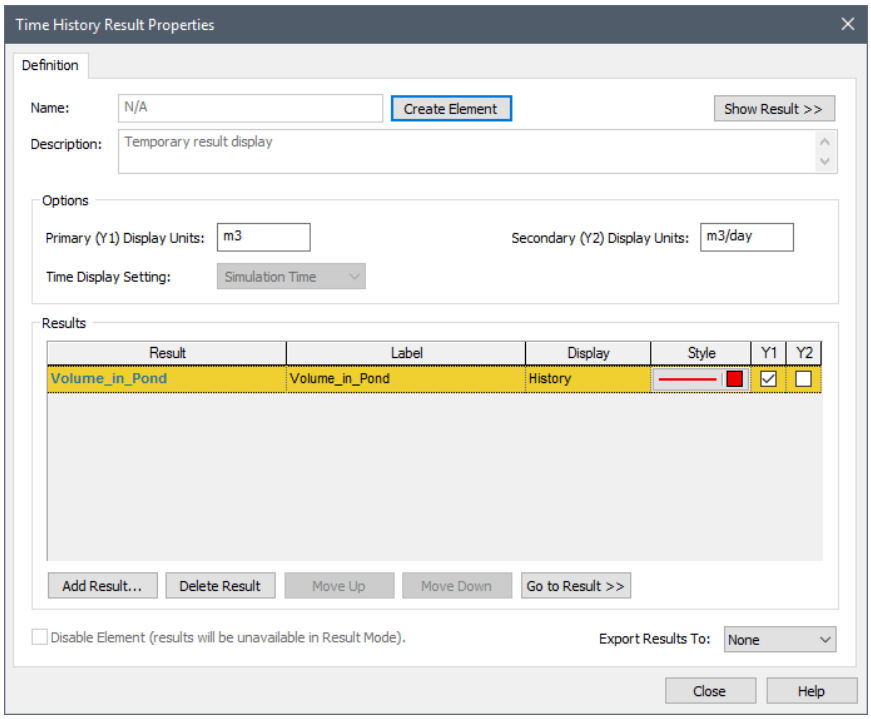
To display multiple results in a Time History Result, you must first open the Result Properties dialog for the result.

Read more: Viewing the Properties of a Time History Result (page 605).

You can do this by pressing the **Edit Properties…** button in any of the Result display windows:

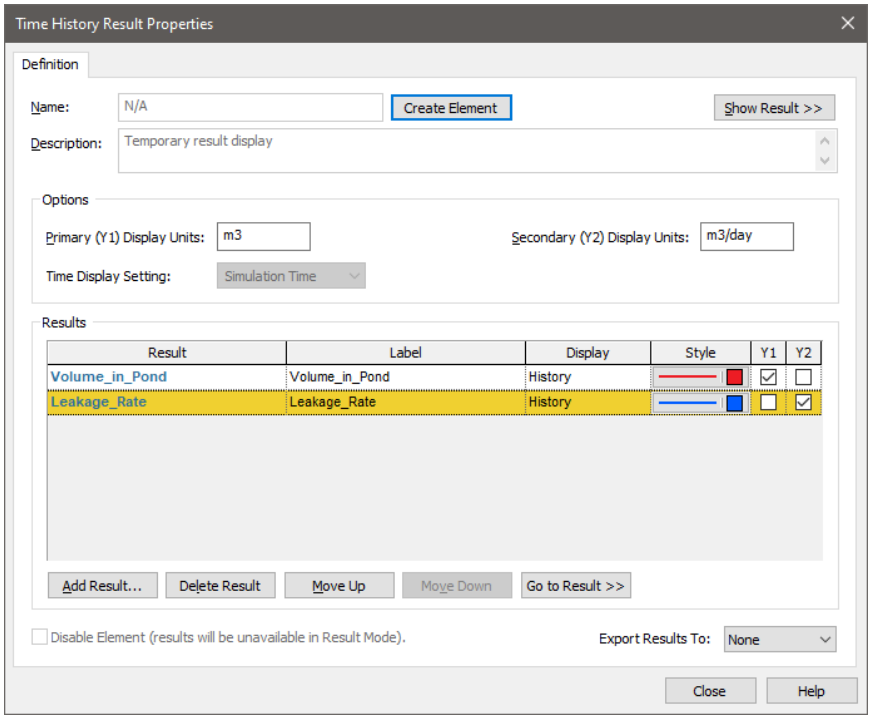


The following dialog will be displayed:



This is the dialog for an interactive result. A Result element will have a Name defined. Note that the Label is user-editable and is used in legends and column headers.

To add additional outputs to the result, press the **Add Result…** button. A dialog for selecting an output will be displayed. After you select the output you wish to add to the result display, and press **OK**, the selected outputs are then shown in the Result Properties dialog:



You can show the full path for each result (showing the containment hierarchy) by placing your cursor over the Result item to display a tool-tip.

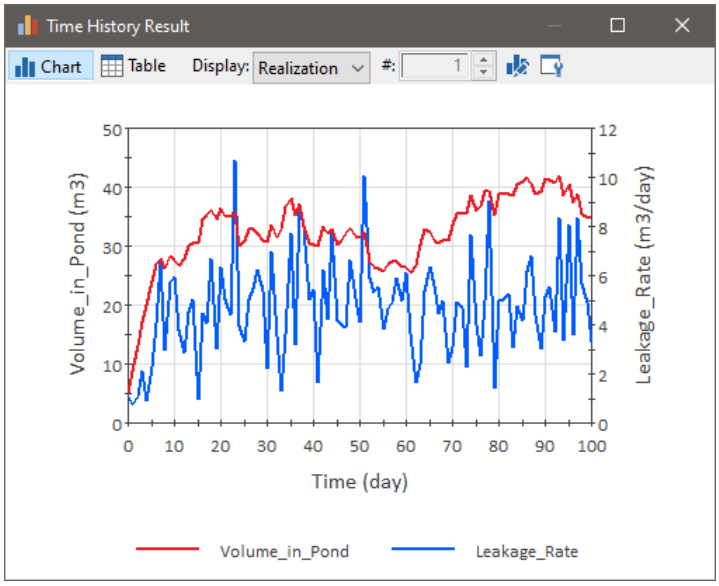
Results can be deleted with the **Delete Result** button (holding the Ctrl key down changes this to a **Delete All** button). The order in which multiple results appear in the list can be changed using the **Move Up** and **Move Down** buttons.

The **Show Result** >> button opens a result display window (while keeping the Properties dialog simultaneously open).

Read more: Viewing a Time History Chart (page 608); Viewing a Time History Table (page 610).

Pressing the **Show Result** button displays the multiple output display.

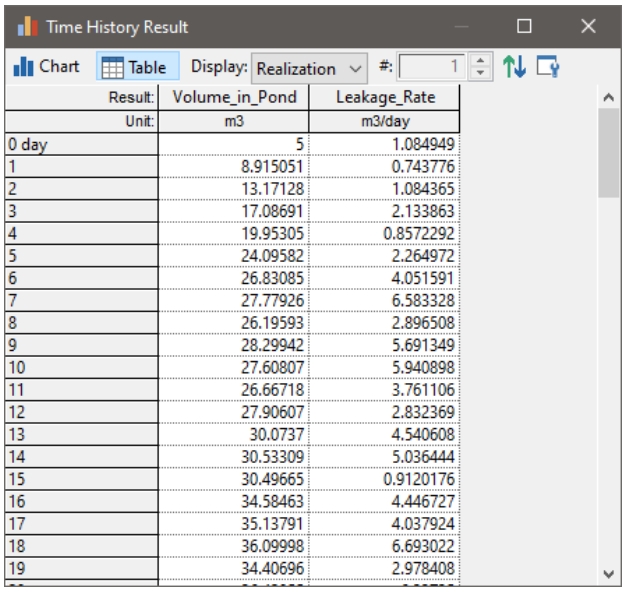
A Time History Chart with multiple outputs looks like this:



The legend displays the (user-editable) Labels defined for each result.

Note that a legend is available for Time History Charts (you may have to turn it on by right-clicking in the chart and selecting to show the legend from the context menu). The Labels specified in the Result Properties dialog are used in the legend to label the different results.

For Time History Tables, the results are listed in separate columns:



Result:	Volume_in_Pond	Leakage_Rate
Unit:	m3	m3/day
0 day	5	1.084949
1	8.915051	0.743776
2	13.17128	1.084365
3	17.08691	2.133863
4	19.95305	0.8572292
5	24.09582	2.264972
6	26.83085	4.051591
7	27.77926	6.583328
8	26.19593	2.896508
9	28.29942	5.691349
10	27.60807	5.940898
11	26.66718	3.761106
12	27.90607	2.832369
13	30.0737	4.540608
14	30.53309	5.036444
15	30.49665	0.9120176
16	34.58463	4.446727
17	35.13791	4.037924
18	36.09998	6.693022
19	34.40696	2.978408

The column headers are the (user-editable) Labels defined for each result.

The following points should be noted regarding the Time History Result Properties dialog when displaying multiple results:

- For each result in the list, you specify a **Style** (used in charts), and the **Label** used in legends in charts and headers in tables.

  Read more: Controlling the Chart Style in Time History Results (page 658).

- The **Y1** and **Y2** checkboxes are used to determine which axis the result is plotted on. If you add a second output that has the same dimensions as the original output, it will automatically be placed on the primary (Y1) axis. If it has different dimensions, it will automatically be assigned to the secondary (Y2) axis. You can add as many outputs as desired to the list. If you add an output whose dimensions do not match those currently assigned to the Y1 or Y2 axes, it will be assigned to neither. As a result, it will not be displayed in the chart (but will be displayed in the table). If you specifically try to assign an unassigned output to an axis, any outputs assigned to that axis with different dimensions will be cleared and the axis will take on the new dimension.

- You can specify the **Display Units** for the Y1 and Y2 axis (which overrides the display units specified within the element's property dialog).

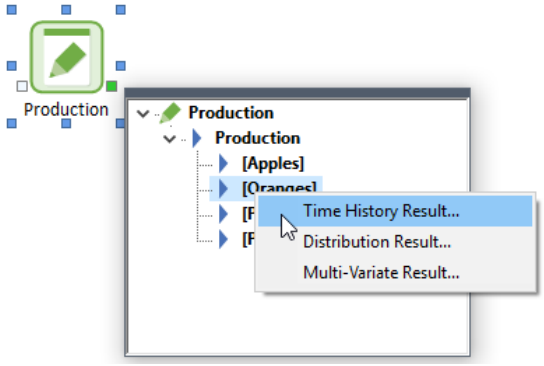
- When you are viewing time histories of multiple realizations of multiple outputs, the display windows provide a number of options that allow you to select how you want to view the results. Some options allow you to view probabilistic results for one result at a time (e.g., all realizations for a single result), while others allow you to view probabilistic results for all results simultaneously (e.g., a particular statistic for each result).

  Read more: Viewing Time Histories of Multiple Realizations for Multiple Outputs (page 628).

Viewing Time Histories for Array Outputs

When you wish to view time history results for an array output, you must first choose whether you wish to view results for a single item of the array, for selected items, or for all items.

If you wish to view results for only a single item, you should expand the array in the browser or output interface, right-click on the specific item which you wish to view, and select **Time History Result…** from the context menu.

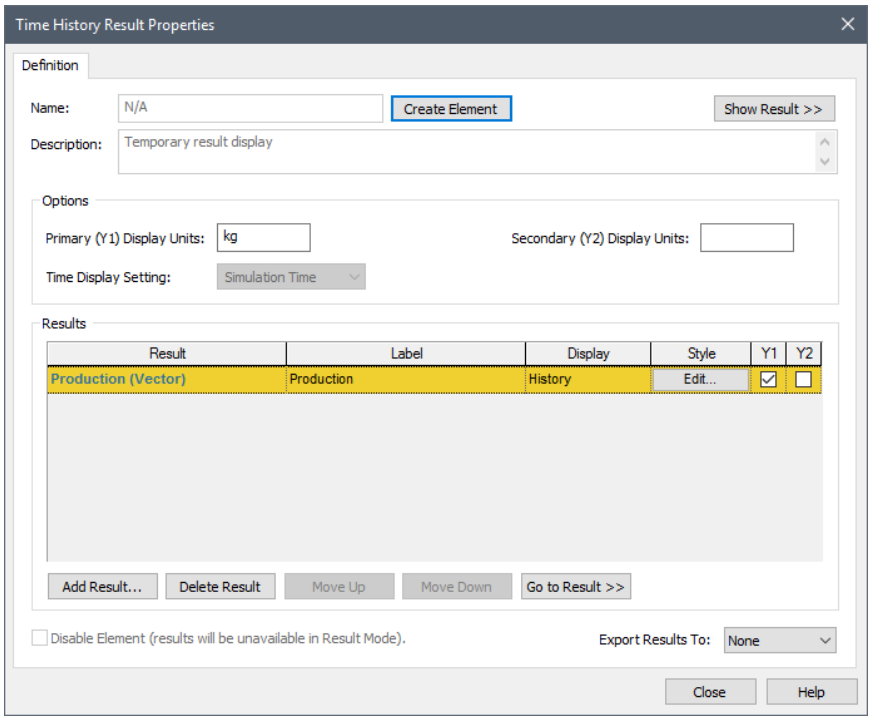


Alternatively, you could do the same thing in the Result Properties dialog (i.e., select a single item) when adding the output to the list.

Note: When you create a new array element, the **Time History** checkbox defaults off (and hence time histories are not saved). If you wish to save time histories for an array, you must specifically check this box (or reference the output in a Time History Result element).

Read more: Specifying Results to be Saved (page 514).

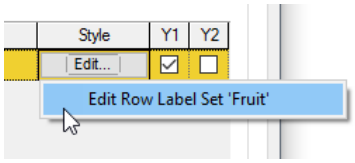
If, however, you wish to view selected items (or all items) of the array, you should either right-click on the entire array, and select **Time History Result…** from the context menu, or add the entire array to the list in the Result Properties dialog. If you do so, the Result Properties dialog looks like this:



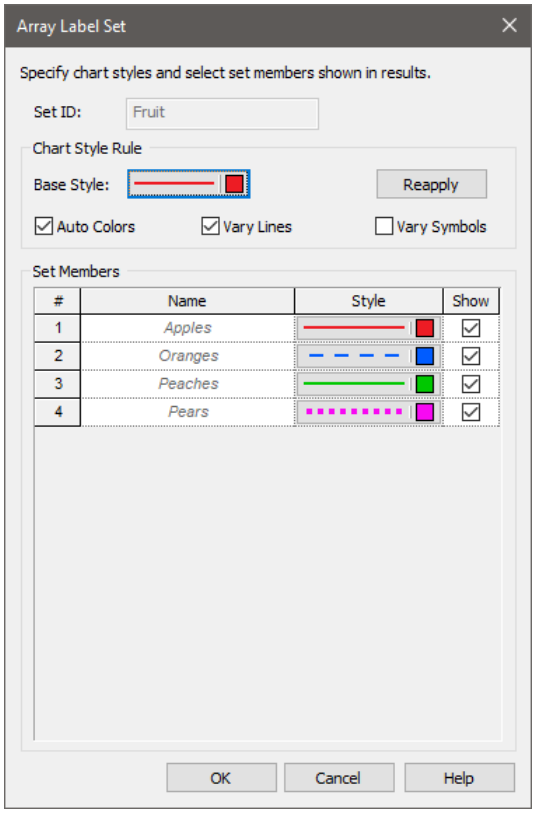
Note that in the **Result** column, the type of array (in this case, a vector) is specified.

In addition, the **Style** column includes an **Edit…** button for each array result. This button can be used to specify the Style for each item being plotted (e.g., line color), and can also be used to specify which items will be included in the display.

Pressing the **Edit…** button for a vector result displays an option to edit the Array Label set defining the vector:



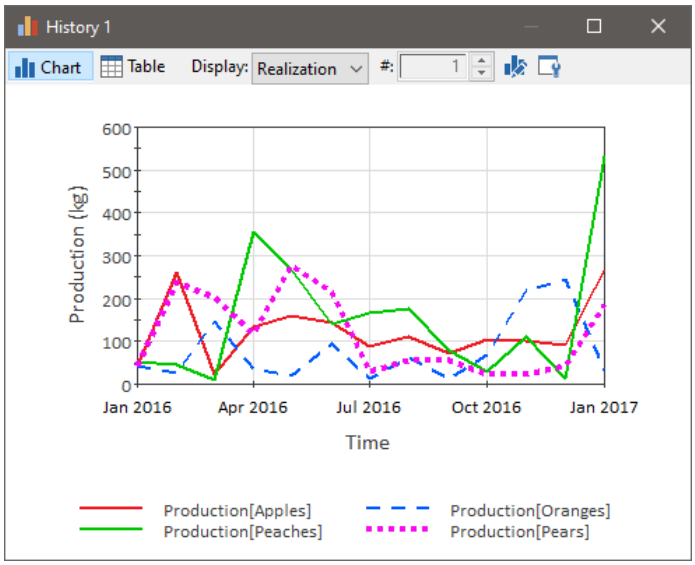
In this example, selecting this option would display the "Fruit" Array Label Set:



Read more: Creating and Editing Array Labels (page 850); Controlling the Chart Style in Time History Results (page 658).

This dialog allows you to change the **Style** for each item used for charts. In addition, the **Show** checkbox allows you to select which items are included in the displays (by default all will be checked).

If you choose to display a time history chart of an entire vector, the chart will look something like this.

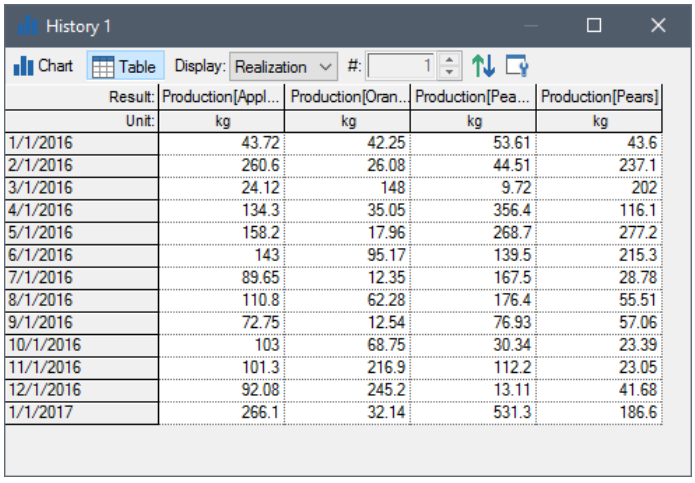


In this example, the vector has four items (Apples, Oranges, Peaches and Pears).

GoldSim will display each item of the vector, and add a legend. The style of each line is defined by the **Style** in the Array Label Set dialog, and the legend lists the array item names.

Note: If you do not want to repeat the name of the array (Production in the example shown above), you can specify a blank Label for that result item in the Properties dialog.

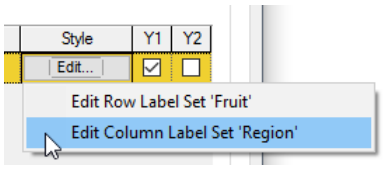
The table view of a vector would look like this:



Result:	Production[Appl...	Production[Oran...	Production[Pea...	Production[Pears]
Unit:	kg	kg	kg	kg
1/1/2016	43.72	42.25	53.61	43.6
2/1/2016	260.6	26.08	44.51	237.1
3/1/2016	24.12	148	9.72	202
4/1/2016	134.3	35.05	356.4	116.1
5/1/2016	158.2	17.96	268.7	277.2
6/1/2016	143	95.17	139.5	215.3
7/1/2016	89.65	12.35	167.5	28.78
8/1/2016	110.8	62.28	176.4	55.51
9/1/2016	72.75	12.54	76.93	57.06
10/1/2016	103	68.75	30.34	23.39
11/1/2016	101.3	216.9	112.2	23.05
12/1/2016	92.08	245.2	13.11	41.68
1/1/2017	266.1	32.14	531.3	186.6

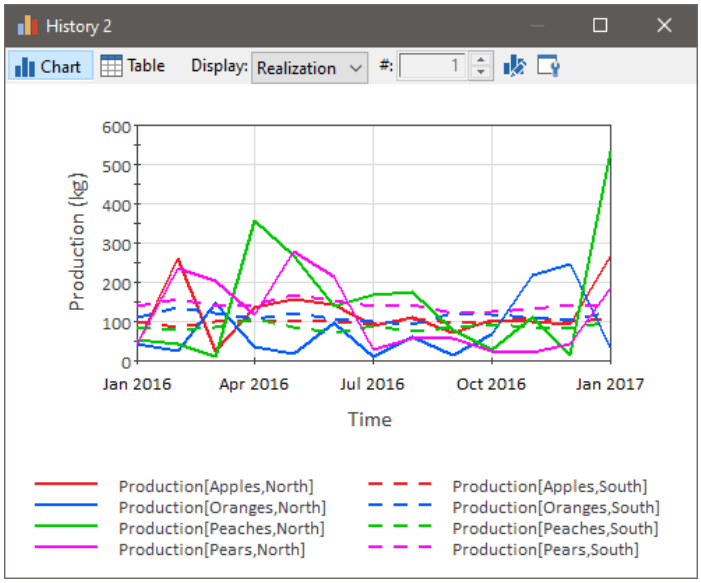
Each item of the vector is displayed in a different column.

Pressing the **Edit…** button for a matrix result displays an option to edit both the row and the column Array Label sets defining the matrix:



This allows you to select specific rows or columns to include/exclude in the displays, and also allows you to define the **Style** for each item in charts.

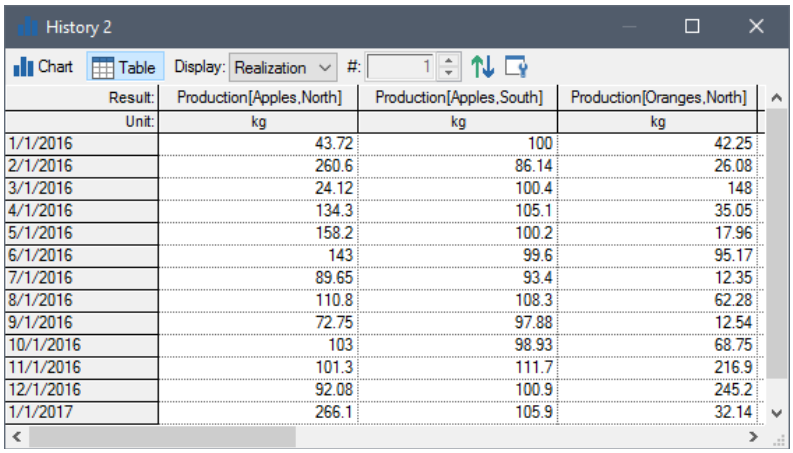
When displaying charts and tables for a matrix, GoldSim, by default, displays all items. For example, the chart below displays a matrix with 4 rows and 2 columns:



In such a chart, how are the Styles determined, since each row and each column has a specified **Style** (defined in the Array Label Set dialog) and each item being plotted is associated with both a row and a column? When plotting a matrix, the following rules are applied for each item:

- The color for an item is based on the **Style** for the row; and
- All other attributes, such as the line width, style (e.g., solid, dashed), symbol style, symbol size and symbol color, are based on the **Style** for the column.

The table view of a matrix looks like this:



Result:	Production[Apples,North]	Production[Apples,South]	Production[Oranges,North]
Unit:	kg	kg	kg
1/1/2016	43.72	100	42.25
2/1/2016	260.6	86.14	26.08
3/1/2016	24.12	100.4	148
4/1/2016	134.3	105.1	35.05
5/1/2016	158.2	100.2	17.96
6/1/2016	143	99.6	95.17
7/1/2016	89.65	93.4	12.35
8/1/2016	110.8	108.3	62.28
9/1/2016	72.75	97.88	12.54
10/1/2016	103	98.93	68.75
11/1/2016	101.3	111.7	216.9
12/1/2016	92.08	100.9	245.2
1/1/2017	266.1	105.9	32.14

Each item of the matrix (which has been selected to be shown in the Array Label Set dialogs) is displayed in a different column of the table.

When you are viewing time histories of multiple realizations of an array, the display windows provide a number of options that allow you to select how you want to view the results. Some options allow you to view probabilistic results for one item at a time (e.g., all realizations for a single result), while others allow you to view probabilistic results for all items simultaneously (e.g., a particular statistic for each result).

Read more: Viewing Time Histories of Multiple Realizations for an Array (page 629).

Viewing Time Histories of Multiple Realizations

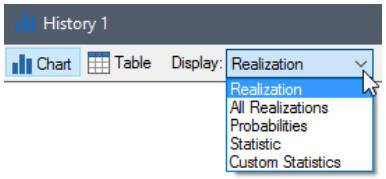
When you are viewing time histories after you have run multiple realizations, there are a number of different ways that you can view the results (e.g., view one realization at a time, view all realizations, view a particular statistic). The Display windows provide a number of options that allow you to select how you want to view the results.

Note: Time History results for simulations with multiple realizations can only be displayed for outputs that are referenced by Time History Result elements.

Note: You can only view those realizations which are available (i.e., those which have been saved and have not been screened out).

Read more: Specifying Results to be Saved (page 514); Using Result Classification and Screening in Time History Results (page 638).

If you have run multiple realizations, the top portion of the display window (either a chart or a table) for a Time History result looks like this:



As can be seen, the **Display** drop-list provides five options:

- **Realization**: This displays a single realization at a time. A control is added to the display window to select any (unscreened) realization:

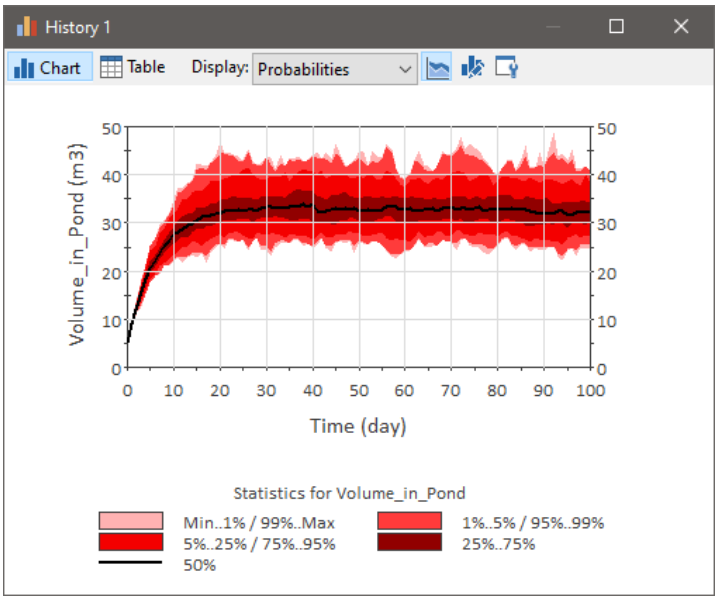
  By default, the final (unscreened) realization is shown. Note that you can also toggle to other realizations using the **Ctrl+Up** and **Ctrl+Down** keys.

- **All Realizations**: This displays all (unscreened) realizations simultaneously. The chart will show multiple lines. The table displays a column for each realization.

Note: If the Time History Result element contains multiple outputs and/or an array, the display window provides a field for selecting a single result to be displayed when this option is selected.

Read more: Viewing Time Histories of Multiple Realizations for Multiple Outputs (page 628); Viewing Time Histories of Multiple Realizations for an Array (page 629).

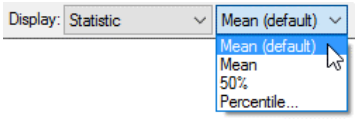
- **Probabilities**: This is the default display. It provides a ***probability histories*** display. This is a powerful probabilistic representation of the time history of an output. In particular, the multiple realizations of the time history are represented by plotting (or tabulating) the statistics (e.g., percentiles, bounds, mean) of the set of time histories:



Read more: Viewing Probability Histories for Multiple Realizations (page 623).

Note: If the Time History Result element contains multiple outputs and/or an array, the display window provides a field for selecting a single result to be displayed when this option is selected.

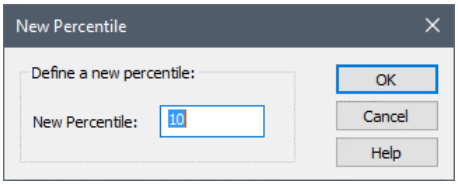
- **Statistic**: This displays a single specified statistic for the collection of (unscreened) realizations. A control is added to the display window to specify the statistic:



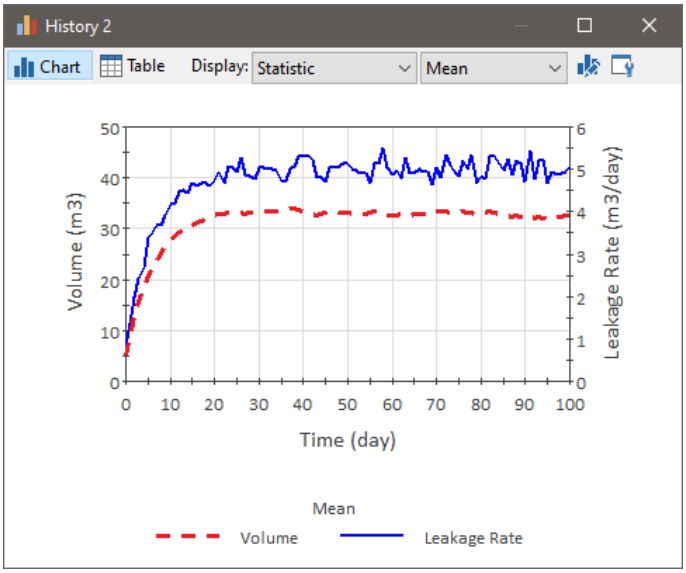
The default statistic that is shown is defined (and can be changed) in the Monte Carlo Result Display dialog (accessed via the **Options…** button in the Result Properties dialog).

Read more: Controlling Monte Carlo Result Options (page 500).

Pressing the **Percentile…** button allows you to define a specific percentile:



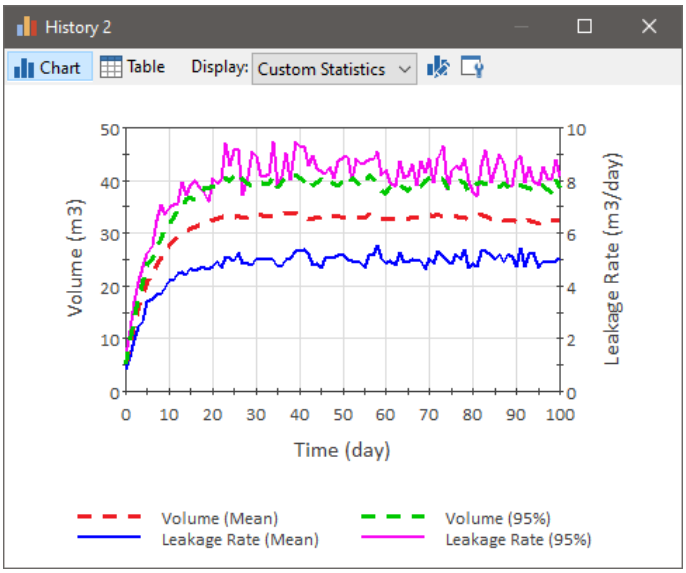
The Statistic option is of particular value when displaying multiple results, as it allows you to quickly view a single statistic for all results:



Note that the legend title indicates the Statistic being plotted.

- **Custom Statistics**: This displays a different custom statistic for each result (as opposed to the same statistic for each result). The Custom Statistic that is shown is specified in the Result Properties dialog.

The Custom Statistic option is valuable if you want to display different statistics for different outputs, or several different statistics for the same output:

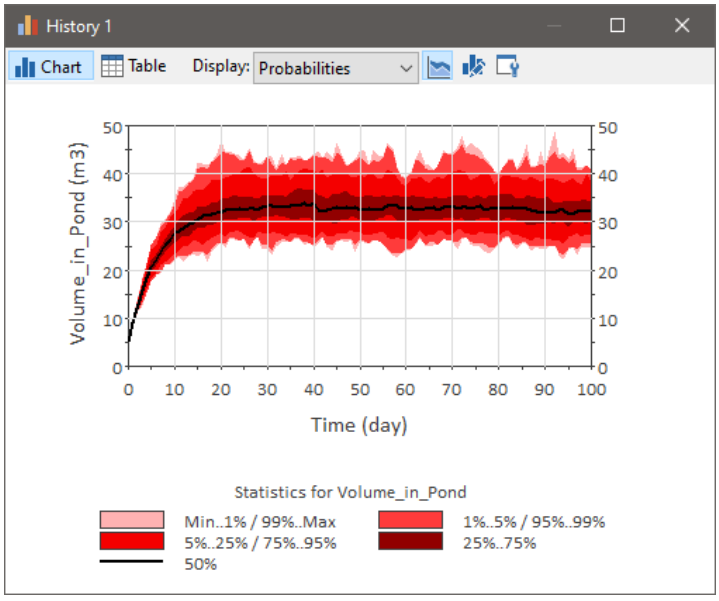


Read more: Viewing Custom Statistics for Multiple Realizations (page 627).

Note: The first time that a Time History Result element is displayed, it will display Probabilities (the default). However, when viewing a Time History Result element, the element "remembers" the last type of display that was selected, and shows that when you double-click on it the next time.

Viewing Probability Histories for Multiple Realizations

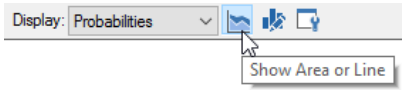
If you have saved multiple realizations for one or more outputs (by referencing them in a time History Result element), by default, a ***probability histories*** display will be shown:

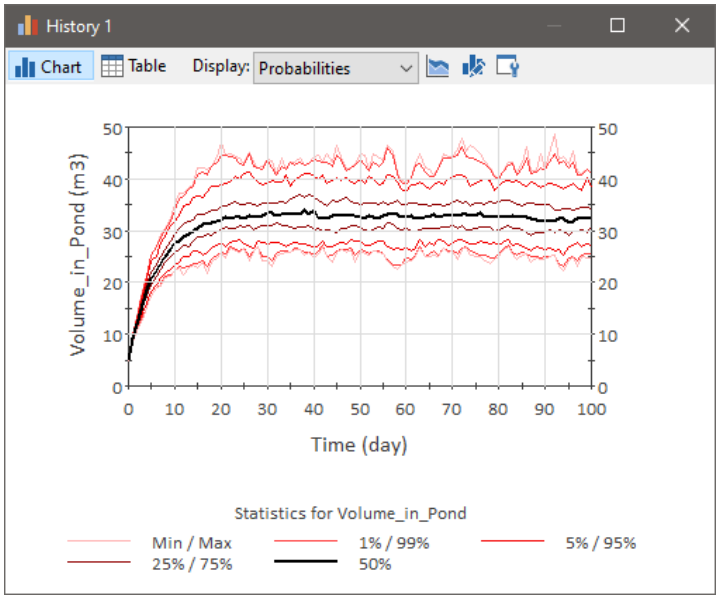


Note: The first time that a Time History Result element is displayed, it will display Probabilities (the default). However, when viewing a Time History Result element, the element "remembers" the last type of display that was selected, and shows that when you double-click on it the next time.

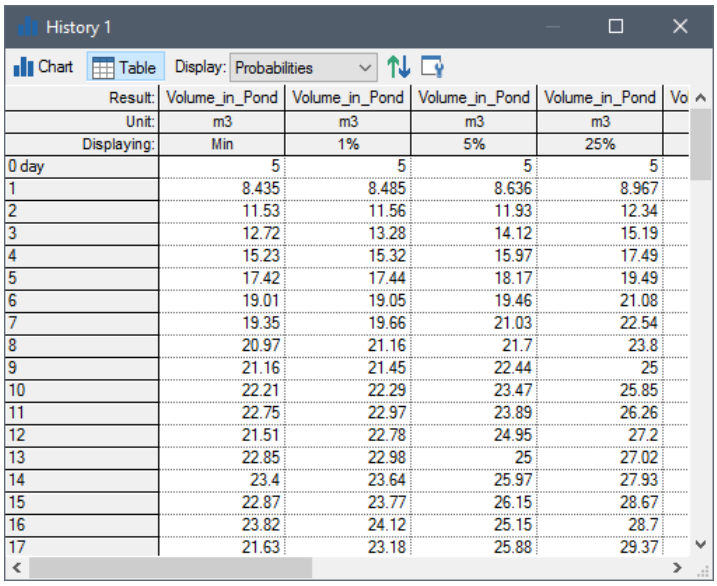
A probability histories display provides a probabilistic representation of the time history of the output. In particular, the multiple realizations of the time history are represented by plotting (or tabulating) the percentiles (as well as the bounds and mean) of the set of time histories for the output.

By default, the areas between the percentile curves are filled. You can show just the lines by clicking the **Show Area or Line** button at the top of the chart:





A table looks like this:



Result:	Volume_in_Pond	Volume_in_Pond	Volume_in_Pond	Volume_in_Pond	Vo
Unit:	m3	m3	m3	m3	
Displaying:	Min	1%	5%	25%	
0 day	5	5	5	5	
1	8.435	8.485	8.636	8.967	
2	11.53	11.56	11.93	12.34	
3	12.72	13.28	14.12	15.19	
4	15.23	15.32	15.97	17.49	
5	17.42	17.44	18.17	19.49	
6	19.01	19.05	19.46	21.08	
7	19.35	19.66	21.03	22.54	
8	20.97	21.16	21.7	23.8	
9	21.16	21.45	22.44	25	
10	22.21	22.29	23.47	25.85	
11	22.75	22.97	23.89	26.26	
12	21.51	22.78	24.95	27.2	
13	22.85	22.98	25	27.02	
14	23.4	23.64	25.97	27.93	
15	22.87	23.77	26.15	28.67	
16	23.82	24.12	25.15	28.7	
17	21.63	23.18	25.88	29.37	

Each statistic is displayed in a different column.

By default, GoldSim plots the following pairs of percentiles when displaying probability histories:

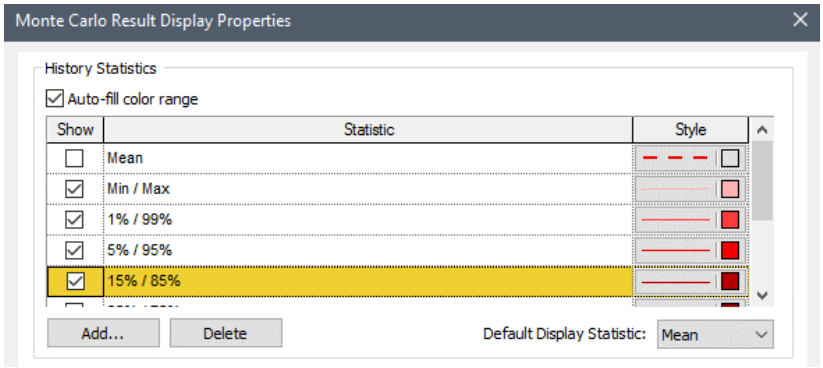
- Min/Max (0%/100%)
- 1%/99%
- 5%/95%
- 15%/85%
- 25%/75%
- 35%/%65
- 45%/%55

It also plots the median (50th percentile). The mean is off by default.

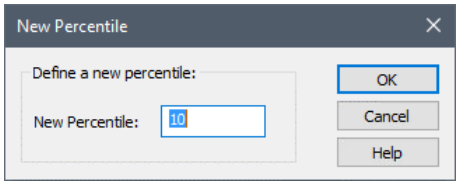
You can customize which of these statistics you would like to plot, as well as add some of your own. You can do so via the Monte Carlo Result Display dialog (accessed via the **Options**… button in the Result Properties dialog).

Read more: Controlling Monte Carlo Result Options (page 500).

The top of this dialog looks like this:



You can activate or deactivate a particular line (or pair of lines) by clicking in the checkbox to the left of the item. You can add new percentile pairs by pressing the **Add…** button. The following dialog is displayed.



You need to only type in one item of a pair (as a percentage, *not* a fraction), and the complementary item will also be added. For example, if you enter 10, both the 10^{th} and 90^{th} percentiles will be added.

You can subsequently remove any percentile pairs using the **Delete** button.

Note: There must be a minimum of two statistics selected: the Mean or Median (50%), and at least one percentile pair.

Warning: You should only view particular percentiles if you have run a sufficient number of realizations such that that statistic can be accurately estimated. As a general rule of thumb, in order to view the Xth percentile (where X is the lower number of the pair, expressed as a fraction), at least 5/X realizations should be available. For example, in order to view the 10th (and 90th) percentile, at least 5/0.1 = 50 realizations should be available. GoldSim does not enforce this limitation automatically (it will try to display any percentiles that you select regardless of the number of realizations available). However, you should manually adjust the percentiles that you choose to view based on the number of realizations available.

Note: The percentiles are truncated at the actual least and greatest values for each timestep. In the absence of importance sampling, these will correspond to probability levels of 1/2N and 1- 1/2N, respectively. For example, if you run 10 realizations, any percentile line below the 5^{th} percentile will be coincident with the 5^{th} percentile.

Note: The manner in which statistics are computed for Time History results is different from how they are computed for Final Value and Distribution results. In particular, Final Value and Distribution results carry out more sophisticated calculations (e.g., values at the tails are extrapolated) in an effort to provide more accurate results (these calculations are described in detail in Appendix B). In general, such differences would only be noticeable when running a small number of realizations.

For each statistic, you select a **Style** for the line and fill color used for the chart. By default, the **Auto-fill color range** option is checked. This option makes it easy to quickly create color gradients for the Styles. Whenever you select one

of the **Styles** (and change a color), GoldSim auto-generates colors for the other statistics to create a logical gradient (e.g., if you select red, all the other statistics will be changed to shades of red). If you want to select your own colors for each statistic, you must clear the **Auto-fill color range** option.

Note: Autofill does not apply to the Mean and the Median (50%). These can be edited separately without affecting the color gradient.

Read more: Using and Managing the Color Palette (page 437).

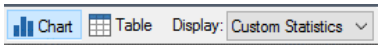
The following additional points should be noted regarding displaying probability histories:

- When you select Mean, GoldSim will also display the Standard Deviation (SD) in tables. However, the SD does not appear in charts.
- All of the information specified in the Monte Carlo Result Display dialog (i.e., the percentiles to display and the styles) is saved with the model and are applied to all probability history displays in the model.
- If the Time History Result element contains multiple outputs and/or an array, the display window provides a field for selecting a single result to be displayed when probability histories are selected.

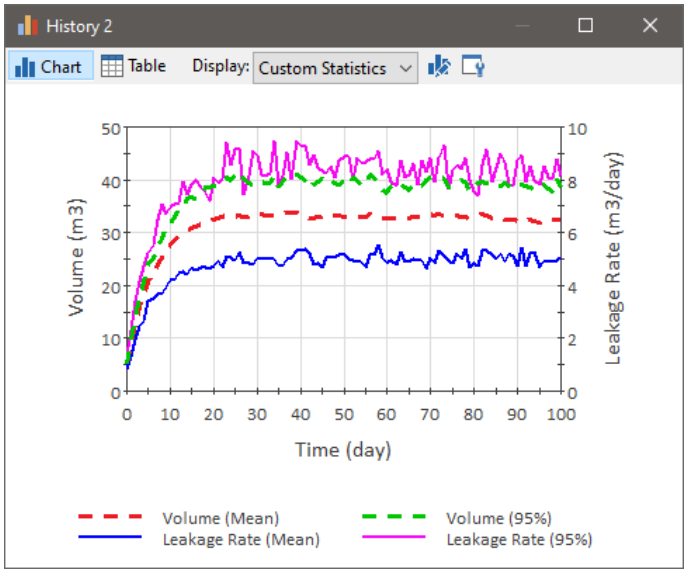
  Read more: Viewing Time Histories of Multiple Realizations for Multiple Outputs (page 628); Viewing Time Histories of Multiple Realizations for an Array (page 629).

Viewing Custom Statistics for Multiple Realizations

If you have saved multiple realizations for one or more outputs (by referencing them in a time History Result element) one of the display options is to show **Custom Statistics**:



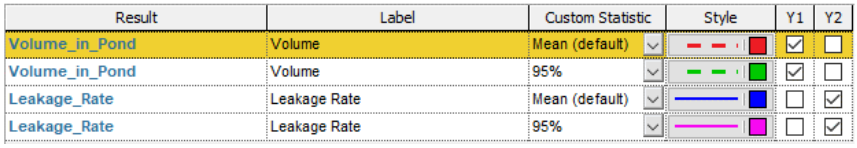
The Custom Statistic option is valuable if you want to display different statistics for different outputs, or several different statistics for the same output:



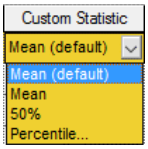
Note that the legend displays the result and the statistic being displayed.

Note: The first time that a Time History Result element is displayed, it will display Probabilities (the default). However, when viewing a Time History Result element, the element "remembers" the last type of display that was selected, and shows that when you double-click on it the next time.

The Custom Statistic that is shown for a particular result is specified in the Result Properties dialog:



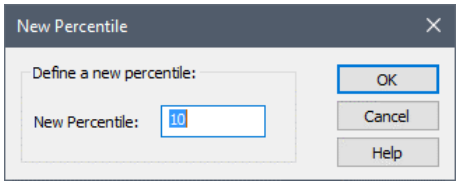
There is a default custom statistic provided in the list:



The default statistic that is shown is defined (and can be changed) in the Monte Carlo Result Display dialog (accessed via the **Options…** button in the Result Properties dialog).

Read more: Controlling Monte Carlo Result Options (page 500).

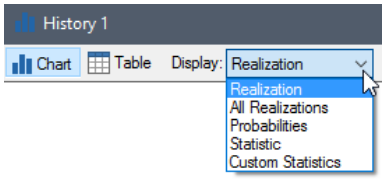
Pressing the **Percentile…** button allows you to define a specific percentile:



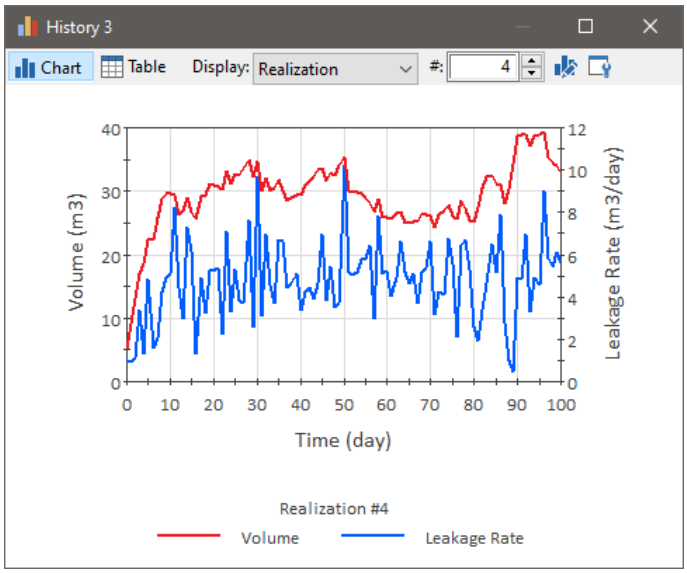
The Custom Statistic option is valuable if you want to display different statistics for different outputs, or several different statistics for the same output.

Viewing Time Histories of Multiple Realizations for Multiple Outputs

If you choose to display a time history of multiple realizations for multiple outputs, what is shown is a function of what has been selected from the Display list:

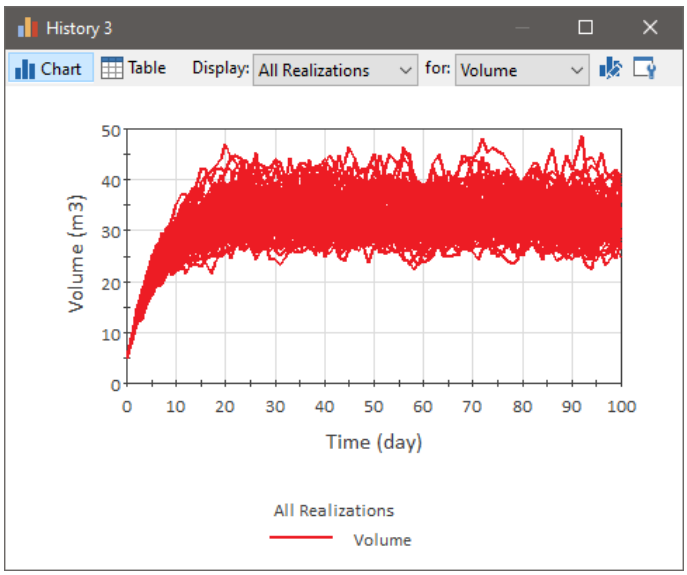


In particular, if **Realization**, **Statistic** or **Custom Statistics** is selected, GoldSim shows the selected result for each output in the list:



This is possible because in these three cases, there is only one set of results to display for each output (e.g., the selected realization for each output).

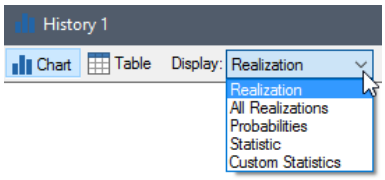
However, if **All Realizations** or **Probabilities** is selected, only one output (result) can be viewed at a time, and it is necessary to select which output you wish to view, since these two displays require multiple sets of results for each output (e.g., all realizations for a selected output):



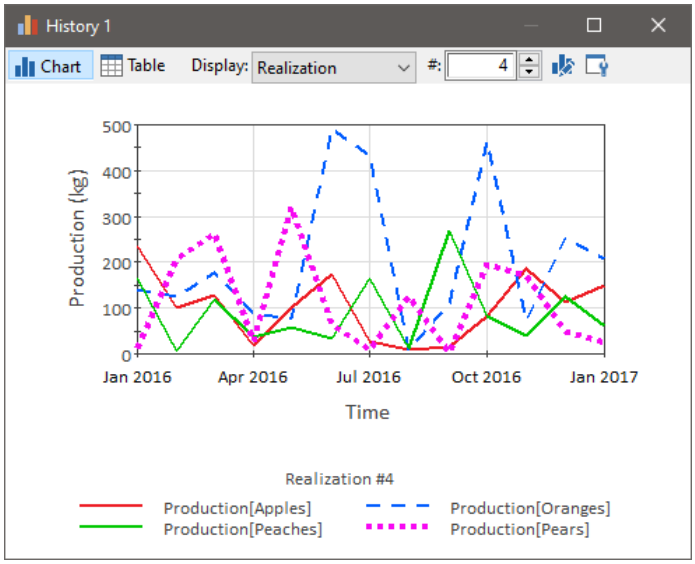
The result that is displayed is selected directly to the right of the **Display** list (after "**for**"). In the example above, the result named "Volume" has been selected.

Viewing Time Histories of Multiple Realizations for an Array

If you choose to display a time history of multiple realizations for an array, what is shown is a function of what has been selected from the Display list:



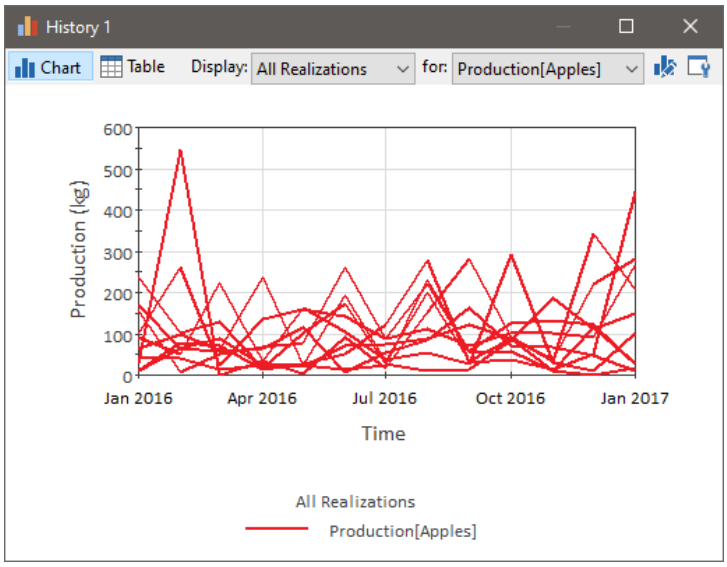
In particular, if **Realization**, **Statistic** or **Custom Statistics** is selected, GoldSim shows the selected result for each item of the array:



In this example, the vector consists of 4 items (Apples, Peaches, Oranges and Pears).

This is possible because in these three cases, there is only one set of results to display for each array item (e.g., the selected realization for each item).

However, if **All Realizations** or **Probabilities** is selected, only one array item can be viewed at a time, and it is necessary to select which item you wish to view, since these two displays require multiple sets of results for each item (e.g., all realizations for a selected item):



The item that is displayed is selected directly to the right of the **Display** list (after "**for**"). In the example above, the result named "Production[Apples]" (i.e., the item named "Apples" from the output "Production") has been selected.

Viewing Reporting Period-Based Results in Time History Result Elements

In some cases, you need to display *accumulated*, *average*, the *change* or the *rate of change* of values over specified periods (e.g., monthly, annually). For example, you may need to report the cumulative amount of money or water that moved from one point to another each month.

To support this, GoldSim allows you to define Reporting Periods. Scheduled updates (timesteps) are created at the end of each Reporting Period. Hence, these can also be thought of as "Reporting Steps". However, whereas results saved at Basic Steps always represent instantaneous values, results saved at Reporting Periods can not only be displayed as instantaneous results, but can also report accumulated, averaged, the change or the rate of change of values over a specified period (e.g., monthly).

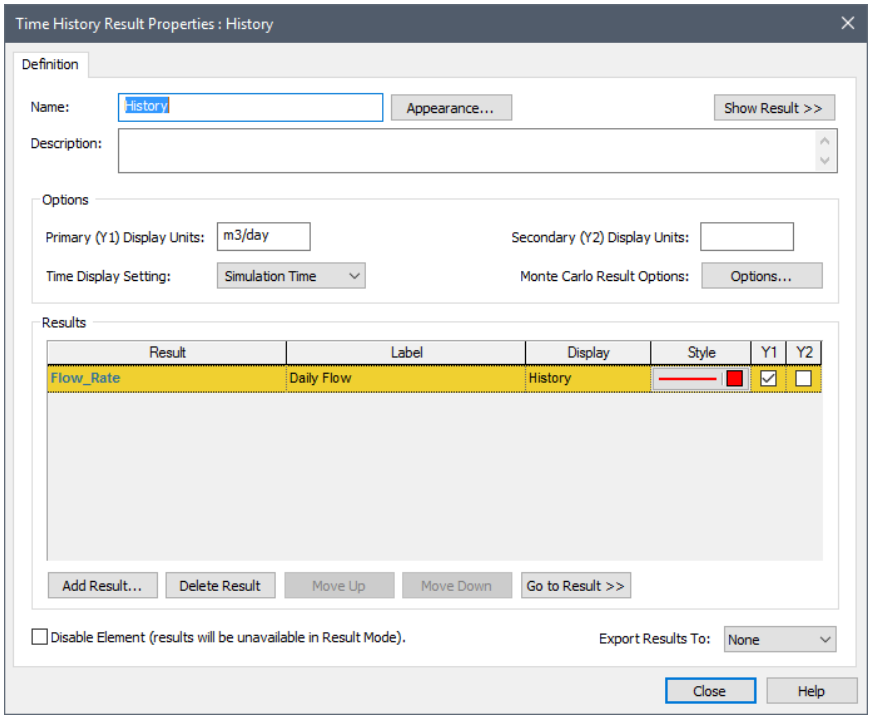
Read more: Defining Reporting Periods (page 479).

Results based on Reporting Periods (e.g., cumulative values over each period, average values over each period, etc.) can be accessed and viewed via Time History Result elements.

It is important to understand that the act of creating Reporting Periods does not in itself provide specialized Reporting Period-based results (e.g., accumulated or averaged results). This is because Reporting Periods by default simply provide another way to define timesteps, since as noted above, scheduled updates (timesteps) are created at the end of each Reporting Period. By default, Time History results simply provide instantaneous values at each timestep (and hence, if Reporting Periods are defined, at the end of each period).

To display specialized Reporting Period-based results, you must add the outputs you are interested in to a Time History Result element, and then specify that you want to view Reporting Period-based results.

By default, the dialog for a Time History Result element looks like this:

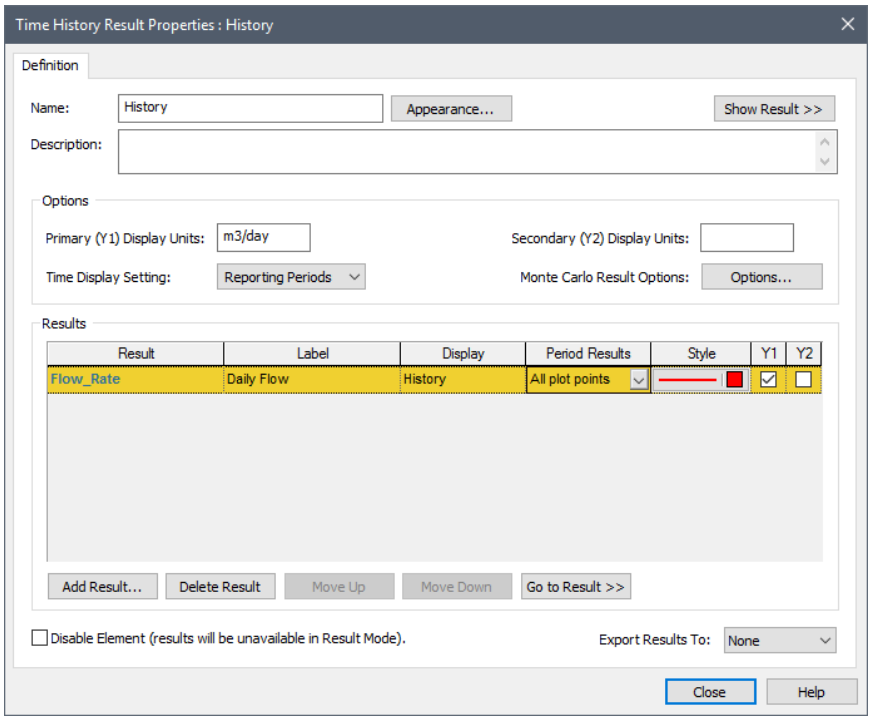


Note: For multiple realization runs, the **Display** column is replaced with **Custom Statistic**.

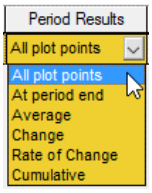
Read more: Viewing Time Histories of Multiple Realizations (page 620).

In particular, note that by default, the **Time Display Setting** in this dialog is set to "Simulation Time". In this case, Time History results simply provide instantaneous values at each timestep (and hence, if Reporting Periods are defined, at the end of each period).

If you have defined Reporting Periods, you can select "Reporting Periods" for the **Time Display Setting**. When you do so, the Result Properties dialog looks like this:



Note that a new column has been added, titled **Period Results**. This is a drop-list that allows you to select results based on Reporting Periods. The list consists the following options:



- **All plot points**: This displays instantaneous values at all the plot points (scheduled updates). This would include not only values at the end of each Reporting Period, but also values at all other scheduled updates (e.g., Basic Steps). This display is identical to what you would see if you selected "Simulation Time" for the **Time Display Settings**. Note, however, that the values of all plot points only appear in charts. In tables, only values at the end of each Reporting Period are shown.

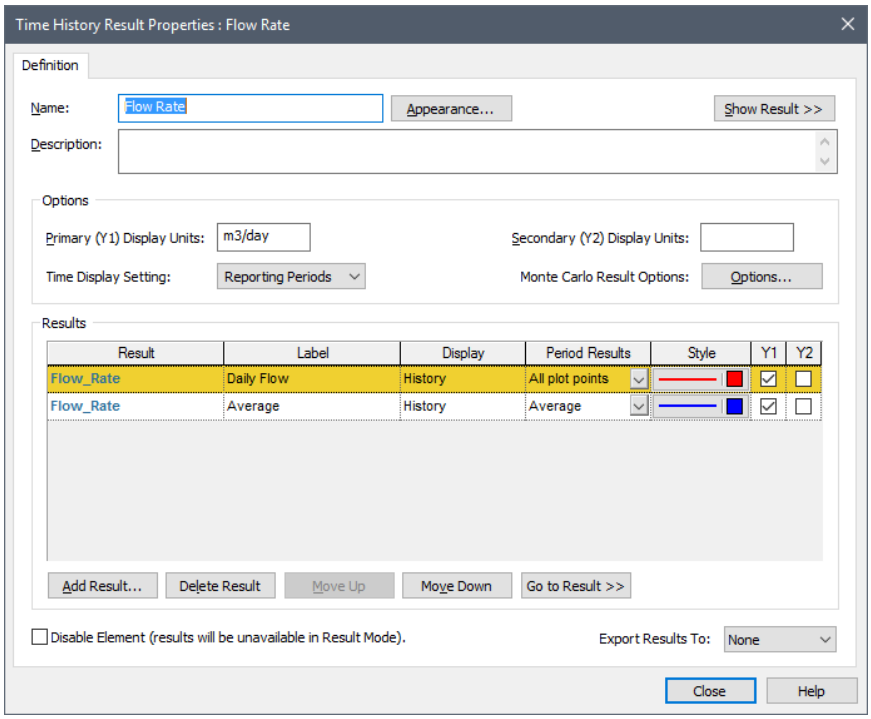
- **At period end**: This displays instantaneous values at at the end of each Reporting Period. It is the default.
- **Average**: This computes the average value for each Reporting Period. For example, if you had a Basic Step of 1 day, a monthly minor Reporting Period and annual major Reporting Period, GoldSim would display either monthly or annual averages (you select in the display window which to show).
- **Change**: This computes the change in the value over each Reporting Period (the difference between the value at the end of the current Reporting Period and the value at the end of the previous Reporting Period).
- **Rate of Change**: This computes the rate of change in the value over each Reporting Period (from the end of the previous Reporting Period to the end of the current Reporting Period). That is, it is the Change (defined above) divided by the length of the Period. It has dimensions of X/Time, where X is the dimensions of the actual output.
- **Cumulative**: This computes the integral of the value over each Reporting Period (from the end of the previous Reporting Period to the end of the current Reporting Period). It has dimensions of X*Time, where X is the dimensions of the actual output. This would typically be used in cases where the output was a rate (e.g., m^3/day), such that the cumulative value represents the quantity (e.g., m^3) that flowed or accumulated over the period.

Note: Most spreadsheet models implicitly compute *accumulated* values (e.g., cumulative flows) over a step. Hence, if you want to compare GoldSim with a spreadsheet model, you should use Reporting Periods to define your steps, and view the Cumulative result.

Note: If your result is a condition, only two of the Period Result types are applicable: "All plot points" and "At period end". Hence, these are the only two choices in the drop-list.

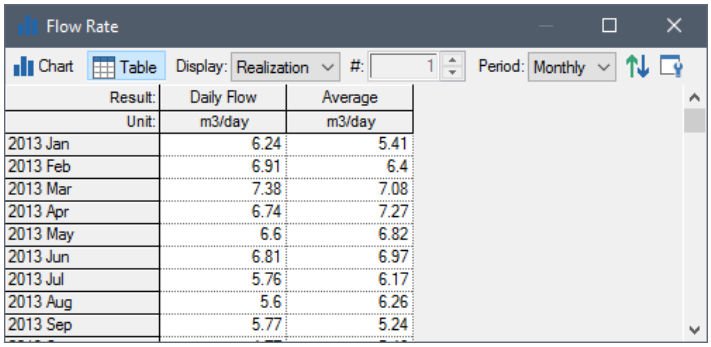
Note: In order to display most types of Reporting Period results, you must add the result to the Result Properties dialog *before* you run the model (i.e., while you are in Edit Mode). This is because they are actually computed "on the fly" as the model is running (e.g., the Cumulative option integrates values during the simulation). Hence, if you try to add a result to a Time History Result element with a **Time Display Setting** of "Reporting Periods" while in Result Mode, the only available Reporting Period options are "All plot points" and "At period end".

To understand the use of Reporting Period-based results, it is instructive to view an example. In the example below, the same output (Flow_Rate) is added to the Result element twice:



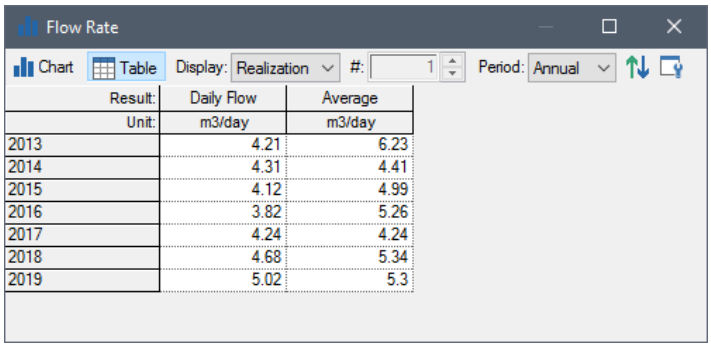
In this particular model, a daily Basic Step has been defined, along with a Major (annual) and minor (monthly) Reporting Period. The first item in the list instructs GoldSim to display the instantaneous value of the output at all plot points. The second item in the list instructs GoldSim to display the average value of the output over the Reporting Period.

If you have defined both a Major Period and a Minor Period, you must specify which Period to display when viewing results. In this example, you would need to select whether you wish to display monthly or annual averages at the top of the display. In this case the monthly values are being shown:



Result:	Daily Flow	Average
Unit:	m3/day	m3/day
2013 Jan	6.24	5.41
2013 Feb	6.91	6.4
2013 Mar	7.38	7.08
2013 Apr	6.74	7.27
2013 May	6.6	6.82
2013 Jun	6.81	6.97
2013 Jul	5.76	6.17
2013 Aug	5.6	6.26
2013 Sep	5.77	5.24

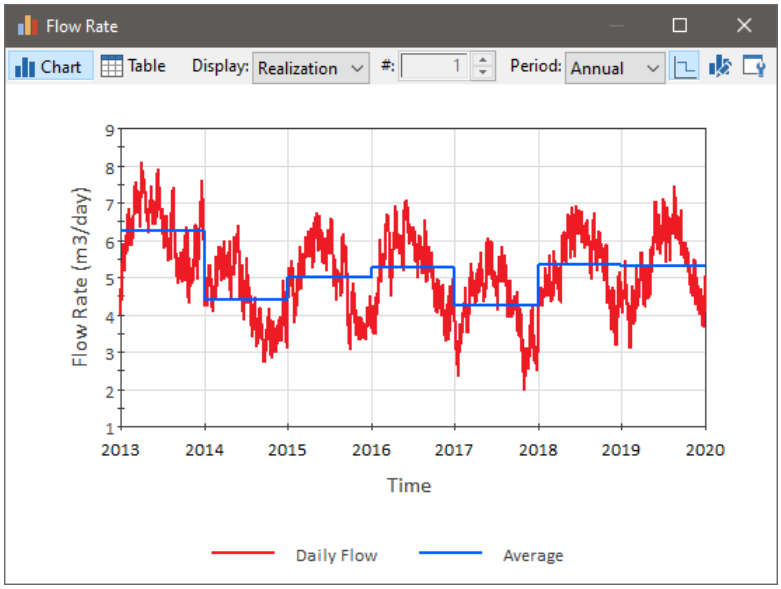
In this case the annual values are being shown:



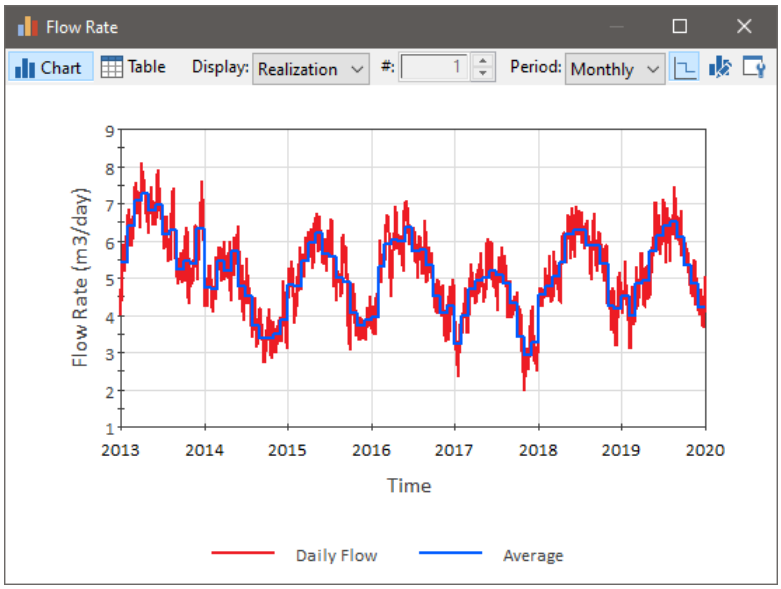
Result:	Daily Flow	Average
Unit:	m3/day	m3/day
2013	4.21	6.23
2014	4.31	4.41
2015	4.12	4.99
2016	3.82	5.26
2017	4.24	4.24
2018	4.68	5.34
2019	5.02	5.3

Note that the table only displays results corresponding to the actual reporting periods (even though the first item, labeled "Daily Flow" here, was selected to display "All plot points" in the Properties dialog). Hence, in this table, the column labeled "Daily Flow" displays the instantaneous values at the *end* of each period, while the column labeled "Average" displays the average values over each period. As will be shown below, however, when "All plot points" is selected for an item, all points are displayed in a chart.

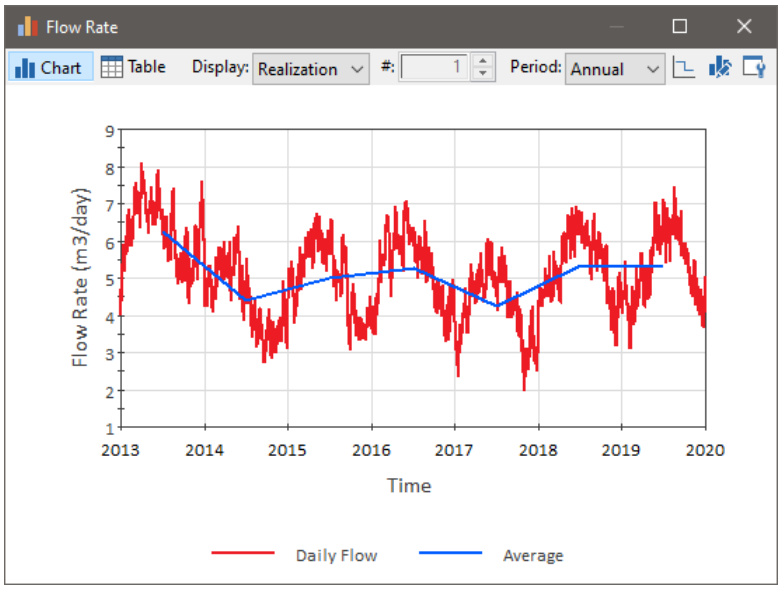
When displaying charts of Reporting Period-based results, you must specify how you would like the values to be plotted. This is because, for four of the result types (Average, Change, Rate of Change and Cumulative), the results actually apply for an *entire period* (as opposed to the end of the period). To represent this, GoldSim provides two options for plotting these results, illustrated in the examples below. In these examples, the Daily Flow and the Average are displayed on the same chart:



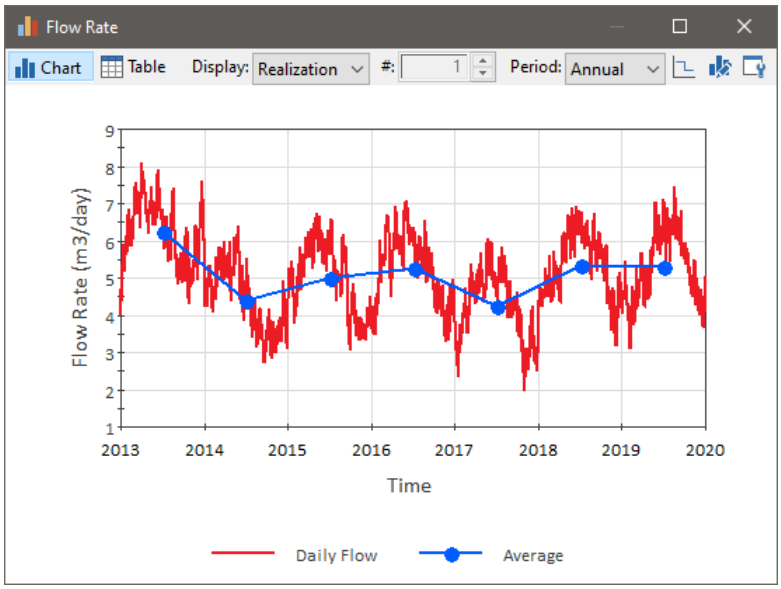
In this case, the major (annual) Reporting Period Average is plotted as a horizontal line over the period (a stair-step). Here is the same plot displaying the minor (monthly) Reporting Period results:



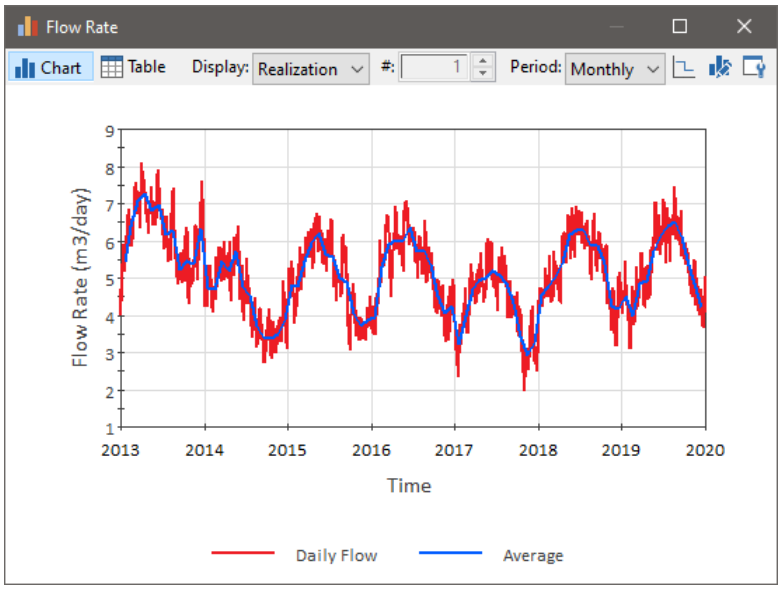
Alternatively, the plot can be displayed like this (these are showing annual results again):



In this case, the major (annual) Reporting Period Average is plotted as a line connecting the **mid-point** of each period (this can be seen better by changing the style to add a symbol at each data point):



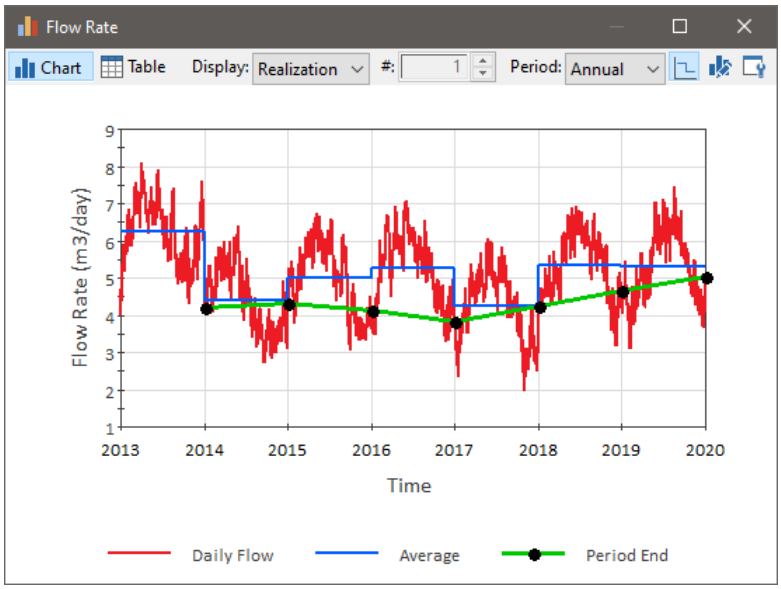
Here is the same plot (without the symbols) displaying the minor (monthly) Reporting Period results with lines drawn between mid-points:



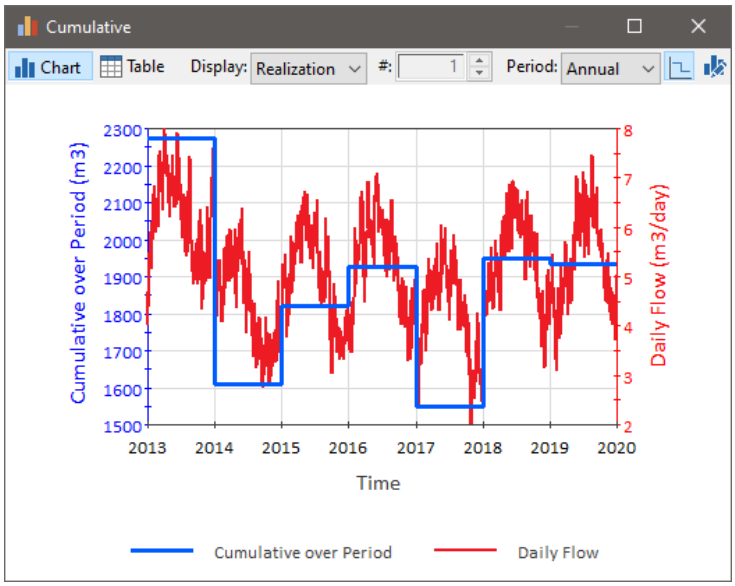
The type of plot is controlled by this button at the top of the display window:

If the button is pressed, the plot is shown as a stair-step; otherwise it is shown as lines connected the mid-points.

Note that this option (to plot as a stair-step) is only used when you have selected to display Average, Change, Rate of Change or Cumulative Reporting Period-based results. If you select "All plot points", all points are plotted (and connected by lines), as shown in the "Daily Flow" line above. If you select "At period end", the values are plotted at the end of each period (as opposed to the mid-points) plotted (connected by lines):



Note that if you select either "Cumulative" or "Rate of change", and you simultaneously select any of the other result types, the Y2 axis must also be used, since the dimensions of the result are different from that of the output:



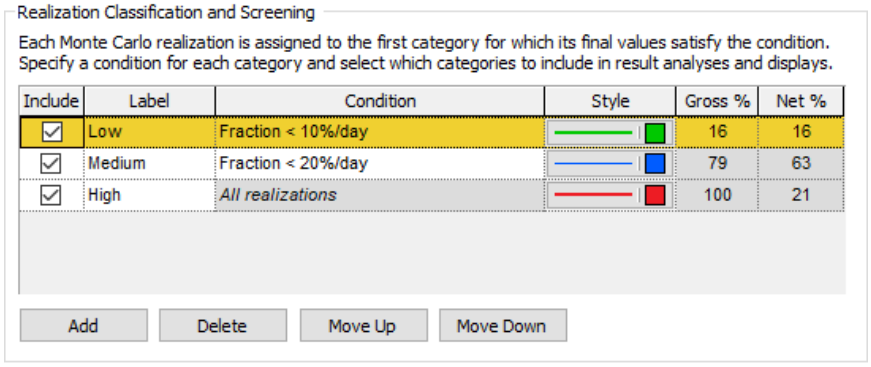
A simple example file illustrating Reporting Periods (ReportingPeriods.gsm) can be found in the can be found in the General Examples/ Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Using Result Classification and Screening in Time History Results

When carrying out probabilistic simulations, you may often run hundreds or thousands of realizations. In order to analyze the results, it is often quite useful to classify the realizations into *categories*. A category is simply defined by a condition relating one or more outputs in the model (e.g., those realizations in which the discount rate was above 3.5%; those realizations in which the profit exceeded $1,000,000; those realizations in which the peak concentration was between 1 mg/l and 10 mg/l).

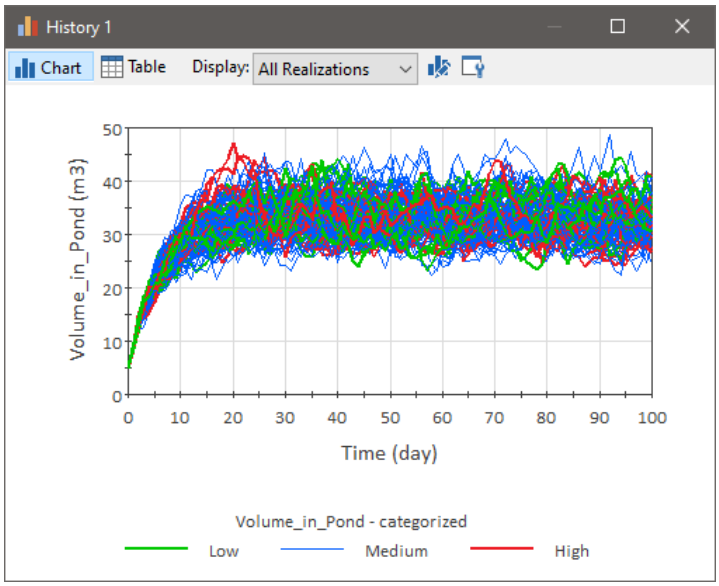
Read more: Classifying and Screening Realizations (page 601).

Classification categories are defined at the bottom of the Monte Carlo Result Display Properties dialog:



This dialog can be accessed from the Monte Carlo tab of the Simulation Settings dialog (via the **Result Options…** button), and is also accessible by pressing the **Options…** button available in the Result Properties dialog of a Time History Result element.

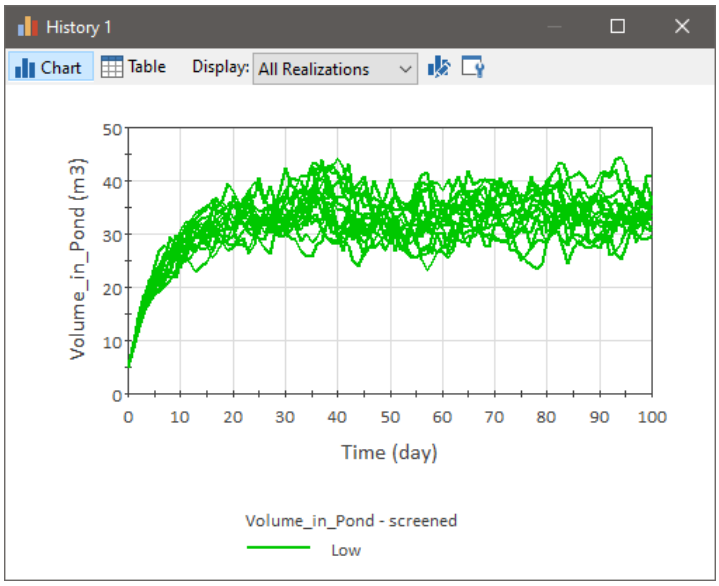
When viewing a Time History result, if 1) you have run multiple realizations; 2) you have defined more than one category; and 3) you are displaying **All Realizations**, GoldSim will label the curves in the Time History Chart based on the categories you have defined:



Read more: Viewing Time Histories of Multiple Realizations (page 620).

In the example shown above, three categories have been defined. The chart is displaying all realizations for a single result, with each curve having a style defined by its category. (Note that for each category, you can edit the **Style** via the Monte Carlo Result Display Properties dialog.)

In addition, screening by category is applied when displaying time histories. That is, if you have chosen to ***screen*** out one or more categories (by clearing the **Include** box in the dialog above), the results (e.g., statistics, realizations) that are shown (in charts and tables) only include those realizations in the categories which you have chosen to include. In the example below, realizations falling into the Medium and High categories have been screened:

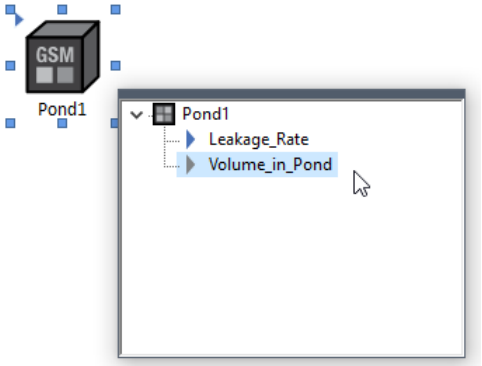


Note that the legend indicates that some categories have been screened out.

Viewing SubModel Results in Time History Result Elements

In most cases, when you add an output to a Time History Result (via the **Add Result…** button in the Result Properties dialog), you will simply be adding a standard output (such as the output of an Expression element or the the primary output of a Reservoir element). However, in one special case, you can add (and view) a specialized output referred to as a Time History Definition output in a Time History Result.

Time History Definition outputs are complex outputs that represent all the information necessary to define a time series. These outputs can be identified when viewing the output port of an element:



In this example, "Volume_in_Pond" is a Time Series Definition Output. Note that the Time History Definition output is highlighted with a gray icon.

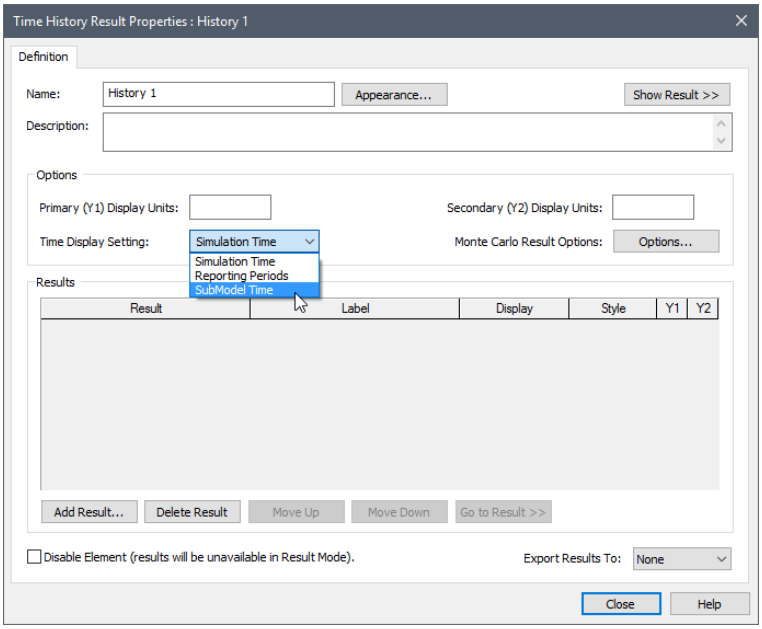
Time Series Definition outputs can be produced by several types of elements, but *only those produced by SubModels can be added to a Time History Result*.

Read more: Using SubModels to Embed Models Within Models (page 1047); Creating the Output Interface to a SubModel (page 1059).

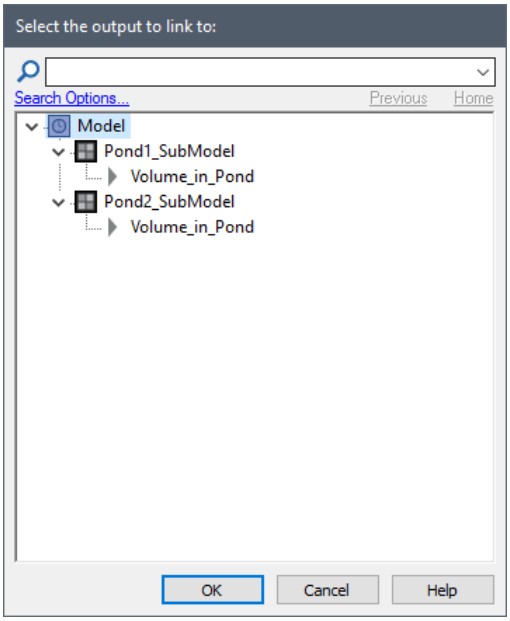
Adding a Time History Definition output of a SubModel to a Time History Result in the parent model provides a mechanism to view the time history results generated by the SubModel directly within the parent model.

In order for SubModel time history results to be displayed in the parent model, you must do the following:

1. Create a Time History Result element in the parent model *before running the model* (i.e., while the model is in Edit Mode).
2. Within the Result Properties dialog, select "SubModel Time" for the **Time Display Setting**:



3. When you do so, this restricts the types of results that can be added via the **Add Result…** button. In particular, when you press this button, you will only be presented with a list of SubModels, and you can only add SubModel Time History Definition outputs:



Several points should be noted:

- You can only add results from a single SubModel. Hence, once you add results from one SubModel, any subsequent results that you add must come from the same SubModel. If you add results from different SubModels, you will not be able to run the model.
- There are three different types of Time History Definition outputs that can be generated by a SubModel (Last Calculated, Statistic History, Realization Histories).

  Read more: Creating the Output Interface to a SubModel (page 1059).

  If you want to plot Realization Histories, it is the only result that can be added to the Result element. If you add multiple results, and one of the results consists of Realizations Histories, you will not be able to run the model.
- The time history results associated with a SubModel can (and typically will) have completely different Time settings than the parent model. When viewing time history results associated with a SubModel in the parent model, these are always based on the Time settings within the SubModel.
- Similarly, the results from a SubModel can (and typically will) have completely different Monte Carlo settings than the parent model. When viewing time history results associated with a SubModel in the parent model, probabilistic results will appropriately reflect the Monte Carlo settings of both the SubModel and the parent model.
- You cannot export time history results (i.e., to a spreadsheet or text file) from a SubModel (i.e., if the **Time Display Setting** in the Result element is "SubModel Time").
- Scenario results are not saved for time history results associated with a SubModel. If a Result element in a parent model is linked to SubModel Time History Definition outputs, no results will be displayed in Scenario Mode.

  Read more: Viewing Scenario Results in Time History Result Elements (page 645).

Note: The Time settings of the parent model have no effect on how time history results associated with a SubModel are plotted in a Time History Result element within the parent model.

As pointed out above, when creating a Time History Definition output for a SubModel, three types of outputs can be specified:

Last Calculated: This represents a single time history of the output for the final realization of the SubModel (which is equivalent to the *only* realization if the SubModel Monte Carlo Settings do not specify multiple realizations).

Statistic: This represents a single time history for a specified statistic (computed over all realizations of the SubModel).

Realization Histories. This is the time history of the output for *all* realizations of the SubModel.

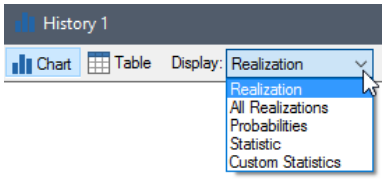
Read more: Creating the Output Interface to a SubModel (page 1059).

The options provided for displaying time history results associated with a SubModel in a Time History Result element within the parent model are a function of the type of Time History Definition output being displayed and the Monte Carlo settings of the SubModel and parent model.

Viewing Last Calculated and Statistic History Results from a SubModel

Due to the manner in which they are defined, "Last Calculated" and "Statistic" Time History Definition outputs produce a single time history for each realization of the parent model (regardless of how many realizations were carried out for the SubModel).

Therefore, the manner in which these results are viewed is identical to how time histories of multiple realizations would be viewed for any other type of output. In particular, when you are viewing time histories of Last Calculated or Statistics for a SubModel output after you have run multiple realizations of the parent model, there are a number of different ways that you can view the results (e.g., view one realization at a time, view all realizations, view a particular statistic). The Display windows provide a number of options that allow you to select how you want to view the results:



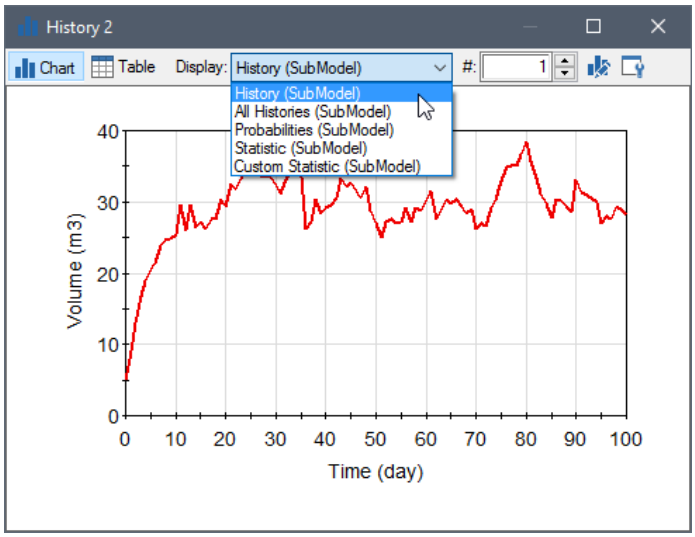
Read more: Viewing Time Histories of Multiple Realizations (page 620).

Note: If only one realization of the parent model is run, only one option (Display Realization or Display History) will be available.

Viewing Realization Histories Results from a SubModel

Viewing "Realization Histories" outputs from a SubModel is considerably more complex than viewing "Last Calculated" and "Statistic" outputs, since "Realization Histories" Time History Definition outputs can produce *multiple* time histories for each realization of the parent model. This is because "Realization Histories" consist of time histories of *all* realizations of the SubModel. For example, if the parent model was run for 100 realizations, and the SubModel was run for 50 realizations, the results being displayed in a Time History Result element within the parent model would be based on 5000 individual time histories (50 * 100).

Fortunately, GoldSim provides some powerful tools to view this complex set of results. To better understand these tools, it is instructive to first understand how such results would be viewed in a simpler case: a model in which the SubModel was run for multiple realizations, but the parent model was run only for a single realization. In such a case, the Result Display (for a chart) would look like this:

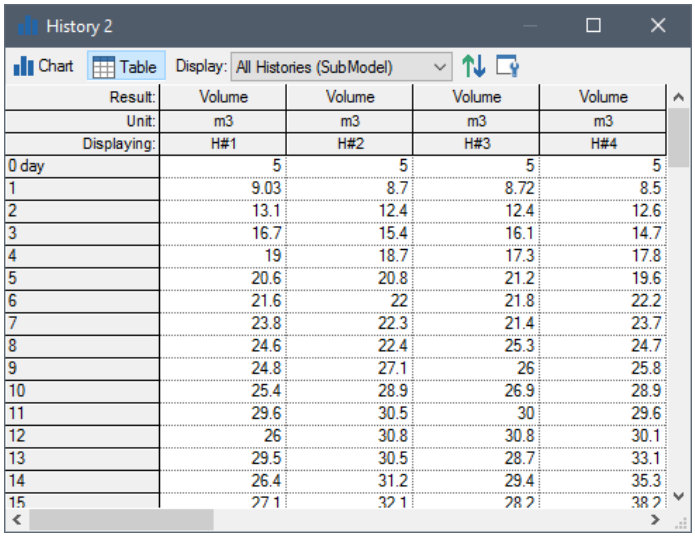


In this particular case, the manner in which these results are viewed is identical to how time histories of multiple realizations would be viewed for any other type of output. The Display windows provide a number of options that allow you to select how you want to view the results.

Read more: Viewing Time Histories of Multiple Realizations (page 620).

Note: If only one realization of the SubModel is run, only one option (Display History) will be available.

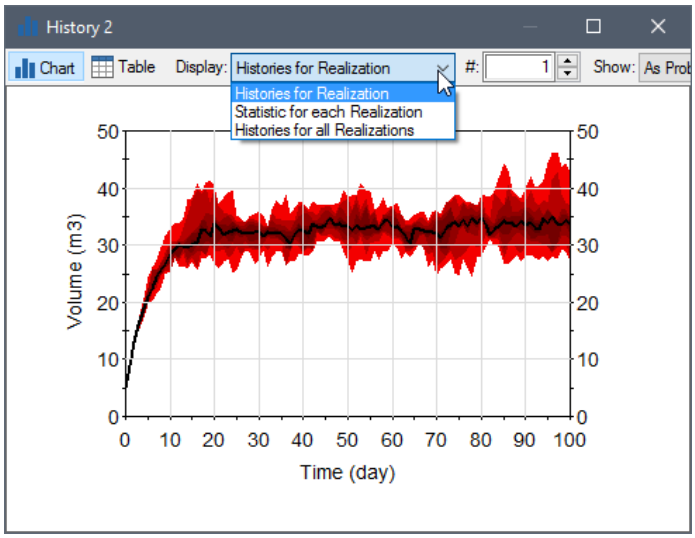
However, there is one very important distinction that is critical to note. This result is not displaying multiple realizations of the parent model (recall that only a single parent model realization was carried out). This result is displaying multiple realizations *from within the SubModel*. That is, although the Result element is located in the parent model, in this particular case, it is displaying the realizations carried out by the SubModel. This is clearly indicated in the Display drop-list by listing "(SubModel)" after each of the five display options. This is also indicated when displaying tables in the manner that the histories are labeled:



Result:	Volume	Volume	Volume	Volume
Unit:	m3	m3	m3	m3
Displaying:	H#1	H#2	H#3	H#4
0 day	5	5	5	5
1	9.03	8.7	8.72	8.5
2	13.1	12.4	12.4	12.6
3	16.7	15.4	16.1	14.7
4	19	18.7	17.3	17.8
5	20.6	20.8	21.2	19.6
6	21.6	22	21.8	22.2
7	23.8	22.3	21.4	23.7
8	24.6	22.4	25.3	24.7
9	24.8	27.1	26	25.8
10	25.4	28.9	26.9	28.9
11	29.6	30.5	30	29.6
12	26	30.8	30.8	30.1
13	29.5	30.5	28.7	33.1
14	26.4	31.2	29.4	35.3
15	27.1	32.1	28.2	38.2

Note that that the various time histories are labeled as H#1, H#2, and so on. For realizations of the parent model, they would be labeled as R#1, R#2, etc. The idea is that H refers to a SubModel "history", while R refers to a parent model "realization".

Result display is more complex when both the parent model and the SubModel are run for multiple realizations (referred to as "nested Monte Carlo simulation"):



As can be seen, multiple options are provided to allow you to view the nested Monte Carlo results. These options are discussed in detail in the section discussing nested Monte Carlo simulation listed below.

Read more: Carrying Out Nested Monte Carlo Simulation Using a SubModel (page 1067).

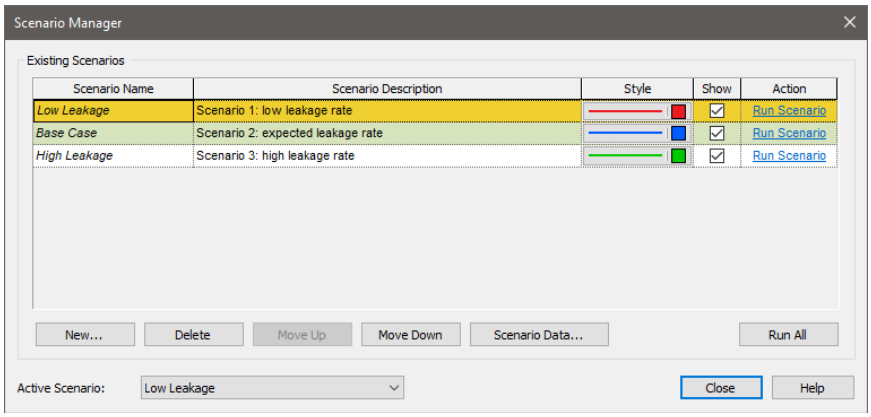
Viewing Scenario Results in Time History Result Elements

GoldSim's scenario modeling capability allows you to directly compare results generated by different sets of input parameters. In effect, when you use this capability, your model can store (and subsequently compare) multiple sets of results (and inputs).

Read more: Creating, Running and Comparing Scenarios (page 525).

When a model is in Scenario Mode, Time History Result elements can be used to view scenario results.

In order for scenario results to be displayed in a Time History Result element, the **Show** button must be checked for each scenario to be displayed in the Scenario Manager (accessed from the main menu (**Run | Scenario Manager…**) or by pressing **F7**):



In this example, the Show box is checked for all three scenarios, so all three will be displayed in results.

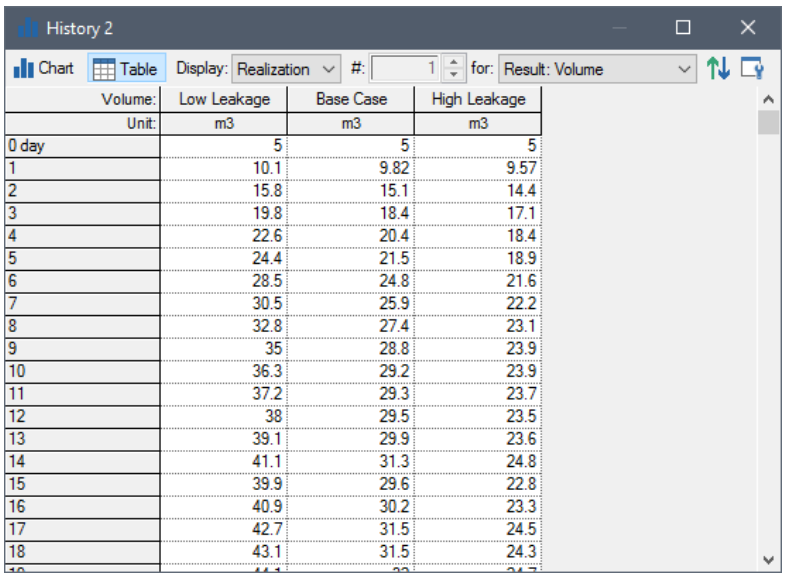
If you double-click on a Time History Result element in Scenario Mode, GoldSim displays results for all scenarios for which scenario results have been generated (and for which the **Show** button has been checked from within the Scenario Manager).

Note that for each scenario, within the Scenario Manager you can edit the **Style**, as well as the **Scenario Name**. These affect how the results are labeled in chart and table displays.

Read more: Controlling the Chart Style in Time History Results (page 658).

The time history display for scenarios differs depending on how the simulation was run (single realization or multiple realizations), what you choose to display (e.g., a statistic or all realizations), and whether the Time History Result element contains multiple results.

In all cases, you can select which results and which scenarios you wish to display. For example, if only a single realization was run (for three different scenarios), the Table display in Scenario Mode would look like this:

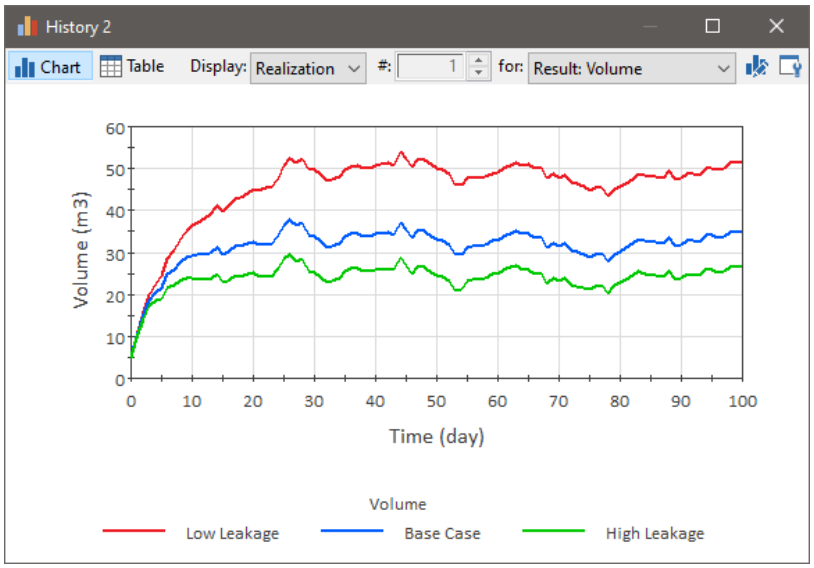


Volume:	Low Leakage	Base Case	High Leakage
Unit:	m3	m3	m3
0 day	5	5	5
1	10.1	9.82	9.57
2	15.8	15.1	14.4
3	19.8	18.4	17.1
4	22.6	20.4	18.4
5	24.4	21.5	18.9
6	28.5	24.8	21.6
7	30.5	25.9	22.2
8	32.8	27.4	23.1
9	35	28.8	23.9
10	36.3	29.2	23.9
11	37.2	29.3	23.7
12	38	29.5	23.5
13	39.1	29.9	23.6
14	41.1	31.3	24.8
15	39.9	29.6	22.8
16	40.9	30.2	23.3
17	42.7	31.5	24.5
18	43.1	31.5	24.3

Read more: Viewing a Time History Table (page 610).

By default, all scenarios are displayed for the first result listed in the Properties dialog for the Result element. Each column then represents a scenario. The result being displayed is indicated in the upper left-hand corner of the table.

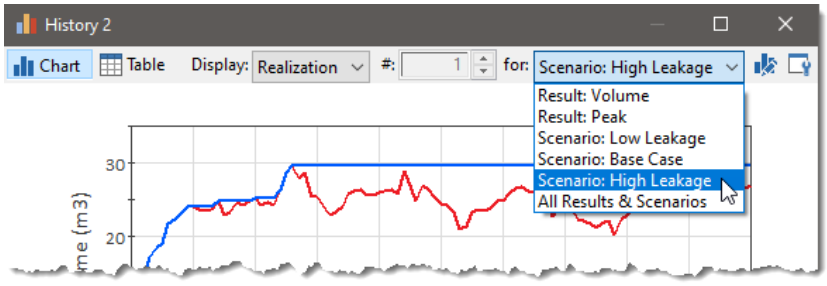
The corresponding chart in Scenario Mode would look like this:



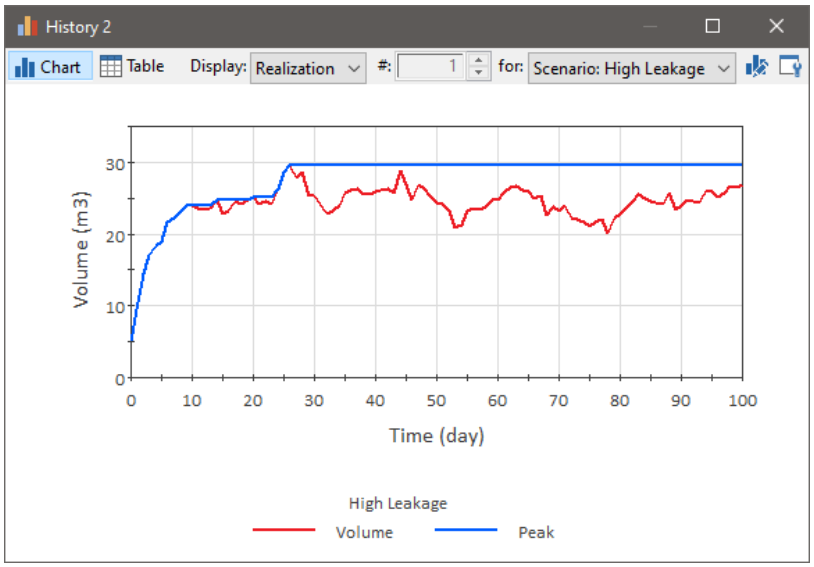
Read more: Viewing a Time History Chart (page 608).

The Scenario Names are shown in the legend. The Result being displayed is indicated in the legend title.

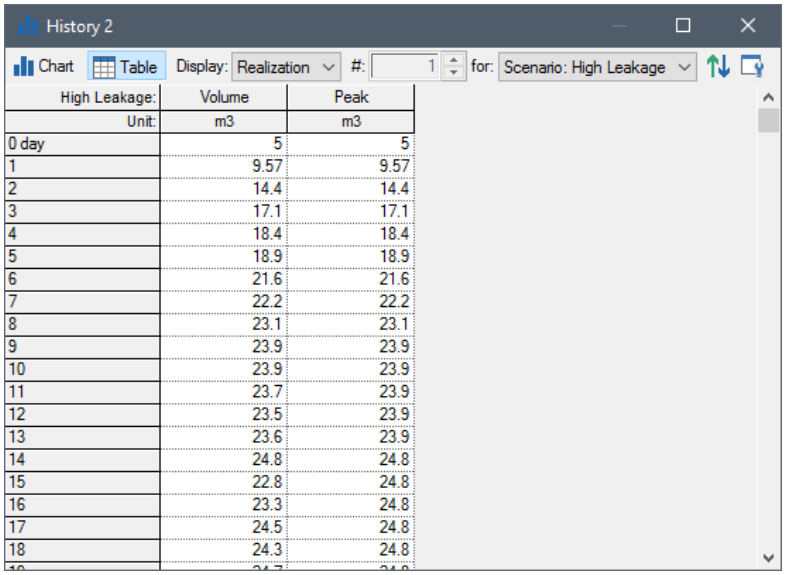
You can specify exactly which scenarios and results you wish to display using a drop-list at the top of the display window. In the example below, there are two results and three scenarios:



Selecting an option prefaced with "Result" displays all the scenarios for that particular result (as shown in the table and chart shown above). Selecting an option prefaced with "Scenario" displays all the results for that particular scenario (as illustrated below):



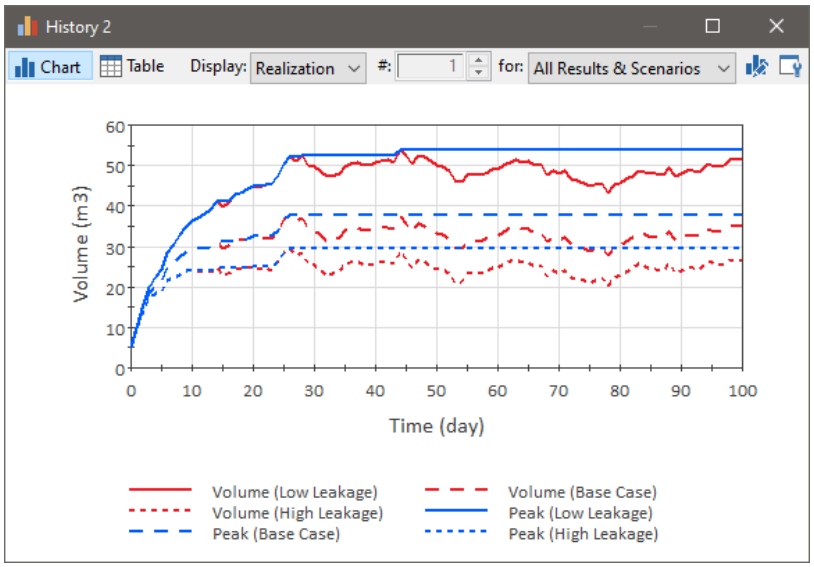
In this example, two different results are shown (Volume and Peak) for the selected scenario (High Leakage). The corresponding Table display would look like this:



High Leakage:	Volume	Peak
Unit:	m3	m3
0 day	5	5
1	9.57	9.57
2	14.4	14.4
3	17.1	17.1
4	18.4	18.4
5	18.9	18.9
6	21.6	21.6
7	22.2	22.2
8	23.1	23.1
9	23.9	23.9
10	23.9	23.9
11	23.7	23.9
12	23.5	23.9
13	23.6	23.9
14	24.8	24.8
15	22.8	24.8
16	23.3	24.8
17	24.5	24.8
18	24.3	24.8

Each column represents a result. The scenario being displayed is indicated in the upper left-hand corner of the table.

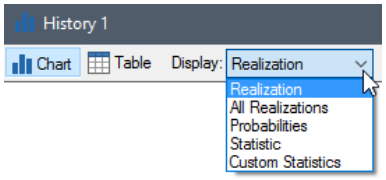
There is also an option to display “All Results & Scenarios”:



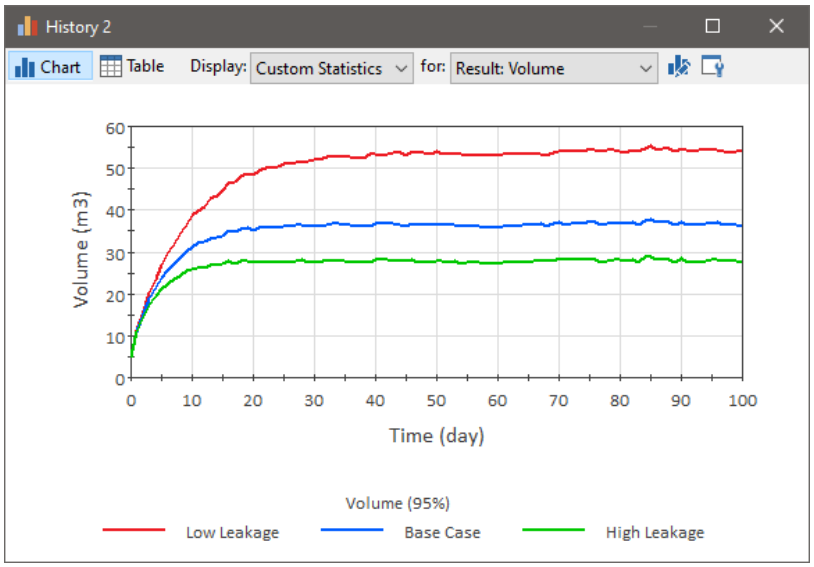
Note: Array results cannot be compared in Scenario Mode. Only scalar results can be displayed. Hence, if an array is listed as one of the results in the Result Properties page, it will not be available for selection in the display dialogs when comparing scenarios (i.e., when the model is in Scenario Mode). If you wanted to compare one or more items from an array in Scenario Mode, you would need to add those scalar array items as separate results in the Result Properties dialog.

Note: Scenario results are only available for results that are added to the Result element before you run a scenario. If you add a result after you run a scenario, scenario results for that output will not be available for that scenario.

If you have run multiple realizations for the various scenarios, what is shown is a function of what has been selected from the Display list:

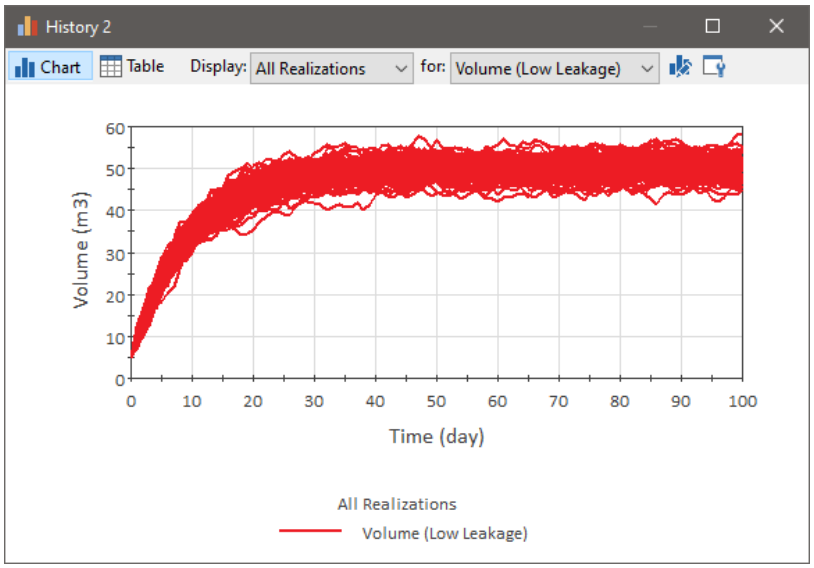


In particular, if **Realization**, **Statistic** or **Custom Statistics** is selected, GoldSim shows the selected result for each scenario:



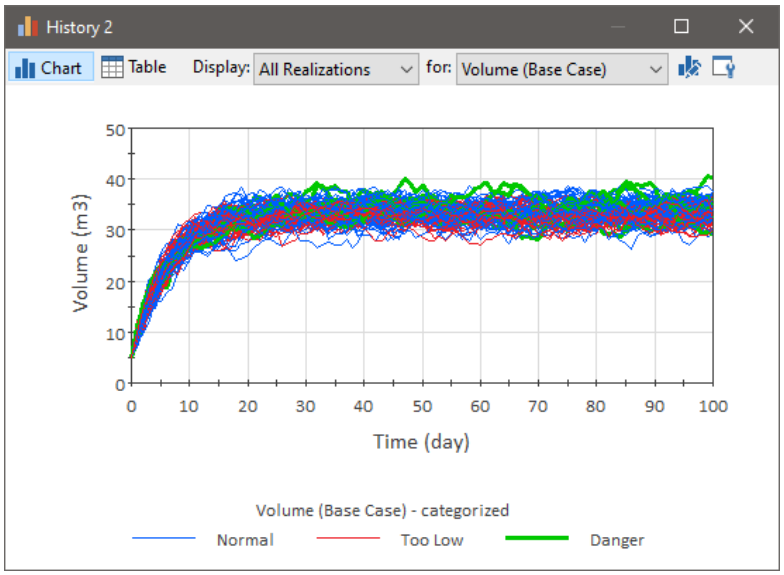
This is possible because in these three cases, there is only one set of results to display for each scenario (e.g., the selected statistic for each output).

However, if **All Realizations** or **Probabilities** is selected, only one scenario can be viewed at a time, and it is necessary to select which scenario (and output if multiple outputs are referenced by the Result element) you wish to view, since these two displays require multiple sets of results for each scenario (e.g., all realizations for a selected scenario and selected output):



The result and scenario that is displayed is selected directly to the right of the **Display** list (after "**for**"). In the example above, the result named "Volume" for scenario "Low Leakage" has been selected.

When viewing a Time History result in Scenario Mode, if 1) you have defined more than one category (defined at the bottom of the Monte Carlo Result Display Properties dialog); and 2) you are displaying **All Realizations** for a multiple realization run, GoldSim will label the curves in the Time History Chart based on the categories you have defined. For example, if your categories were defined as "Normal", "Too Low" and "Danger", a chart with categories might look like this:



Note that the chart is displaying a single result for a single scenario.

In addition, screening by category is active in Scenario Mode. That is, if you have chosen to ***screen*** out one or more categories (by clearing the **Include** box in the dialog above), the scenario results that are shown (in charts and tables) only include those realizations in the categories which you have chosen to include.

Note that depending on how you have defined the categories, it is possible for a realization to fall into a different category in different scenarios. Hence, when screening results in Scenario Mode, the number of realizations within each scenario may differ. In the example below (displayed as a table), realization #18 is included in the first two scenarios, but is screened from the third:

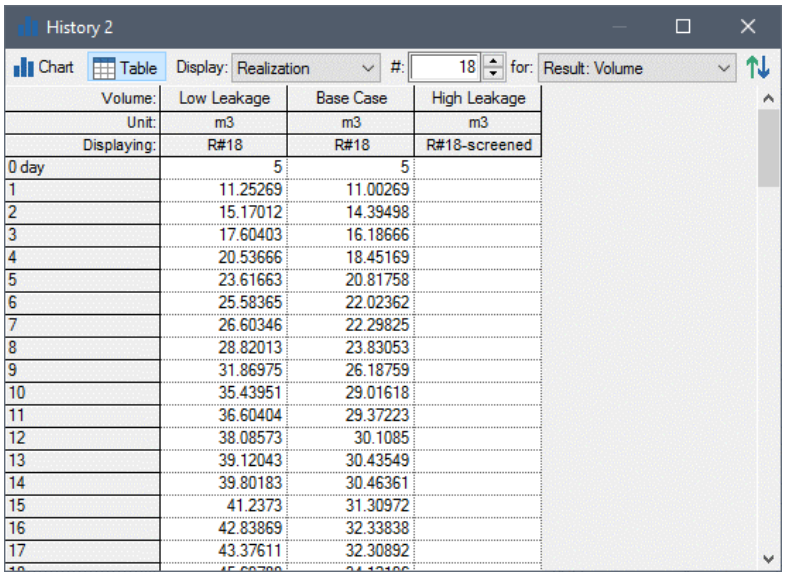

History 2

Chart | Table | Display: Realization | #: 18 | for: Result: Volume

Volume:	Low Leakage	Base Case	High Leakage
Unit:	m3	m3	m3
Displaying:	R#18	R#18	R#18-screened
0 day	5	5	
1	11.25269	11.00269	
2	15.17012	14.39498	
3	17.60403	16.18666	
4	20.53666	18.45169	
5	23.61663	20.81758	
6	25.58365	22.02362	
7	26.60346	22.29825	
8	28.82013	23.83053	
9	31.86975	26.18759	
10	35.43951	29.01618	
11	36.60404	29.37223	
12	38.08573	30.1085	
13	39.12043	30.43549	
14	39.80183	30.46361	
15	41.2373	31.30972	
16	42.83869	32.33838	
17	43.37611	32.30892	

Read more: Using Result Classification and Screening in Time History Results (page 638).

Note: High resolution results (unscheduled updates) are never displayed in Scenario Mode. They are only available in Result Mode. Hence, you cannot view high resolution results when comparing scenario results. When comparing scenarios, only scheduled updates are included in displays.

Read more: Viewing Unscheduled Updates in Time History Result Elements (page 652).

Note: Scenario results are not saved for time history results associated with a SubModel. If a Result element in a parent model is linked to SubModel time history results, no results will be displayed in Scenario Mode.

Read more: Viewing SubModel Results in Time History Result Elements (page 640).

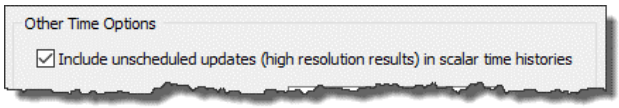
Viewing Unscheduled Updates in Time History Result Elements

In some cases, events or other changes in the model may not fall exactly on a scheduled update. That is, some events or changes may actually occur between scheduled updates of the model. These trigger an "unscheduled update" of the model. Unscheduled updates are timesteps that are dynamically inserted by GoldSim during the simulation in order to more accurately simulate the system.

Read more: Understanding Timestepping in GoldSim (page 473).

Unlike scheduled updates, unscheduled updates do not normally appear in time history plots and tables. That is, although these timesteps may affect the results (e.g., by making them more accurate at the scheduled timesteps), unscheduled updates of the model are not saved and displayed. Only the scheduled updates are actually saved and displayed.

In some cases, however, it may be of interest to see the values of selected outputs at unscheduled updates. To facilitate this, GoldSim provides an option in the Advanced Time settings to save results at unscheduled updates (referred to as "high resolution" results). This option appears at the bottom of the Advanced Time Settings dialog (accessed from the **Advanced…** button on the **Time** tab of the Simulation Settings dialog):

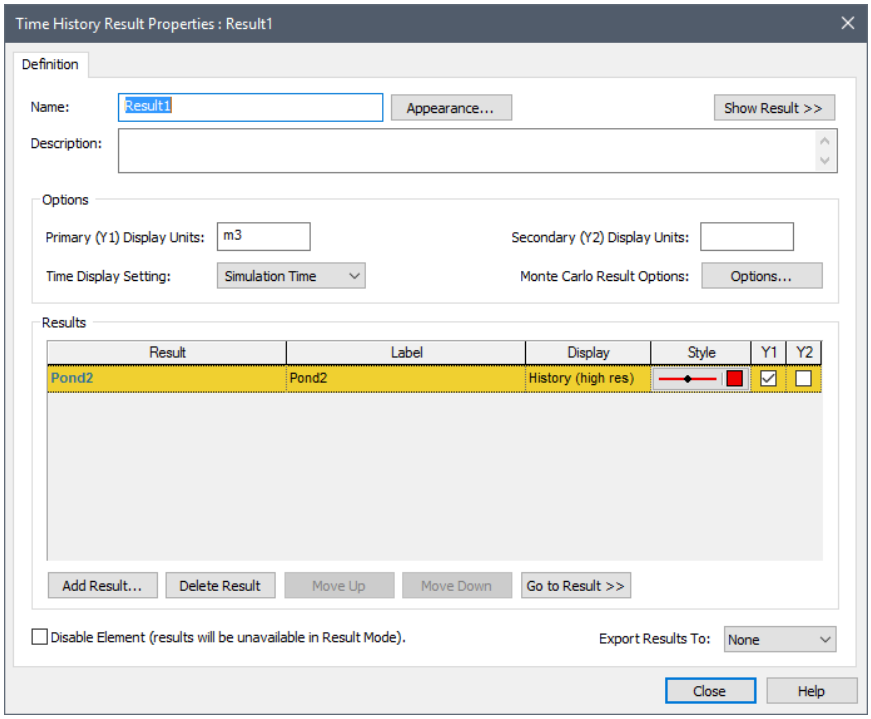


By default, the checkbox labeled **Include unscheduled updates (high resolution results) in scalar time histories** is cleared. If you check this box, GoldSim will save unscheduled updates for time history results (referred to as "high resolution" results) under the following conditions:

- High resolution results can only be viewed from within Time History Result elements. If the output is not referenced by a Time History Result element, high resolution results will not be displayed.
- High resolution results are only available for single realization runs (Deterministic simulations or probabilistic simulation with a single realization).
- High resolution results are only available for scalar outputs.

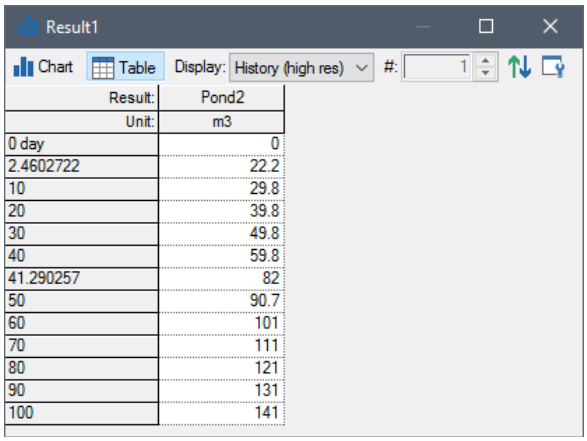
- The **Time Display Setting** in the Result Properties dialog for the Time History Result element must be set to "Simulation Time". High resolution results are not available when viewing Reporting Period-based results.
- High resolution results are only available for results that are added to the Result element before you run the model. If you add a result after you run the model, it will only show results at scheduled updates.

If these conditions are met, and you view a Time History Result element, the Result Properties will look like this:



If all necessary conditions are met, the **Display** column will list "History (high res)", indicating that the Result element will display high resolution results for that output.

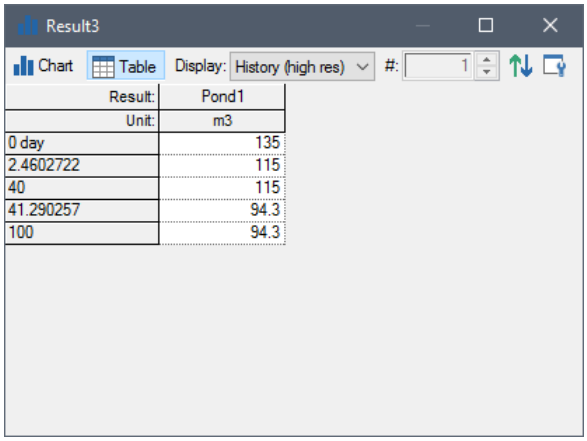
In such a case, the display will include unscheduled updates. In the example below (showing a table display), scheduled updates occur every 10 days (there is a Basic Step of 10 days), but unscheduled updates occur at 2.46 days and 41.29 days:



Result:	Pond2
Unit:	m3
0 day	0
2.4602722	22.2
10	29.8
20	39.8
30	49.8
40	59.8
41.290257	82
50	90.7
60	101
70	111
80	121
90	131
100	141

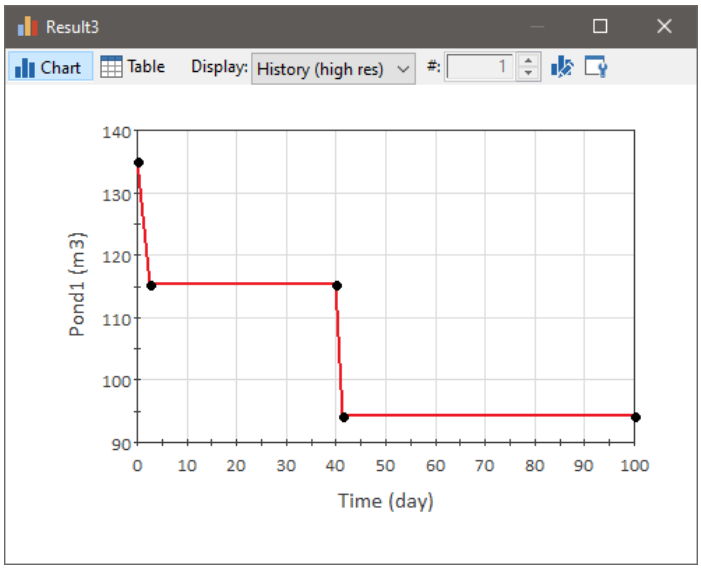
Note that when saving "high resolution" results, to reduce storage requirements, GoldSim does not actually save every unscheduled and scheduled update. Rather, the GoldSim only saves results 1) at each update for which the result is different from the previous update; and 2) the previous update (i.e., the update immediately before the update where the value changed). This information is sufficient to create an accurate chart display. All other updates (representing updates during which the value did not change from the previous value) do not need to be saved.

In the example above, the value is changing continuously. Hence, all scheduled and unscheduled updates must be saved. In the example below, however, the value only changes at unscheduled updates (and remains unchanged in between), and hence there is no reason to save all scheduled updates; only those immediately preceding a change (at an unscheduled update) are saved:



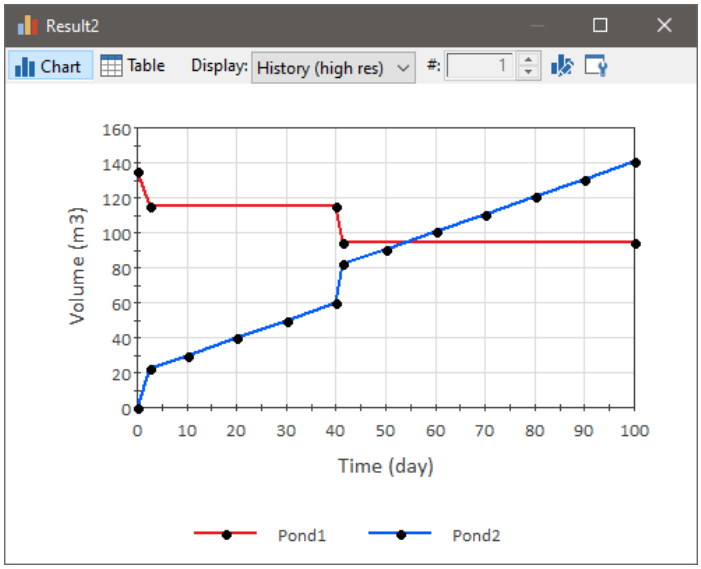
Result:	Pond1
Unit:	m3
0 day	135
2.4602722	115
40	115
41.290257	94.3
100	94.3

The chart corresponding to the table shown above would look like this (symbols are placed at locations where a plot point occurs):



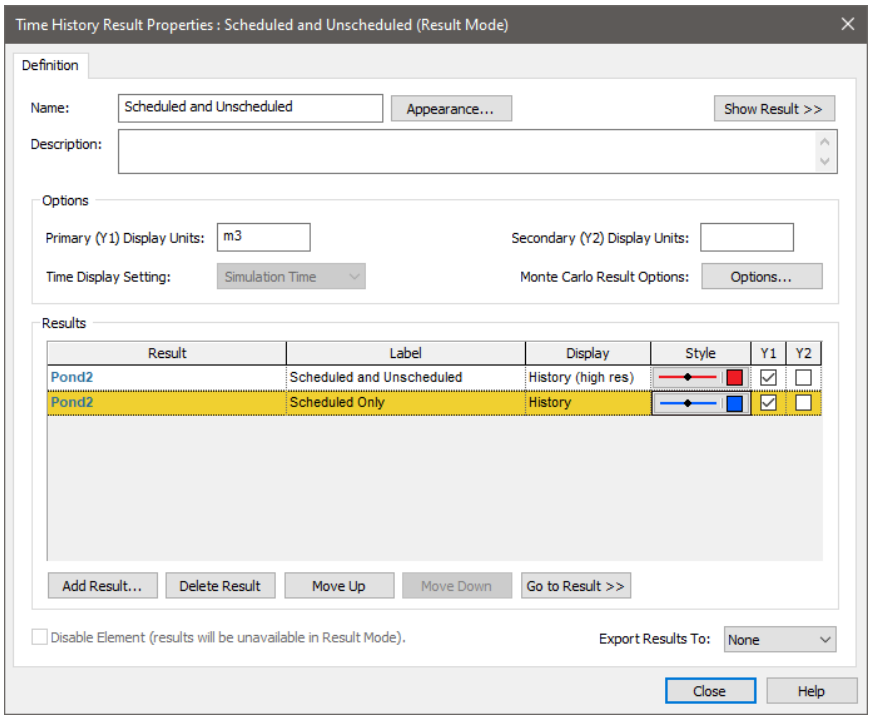
Note that there are no plot points for periods over which the plotted line is horizontal (since the value has not changed) even though there may have been scheduled (and unscheduled) updates during that period that did not affect the value.

The chart below displays the results for the two outputs in the example above in the same chart:



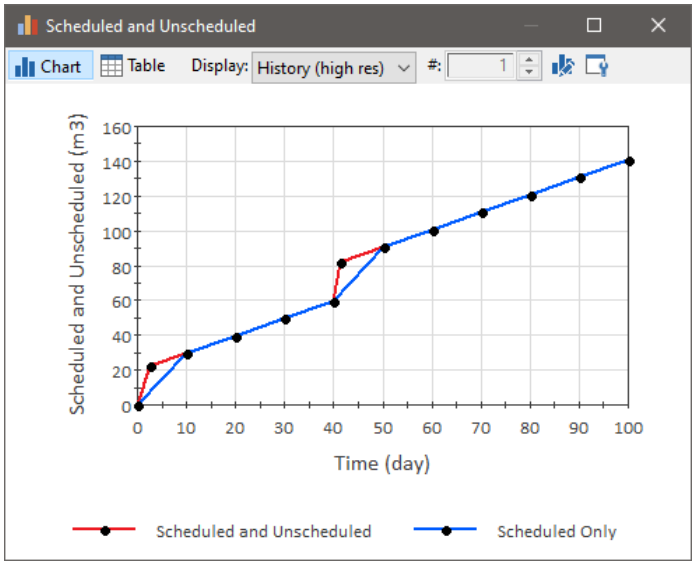
Note that Pond2 actually has more plot points than Pond1 (since it is changing continuously).

In some cases, it may be of value to view the same result with and without unscheduled updates. You can do this by taking advantage of the fact that high resolution results are only available for results that are added to the Result element *before* you run the model. If you add a result after you run the model, it will only show results at scheduled updates. Hence, to do such a comparison, you would 1) check **Include unscheduled updates (high resolution results) in scalar time histories** in the Advanced Time Settings dialog; 2) add a result to a Result element; 3) run the model; and 4) add the same result again after running the model. When you do this, the Result element will look like this:

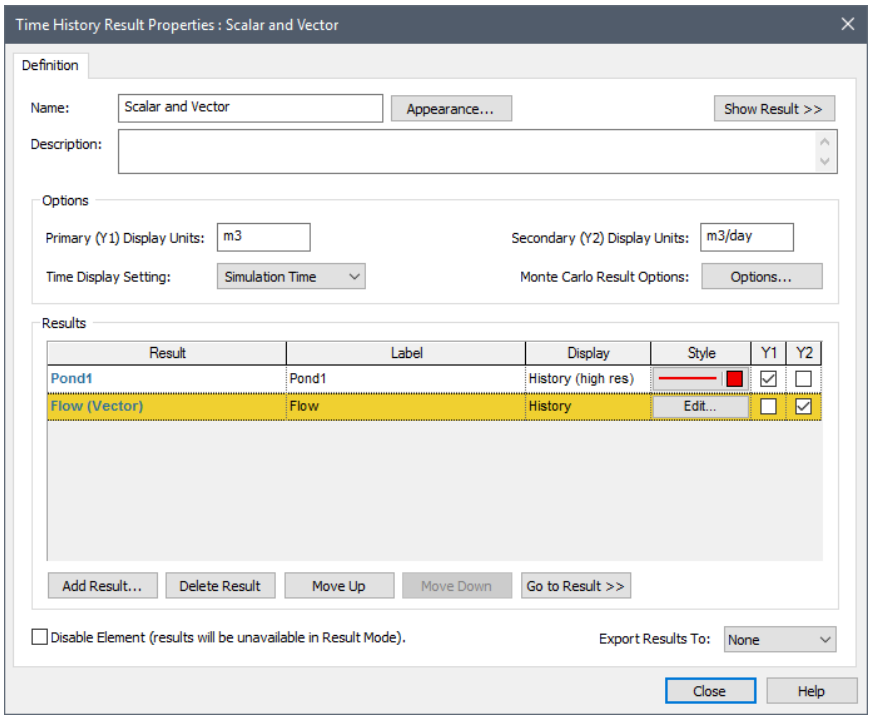


Note that the first item (added before the simulation was run) will display high resolution results, while the second item (added after the simulation was run) will display a normal time history.

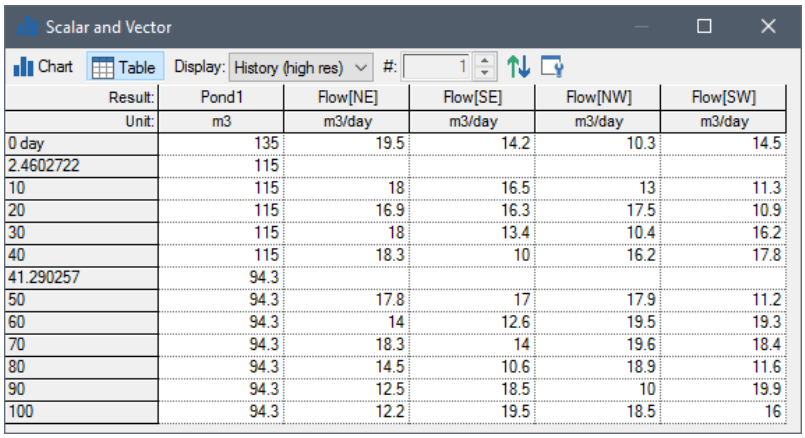
In this example, scheduled updates occur every 10 days (there is a Basic Step of 10 days), and unscheduled updates occur at 2.46 days and 41.29 days:



If your Time History Result element included one scalar output and one array, the scalar would provide high resolution results, while the array would not. This would be indicated in the Result Properties dialog:



The Table display would show blank cells for the array at unscheduled updates:



Result:	Pond1	Flow[NE]	Flow[SE]	Flow[NW]	Flow[SW]
Unit:	m3	m3/day	m3/day	m3/day	m3/day
0 day	135	19.5	14.2	10.3	14.5
2.4602722	115				
10	115	18	16.5	13	11.3
20	115	16.9	16.3	17.5	10.9
30	115	18	13.4	10.4	16.2
40	115	18.3	10	16.2	17.8
41.290257	94.3				
50	94.3	17.8	17	17.9	11.2
60	94.3	14	12.6	19.5	19.3
70	94.3	18.3	14	19.6	18.4
80	94.3	14.5	10.6	18.9	11.6
90	94.3	12.5	18.5	10	19.9
100	94.3	12.2	19.5	18.5	16

Note that in this case, the high resolution results include all scheduled updates (since a row is provided for each scheduled update point due to the presence in the table of the array).

Note: High resolution results (unscheduled updates) are never displayed in Scenario Mode. They are only available in Result Mode. Hence, you cannot view high resolution results when comparing scenario results. When comparing scenarios, only scheduled updates are included in displays.

Read more: Viewing Scenario Results in Time History Result Elements (page 645).

A simple example file illustrating display of unscheduled updates (UnscheduledTimeSteps.gsm) can be found in the can be found in the General

Examples/ Running folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Related Topics…

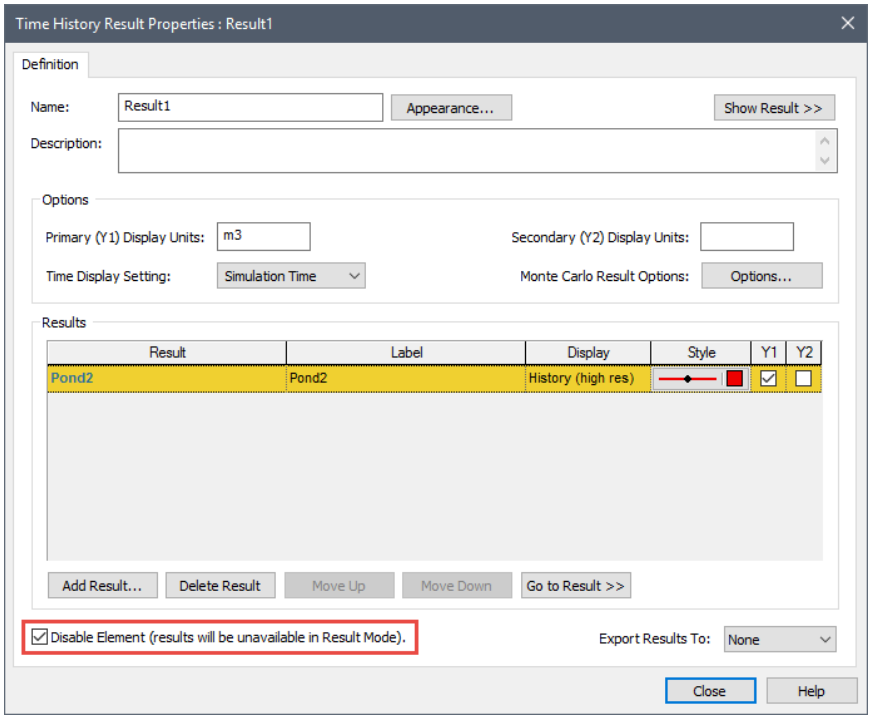
Disabling a Time History Result Element

If an output is linked to a Time History Result element, GoldSim automatically saves the results for the element (even if you have manually specified in the element's property dialog or the property dialog for a parent Container that time histories are not to be saved).

Read more: Saving Outputs as Results (page 514); Controlling Result Flags for Elements in the Container (page 146).

Under some circumstances, you may want to temporarily disable saving the results for an element that is linked to a Time History Result element (e.g., if you wish to run a large number of realizations).

You can do this by checking the **Disable Element** checkbox at the bottom of the Time History Result element dialog:

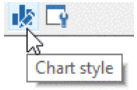


Note that you can enable or disable all of the Time History Result elements within a Container directly from the Container's property dialog.

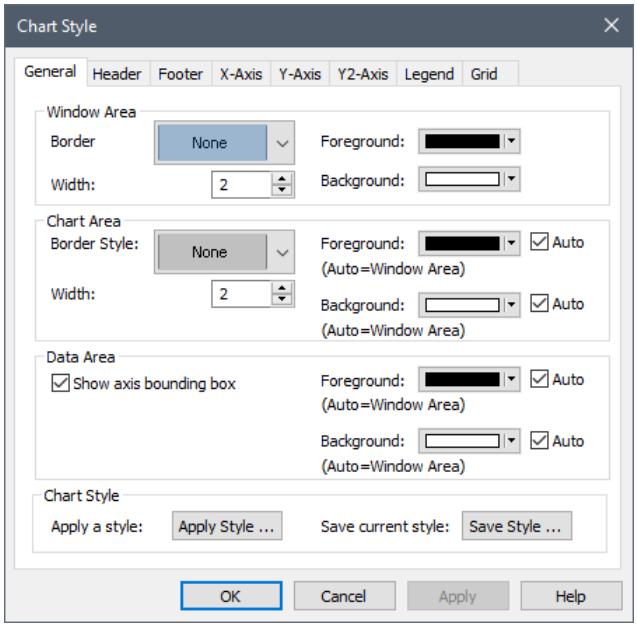
Read more: Controlling Result Flags for Elements in the Container (page 146).

Controlling the Chart Style in Time History Results

GoldSim has powerful charting capabilities that allow you to customize the appearance of each chart. This includes adding headers and footers, and changing axis scales and labels. Most of these attributes can be edited by pressing the **Edit Chart Style** button at the top of the Time History Chart window:



Pressing this button (or right-clicking in a chart and selecting **Edit Chart Style…**) provides access to the following dialog for editing the various chart properties:



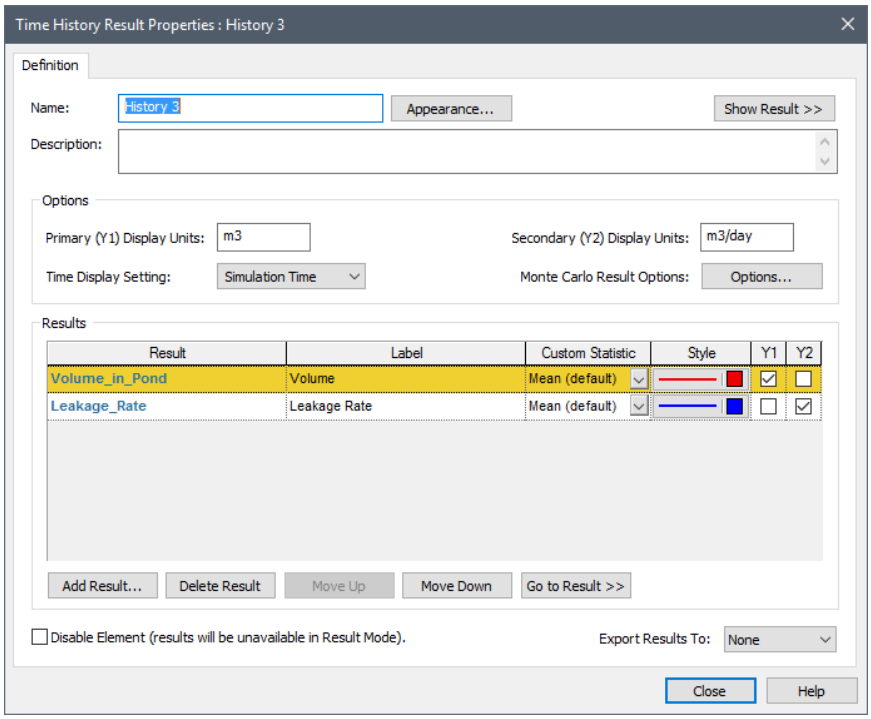
This dialog is common to all types of charts, and is discussed elsewhere.

Read more: Editing the Appearance of a Chart (page 768).

One key attribute for charts is how values on axes are displayed. You cannot control the number of significant figures displayed (this is automatically determined). You can, however, control under what circumstances scientific notation is used via the **Results** tab of the Options dialog (accessed via **Model |Options…** from the main menu).

Read more: Controlling Significant Figures and Scientific Notation in Result Displays (page 591).

In addition to the basic chart attributes controlled by the Chart Style dialog, the Time History Result Properties dialog itself is used to control some of the attributes of a chart:

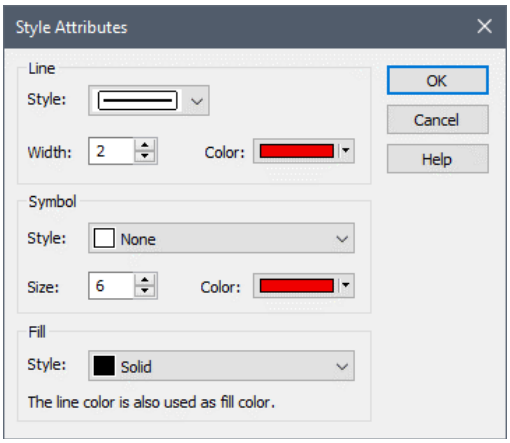


In particular,

- The units for each axis default to the Display Units of the first result added to each axis. However, you can change the **Display Units** that are displayed from within the Result Properties dialog.
- Only those results in which either the **Y1** or **Y2** box is checked will be included in displays. Hence, after adding a result to the list, you can temporarily hide it from displays by clearing one of these boxes.
- The **Label** is user-editable, and is used in legends (and column headers for tables).

Note: You can hide or show the legend on a chart via the context menu (i.e., accessed by right-clicking in the chart).

- The Style of each line displayed in a Time History Chart can be edited by clicking on the field (in the **Style** column) corresponding to each result. This provides access to the following dialog for editing the line style (for a distribution) or the fill style (for a single realization display):



Read more: Editing Data Styles (page 776).

If you are plotting an array, the Data Style for the different array items is defined in the Array Label Set dialog.

Read more: Viewing Time Histories for Array Outputs (page 615).

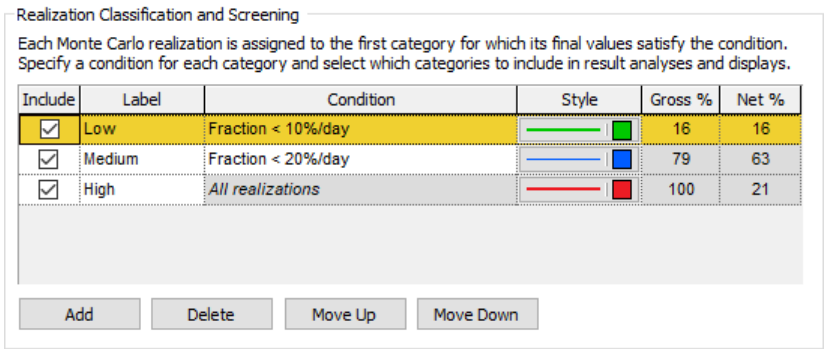
If you have run multiple realizations and you are displaying **Probabilities**, the Data Style for the display is specified at the top of the Monte Carlo Result Display Properties dialog (in the section labeled "History Statistics"). This dialog is accessed by pressing the **Options…** button in the Result Properties dialog of a Time History Result element.

Read more: Viewing Probability Histories for Multiple Realizations (page 623).

When viewing a Time History result, if 1) you have run multiple realizations; 2) you have defined more than one category; and 3) you are displaying **All Realizations**, GoldSim will label the curves in the Time History Chart based on the categories you have defined.

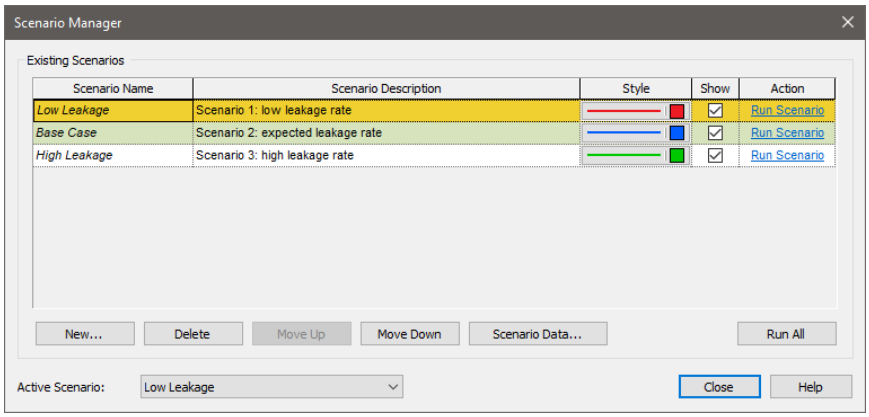
Read more: Using Result Classification and Screening in Time History Results (page 638).

The chart will display all realizations for a single result, with each curve having a style defined by its category. For each category, you can edit the **Style** via the Monte Carlo Result Display Properties dialog (accessed by pressing the **Options…** button in the Result Properties dialog of a Time History Result element):



The Style used for each category displayed in a Time History Chart can be edited by clicking on the field (in the **Style** column) corresponding to each category.

When a model is in Scenario Mode, Time History Result elements can be used to view scenario results. In this case, the line style for time history results for the different scenarios is controlled by the Scenario Manager dialog (accessed from the main menu (**Run | Scenario Manager…**) or by pressing **F7**):



Read more: Viewing Scenario Results in Time History Result Elements (page 645).

In order for scenario results to be displayed in a Time History Result element, the **Show** button must be checked for each scenario to be displayed in the Scenario Manager.

Note that for each scenario, you can edit the **Style**, as well as the **Scenario Name**, which is used used in legends (and column headers for tables).

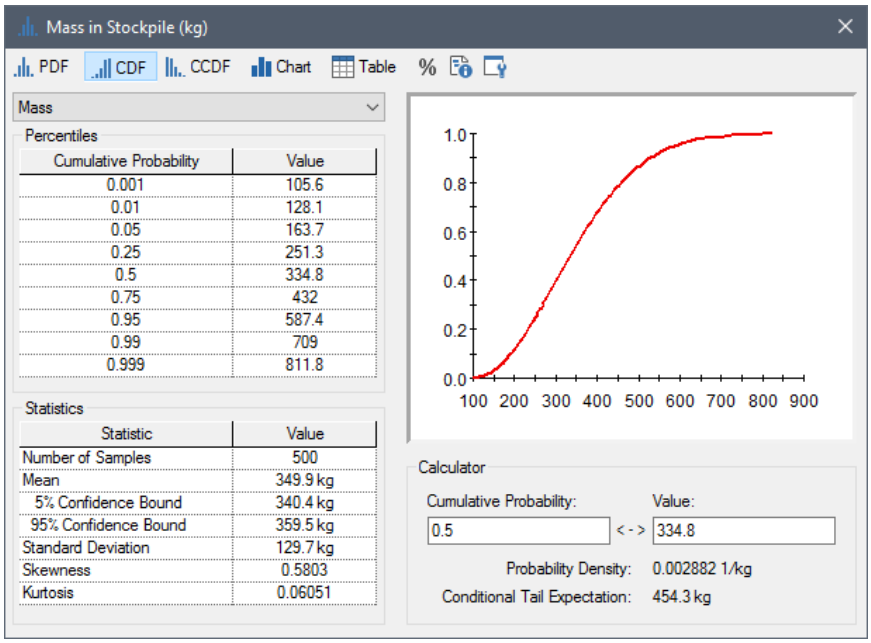
Viewing Distribution Results

Distribution results provide a way to view the final values of probabilistic outputs. Distribution results can only be viewed for scalar outputs (or scalar items of arrays).

A Distribution result has three types of views:

- Distribution Summary;
- Chart View; and
- Table View.

If you have saved Final Values for an output, you can display a Distribution result by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Distribution Result…** from the context menu. By default, a Distribution Summary will be displayed:

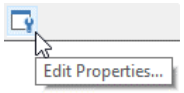


Note: When viewing a Distribution Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

Read more: Creating and Using Result Elements (page 593).

Viewing the Properties of a Distribution Result

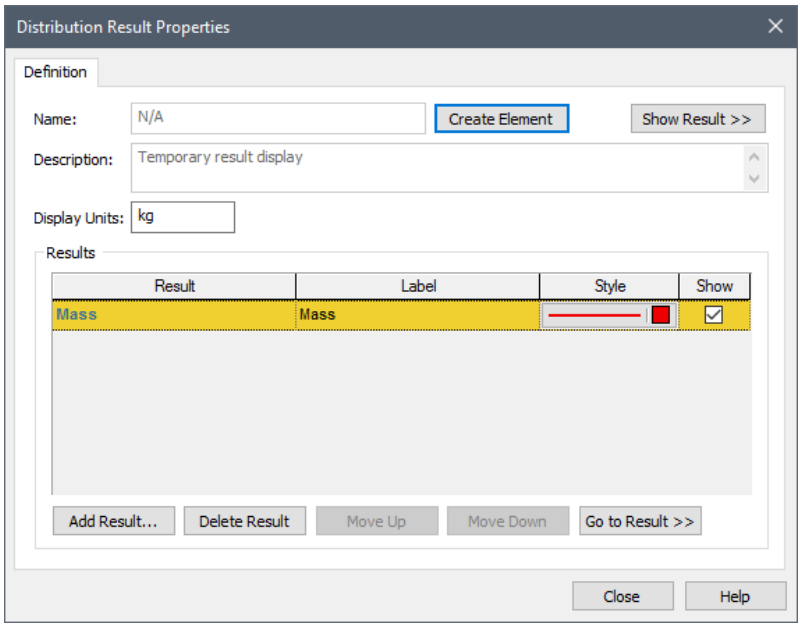
If you create a new Distribution Result element in Edit Mode or you click on the Result Properties button when viewing a Distribution Result chart or table, the Properties dialog for the result will be displayed. The Result Properties button is the furthest button to the right at the top of the display window:



Note that when you press this button while viewing results, it does not close the result display window you were displaying. Both windows are displayed simultaneously (although you can subsequently close one or the other). When viewing results, any changes you make to the Result Properties are immediately represented in the result display.

The Result Properties dialog is always modal. That is, it cannot be minimized, and with the exception of viewing the result display (which can be displayed simultaneously and share the focus with the Properties dialog), it retains the focus while it is displayed. As a result, you must close the Result Properties dialog before you can edit any other part of your GoldSim model.

The Result Properties dialog for an interactive Distribution result looks like this:



At the top of the page is a button to **Create Element**. By pressing this button, a Result element is created. When you do so, the key change that will be noticeable is that the **Name** will now be editable. The **Create Element** button becomes an **Appearance** button (which is used to modify the appearance of the element itself).

Read more: Creating and Using Result Elements (page 593).

The **Show Result** >> button opens a result display window (while keeping the Properties dialog simultaneously open.

Read more: Viewing a Distribution Summary (page 666); Viewing a Distribution Chart (page 670); Viewing a Distribution Table (page 674).

The **Add Result…** button allows you to add other results to the chart. Results can be deleted with the **Delete Result** button. In addition to adding standard outputs (such as Expressions or the primary output of a Reservoir element), you can also add Distribution outputs, which are complex outputs that represent all the statistical information necessary to define a probability distribution (and can only be produced by certain elements).

Read more: Adding a Distribution Output to a Distribution Result (page 686).

The order in which multiple results appear in the list can be changed using the **Move Up** and **Move Down** buttons. Pressing **Go to Result** >> closes the Properties dialog and selects the element associated with the result in the graphics pane.

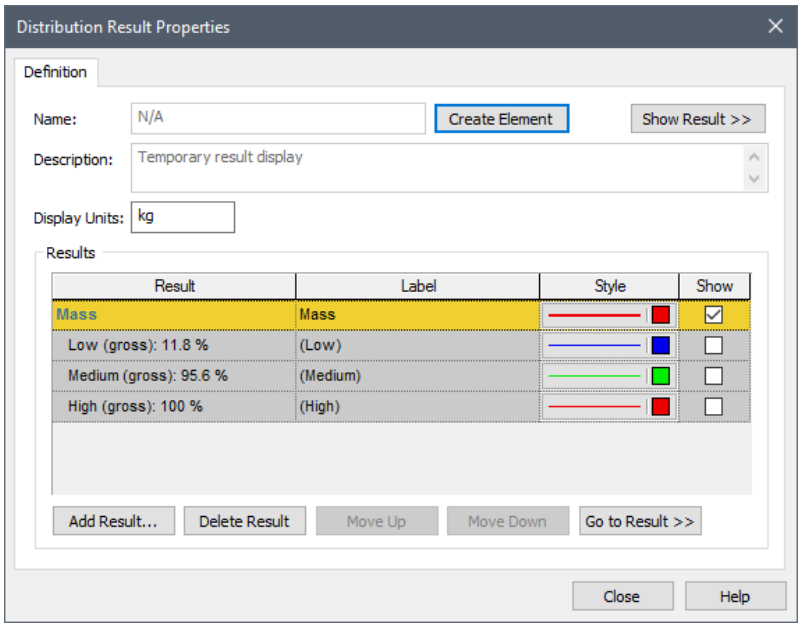
Read more: Viewing Distributions of Multiple Outputs (page 677).

For each result in the list, you specify a **Style** (used in charts), whether or not the result is to be included when displaying results (**Show**), and the **Label** used in legends in charts and headers in tables.

Read more: Controlling the Chart Style in Distribution Results (page 691).

You can also specify the **Display Units** for the X-axis of the result (which overrides the display units specified within the element's property dialog).

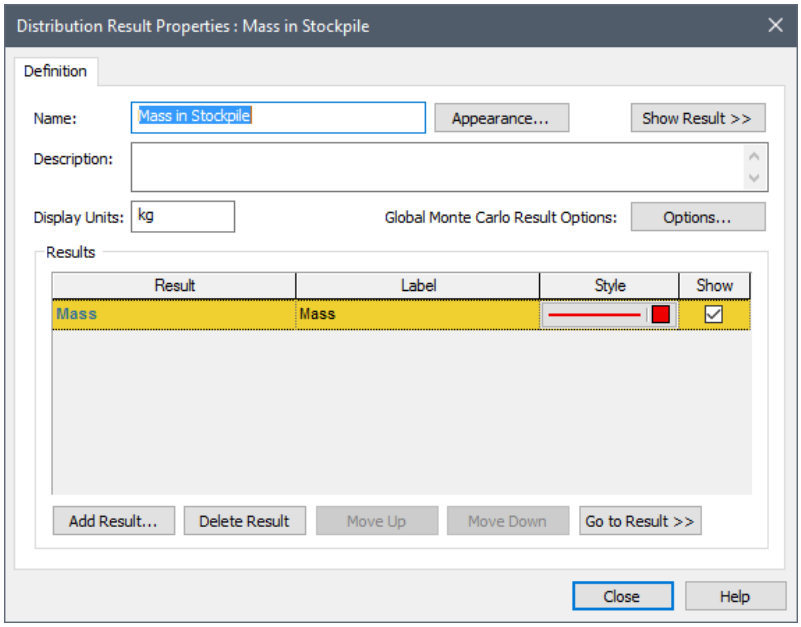
If you have created categories (and have specified only a single result in the list), you will note that the various categories will also be listed in the dialog:



Categories allow you to classify the realizations into various groups in order to analyze the results.

Read more: Using Result Classification and Screening in Distribution Results (page 681).

The Properties dialog for a Distribution Result element has several differences:



- The **Create Element** button is replaced by an **Appearance** button (which is used to modify the appearance of the element itself).
- The **Name** (and **Description**) are editable (since this is an element).
- An **Options…** button is available that provides access to the Monte Carlo Result Display Properties.

Read more: Controlling Monte Carlo Result Options (page 500).

Viewing a Distribution Summary

If you have saved Final Values for an output, you can display a Distribution Result by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Distribution Result…** from the context menu. By default, a Distribution Summary will be displayed.

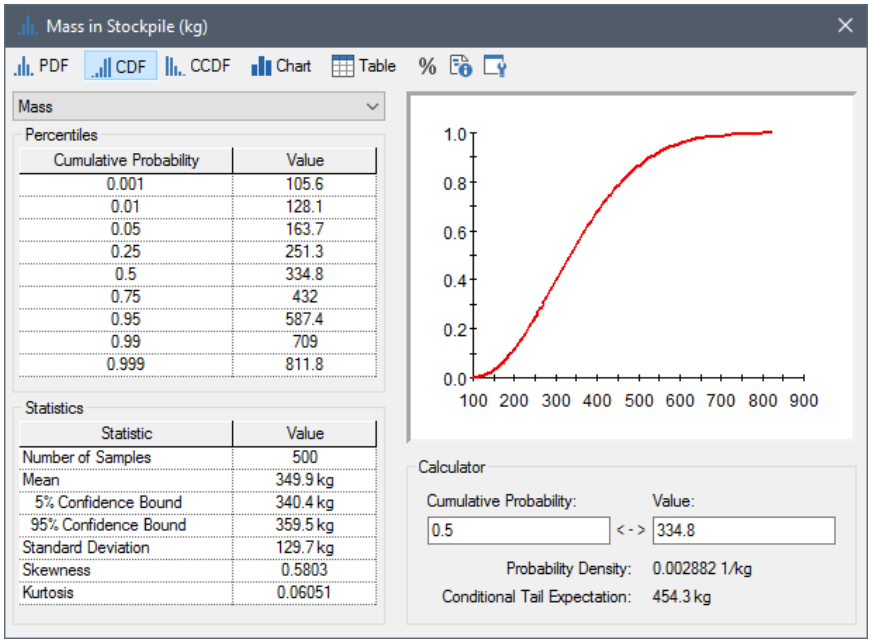
If you are viewing a different type of display (either a chart or table), you can view a Distribution Summary by pressing the **Chart** or **Table** button at the top of the display (i.e., making sure both are buttons are cleared).

Note: When viewing a Distribution Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

The Distribution Summary view of a distribution result is similar in appearance to the dialog used for defining a Stochastic element.

Read more: Specifying the Distribution for a Stochastic Element (page 160).

A Distribution Summary looks like this:

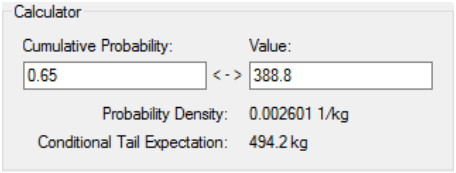


The *preview pane* (in the upper right-hand corner of the screen) shows a preview of the chart view of the distribution. You can copy the preview pane to the clipboard using **Ctrl+C**.

The left side of the screen displays a common set of percentiles for the distribution (in terms of Cumulative Probability/Value pairs).

The statistics for the distribution (***Mean***, 5% and 95% Confidence Bounds on the Mean, ***Standard Deviation***, ***Skewness***, and ***Kurtosis***) are shown directly below the distribution's percentiles. The significance of these statistics is described in Appendix A. The number of realizations (**Number of Samples**) is also indicated.

The Calculator section of the window allows you to compute the value associated with a particular percentile or the percentile associated with a particular value:

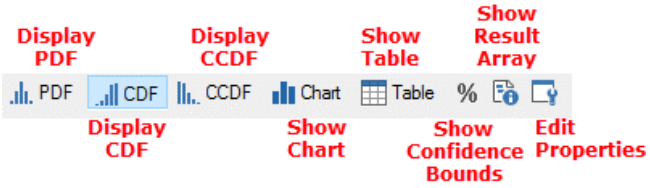


Enter the percentile in the Cumulative Probability field and the corresponding value will be displayed in Value OR Enter the value in the Value field and the corresponding percentile will be displayed in Cumulative Probability.

The Calculator also displays the Probability Density and the ***Conditional Tail Expectation*** for the specified Cumulative Probability/Value pair. The Conditional Tail Expectation is the expected value of the output given that it lies above a specified Cumulative Probability. That is, it represents the mean of the worst 100(1 - α)% of outcomes, where α is the specified Cumulative Probability.

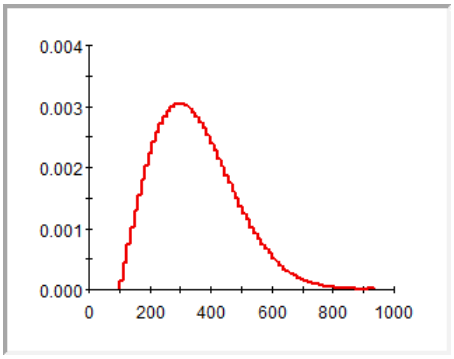
Note: Calculation of the Conditional Tail Expectation is discussed in detail in Appendix B.

The Distribution Summary has a variety of buttons at the top of the window:



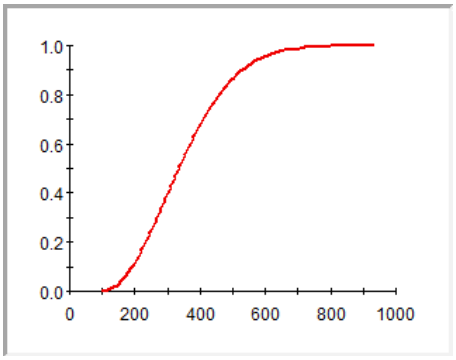
The functions of these buttons are as follows:

Display PDF: This displays the preview pane as a probability density function (PDF):

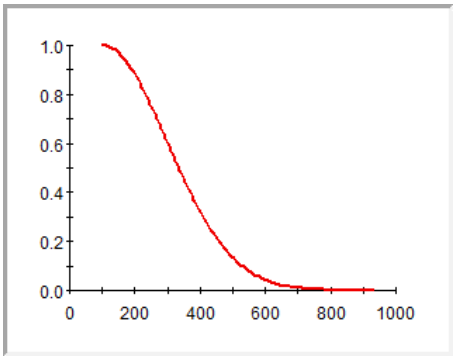


Note: The algorithim used to create a PDF plot is discussed in detail in Appendix B.

Display CDF: This displays the preview pane as a cumulative distribution function (CDF):



Display CCDF: This displays the preview pane as a complementary cumulative distribution function (CCDF):



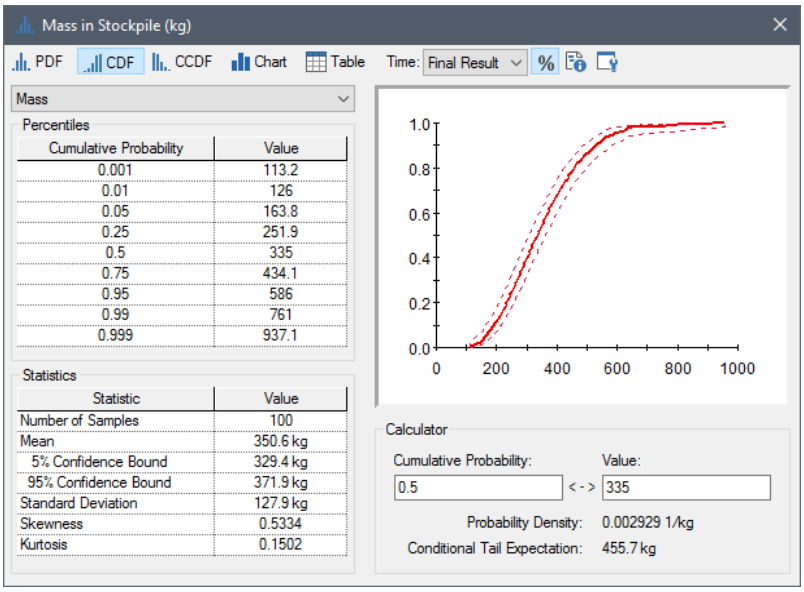
Show Chart: Selecting this button switches to a Chart view of the result. You can also toggle between the Distribution Summary View and the Chart View by double-clicking in the preview pane. Note that when viewing a Distribution Summary, both the Display Chart and the Display Table buttons appear deselected.

Read more: Viewing a Distribution Chart (page 670).

Show Table: Selecting this button switches to a Table view of the result. Note that when viewing a Distribution Summary, both the Display Chart and the Display Table buttons appear deselected.

Read more: Viewing a Distribution Table (page 674).

Show Confidence Bounds: If you press this button or press **Ctrl+Shft+B**, GoldSim will display confidence bounds on CDFs and CCDFs (they cannot be shown for PDFs):



These bounds reflect uncertainty in the probability distribution due to the finite number of Monte Carlo realizations (as the number of realizations is increased, the uncertainty in the distribution decreases). The confidence bounds represent the 5% and 95% confidence limits on the distribution. The calculation of confidence bounds is discussed in detail in Appendix B. Note that confidence bounds cannot be displayed if importance sampling has been used in the model.

Show Result Array: Pressing this button displays a new (modal) window containing the result array.The result array represents a sorted table of all of the results, and is used to produce the charts and statistics for the distribution. The table shows the value, the weight, the number of occurrences of the value, the cumulative probability of the value, and the 5% and 95% confidence bounds for the value at that cumulative probability. (Note, however, that confidence bounds cannot be computed if importance sampling has been used in the model.)

Read more: Viewing the Distribution Result Array (page 676).

Edit Properties: This provides access to the Result Properties.

Read more: Viewing the Properties of a Distribution Result (page 663).

Note: If you press the Copy button (or **Ctrl+C**) from the Summary View of a Distribution result, the preview pane chart is copied to the clipboard.

By default, Distribution results operate on Final Values. That is, the display uses the values at the end of each realization. However, by defining Capture Times, you can display results at any specified time. If you have created Capture Times, an additional drop-list is added to the display window to allow you to select the set of data (i.e., the results at the specified Capture Time) that you would like to display.

Read more: Viewing Results at Capture Times (page 592).

Note: When viewing distribution results produced by a nested Monte Carlo simulation (using a SubModel), the Distribution Summary dialog is modified somewhat and provides slightly different options.

Read more: Carrying Out Nested Monte Carlo Simulation Using a SubModel (page 1067).

Viewing a Distribution Chart

When you display a Distribution Result by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Distribution Result…** from the context menu., by default, a Distribution Summary will be displayed.

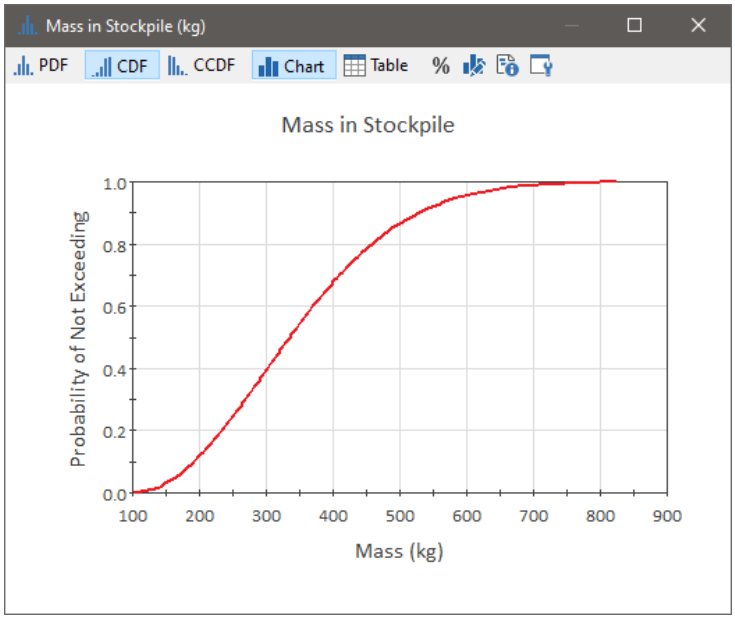
Read more: Viewing a Distribution Summary (page 666).

You can view a Distribution Chart by pressing the **Show Chart** button when viewing a Distribution Summary or a Distribution Table:

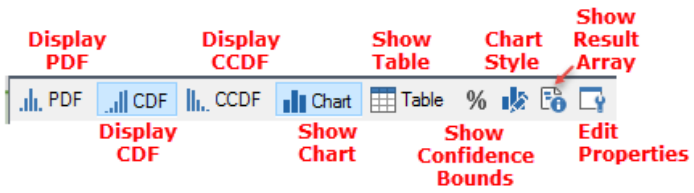
You can also view a Distribution Chart by double-clicking on the preview pane in the Distribution Summary window.

Note: When viewing a Distribution Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

A Distribution Chart looks like this:



The Distribution Chart has a variety of buttons at the top of the window:



The functions of these buttons are:

Display PDF: This displays the chart as a probability density function (PDF).

Note: The algorithim used to create a PDF plot is discussed in detail in Appendix B.

Display CDF: This displays the chart as a cumulative distribution function (CDF).

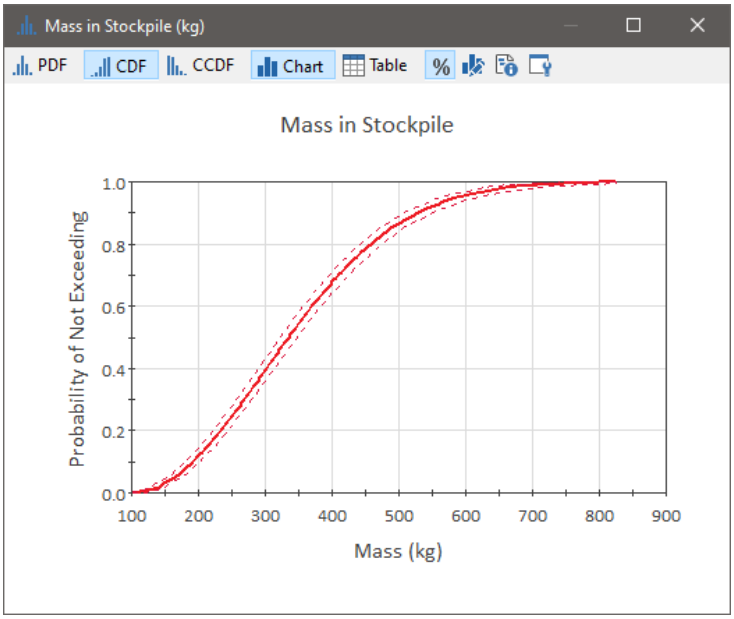
Display CCDF: This displays the chart as a complementary cumulative distribution function (CCDF).

Show Chart: Deselecting this button switches to a Distribution Summary view of the result. You can also toggle from the Chart View to the Distribution Summary View by double-clicking anywhere in the chart. Note that when viewing a Distribution Chart, the Display Chart button appears selected.

Show Table: Selecting this button switches to a Distribution Table view of the result. Note that when viewing a Distribution Table, the Display Table button appears selected.

Read more: Viewing a Distribution Table (page 674).

Show Confidence Bounds: If you press this button or press **Ctrl+Shft+B**, GoldSim will display confidence bounds on CDFs and CCDFs (they cannot be displayed for PDFs):



These bounds reflect uncertainty in the probability distribution due to the finite number of Monte Carlo realizations (as the number of realizations is increased, the uncertainty in the distribution decreases). The confidence bounds represent the 5% and 95% confidence limits on the distribution. The calculation of confidence bounds is discussed in detail in Appendix B. Note that confidence bounds cannot be displayed if importance sampling has been used in the model.

Show Result Array: Pressing this button displays a new (modal) window containing the result array.The result array represents a sorted table of all of the results, and is used to produce the charts and statistics for the distribution. The table shows the value, the weight, the number of occurrences of the value, the cumulative probability of the value, and the 5% and 95% confidence bounds for the value at that cumulative probability. (Note, however, that confidence bounds cannot be computed if importance sampling has been used in the model.)

Read more: Viewing the Distribution Result Array (page 676).

Edit Chart Style: This button provides access to a dialog for editing the chart style.

Read more: Controlling the Chart Style in Distribution Results (page 691).

Edit Properties: This provides access to the Result Properties.

Read more: Viewing the Properties of a Distribution Result (page 663).

Like all result charts, you can also control various attributes of the chart via a context menu. This includes the ability to turn on and off a legend. The legend uses the **Label** for the result defined in the Result Properties page. When viewing multiple results on one chart, you will always want to display the legend.

Read more: Using Context Menus in Charts (page 588); Viewing Distributions of Multiple Outputs (page 677).

When the results being plotted are conditions (i.e., True or False) or represent discrete (as opposed to continuous) distributions, GoldSim uses special algorithms to plot these in a consistent and effective manner.

Read more: Plotting Condition Distributions (page 673); Plotting Discrete Distributions (page 673).

You can copy the chart to the clipboard by right-clicking in the chart, and selecting **Copy** from the context menu. Alternatively, you can press **Ctrl+C** while viewing the chart. To export a chart, right-click in the chart, and select **Export…** from the context menu.

Read more: Copying a Chart or Table (page 800); Exporting a Chart (page 801).

By default, Distribution results operate on Final Values. That is, the display uses the values at the end of each realization. However, by defining Capture Times, you can display results at any specified time. If you have created Capture Times, an additional drop-list is added to the display window to allow you to select the set of data (i.e., the results at the specified Capture Time) that you would like to display.

Read more: Viewing Results at Capture Times (page 592).

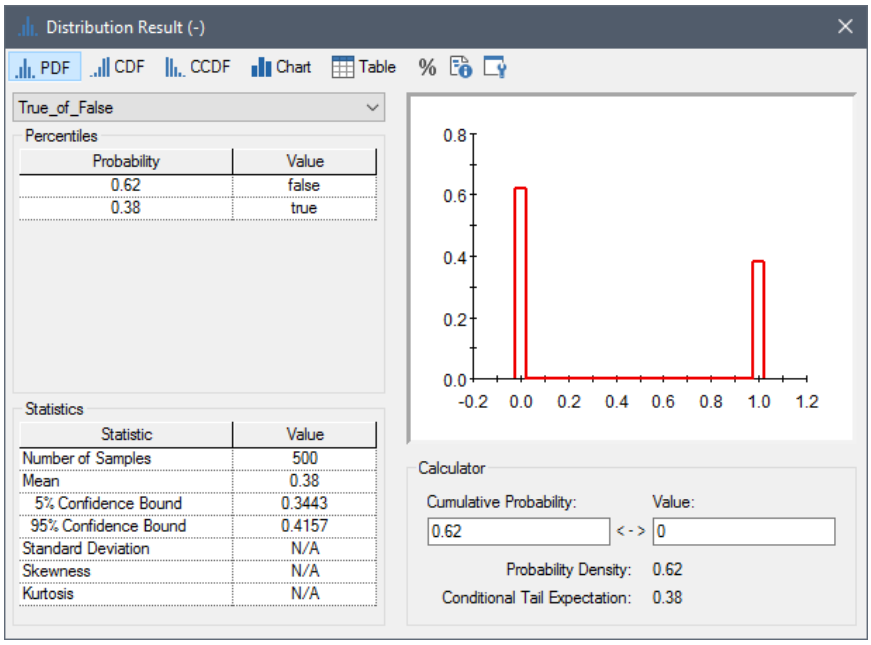
Note: When viewing distribution results produced by a nested Monte Carlo simulation (using a SubModel), the Distribution Chart display is modified somewhat and provides slightly different options.

Read more: Carrying Out Nested Monte Carlo Simulation Using a SubModel (page 1067).

Plotting Condition Distributions

Condition outputs are either True or False and are typically used as state variables or flags in a simulation. As a result, in some situations, you may want to save and plot distributions of conditions. To facilitate this, when plotting a distribution of a condition, GoldSim plots True as 1 and False as 0.

When viewing a distribution of conditions in the Distribution Summary window, within the Percentile portion of the window, GoldSim does not display percentiles; rather it displays the probability of True and False:



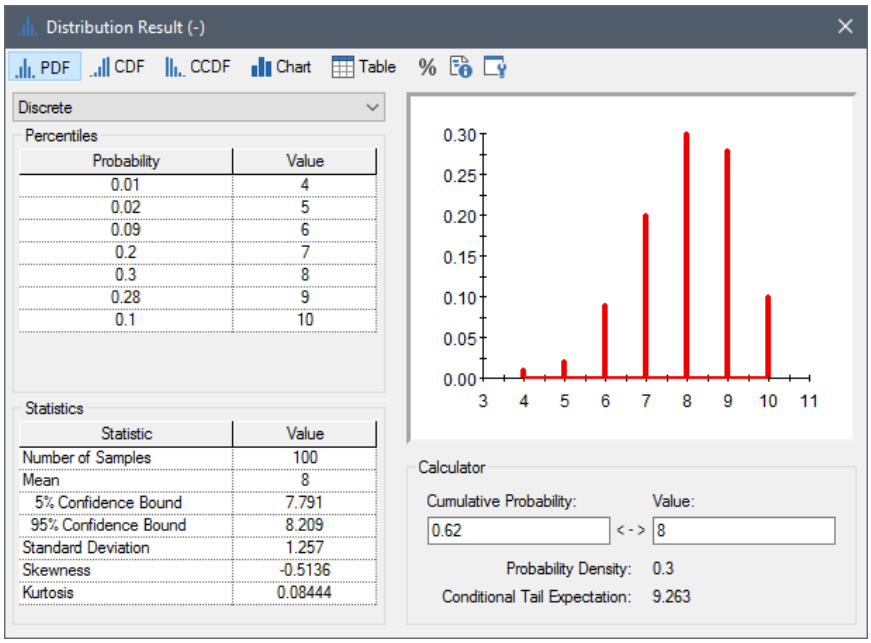
The displayed Mean is actually computed as the probability of being True. The other statistics are not computed. GoldSim also displays the 5% and 95% confidence bounds on the Mean.

Read more: Understanding Output Attributes (page 88); Viewing a Distribution Summary (page 666).

Plotting Discrete Distributions

Discrete distributions only take on a finite number of discrete values (i.e., they are not continuous). GoldSim's Monte Carlo engine includes algorithms that attempt to identify discrete (as opposed to continuous) results, and plot them as such.

When viewing a discrete distribution in the Distribution Summary window, within the Percentile portion of the window GoldSim does not display percentiles; rather, it displays the actual probability of each result:



Read more: Viewing a Distribution Summary (page 666).

Viewing a Distribution Table

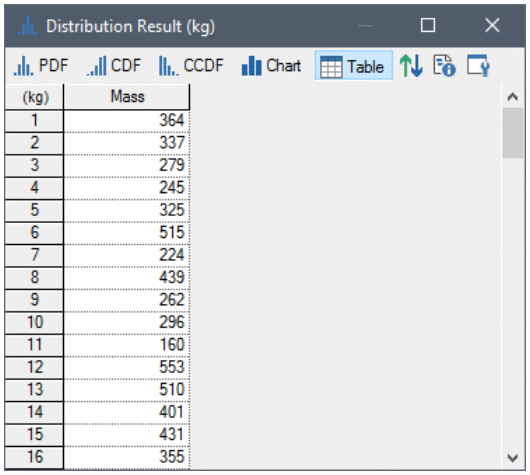
When you display a distribution result by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Distribution Result…** from the context menu., by default, a Distribution Summary will be displayed.

Read more: Viewing a Distribution Summary (page 666).

You can view a Distribution Table by pressing the **Show Table** button when viewing a Distribution Summary or a Distribution Chart.

Note: When viewing a Distribution Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

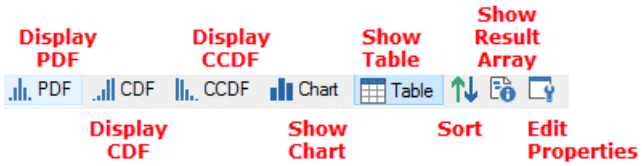
A Distribution Table looks like this:



Each row of the table is a separate realization. The header row for a table shows the units for the result above the first column and the Label for the result. The Label is specified in the Result Properties dialog and defaults to the result (output) name.

You can increase or decrease the width of a column by dragging the line separating columns to the right or to the left, respectively. If the column is too narrow to display the contents of a cell, holding the cursor over the cell displays a tool-tip with the contents.

The Distribution Table has a variety of buttons at the top of the window:



Display PDF: Switches to Distribution Summary view and displays the preview pane as a probability density function (PDF).

Display CDF: Switches to Distribution Summary view and displays the preview pane as a cumulative distribution function (CDF).

Display CCDF: Switches to Distribution Summary view and displays the preview pane as a complementary cumulative distribution function (CCDF).

Show Chart: Selecting this button switches to a Distribution Chart view of the result.

Read more: Viewing a Distribution Chart (page 670).

Show Table: Deselecting this button switches to a Distribution Summary view of the result. Note that when viewing a Distribution Table, the Display Table button appears selected.

Sort: This button allows you to sort the rows based on a selected column.

Read more: Sorting Values in Result Tables (page 590).

Show Result Array: Pressing this button displays a new (modal) window containing the result array.The result array represents a sorted table of all of the results, and is used to produce the charts and statistics for the distribution. The table shows the value, the weight, the number of occurrences of the value, the cumulative probability of the value, and the 5% and 95% confidence bounds for the value at that cumulative probability. (Note, however, that confidence bounds cannot be computed if importance sampling has been used in the model.)

Read more: Viewing the Distribution Result Array (page 676).

Edit Properties: This provides access to the Result Properties.

Read more: Viewing the Properties of a Distribution Result (page 663).

Several additional points should be noted regarding Distribution Tables:

- Conditions are displayed in tables as either 1/0, true/false, True/False, TRUE/FALSE, on/off, or High/Low. You select which of these pairs to use on the **Results** tab of the Options dialog (accessed via **Model |Options…** from the main menu).

- You can control the number of significant figures displayed in tables from the **Results** tab of the Options dialog (accessed via **Model |Options…** from the main menu).

  Read more: Controlling Significant Figures and Scientific Notation in Result Displays (page 591).

- You can copy the contents of a distribution table to the clipboard by pressing **Ctrl+C**. You must first select the cells you wish to copy. You can do so by placing your cursor in one cell and dragging to another location. You can select the entire table by pressing the cell in the upper left-hand corner of the table. Cells that are not adjacent can be selected using **Ctrl** key when selecting. Selected items will be highlighted in black. You can subsequently paste the table into another application (such as a spreadsheet).

  Read more: Selecting Items and Copying Values in Result Tables (page 590).

By default, Distribution results operate on Final Values. That is, the display uses the values at the end of each realization. However, by defining Capture Times, you can display results at any specified time. If you have created Capture Times, an additional drop-list is added to the display window to allow you to select the set of data (i.e., the results at the specified Capture Time) that you would like to display.

Read more: Viewing Results at Capture Times (page 592).

Viewing the Distribution Result Array

GoldSim allows you to view an alternative kind of table view of a distribution result referred to as the **result array**. This table is accessed by pressing the **Show Result Array** button in any of the Distribution Result display windows:

A typical result array is shown below:

Result Array: Mass

#	Value	Weight	Count	Cum	Q05	Q95
1	119	0.01	1	0.005	112	141
2	133	0.01	1	0.015	112	157
3	148	0.01	1	0.025	112	167
4	156	0.01	1	0.035	122	173
5	160	0.01	1	0.045	131	181
6	168	0.01	1	0.055	140	191
7	172	0.01	1	0.065	149	195
8	176	0.01	1	0.075	156	202
9	184	0.01	1	0.085	158	208
10	191	0.01	1	0.095	163	212
11	194	0.01	1	0.105	169	217
12	198	0.01	1	0.115	172	222
13	205	0.01	1	0.125	175	227
14	209	0.01	1	0.135	180	232
15	212	0.01	1	0.145	186	236
16	215	0.01	1	0.155	192	238
17	220	0.01	1	0.165	194	244
18	224	0.01	1	0.175	198	247

The result array represents a sorted table of all of the results, and is used to produce the charts and statistics for the distribution. The table shows the value, the weight, the number of occurrences of the value, the cumulative probability of the value, and the 5% and 95% confidence bounds for the value at that cumulative probability. (Note, however, that confidence bounds cannot be computed if importance sampling has been used in the model.)

You can increase or decrease the width of a column by dragging the line separating columns to the right or to the left, respectively. If the column is too narrow to display the contents of a cell, holding the cursor over the cell displays a tool-tip with the contents.

Several additional points should be noted regarding Distribution Result Arrays:

- You can copy the contents of the table to the clipboard by pressing the cell in the upper left-hand corner (#) to select the entire table, and then pressing **Ctrl+C** to copy the contents to the clipboard**.** You can subsequently paste the table into another application (such as a spreadsheet).
- Values in the table, by definition, are sorted in ascending order. To sort in descending order, double-click on a column header twice. Double-click on a header again to return to ascending order.
- You can control the number of significant figures displayed in tables from the **Results** tab of the Options dialog (accessed via **Model |Options…** from the main menu).

  Read more: Controlling Significant Figures and Scientific Notation in Result Displays (page 591).

The manner in which the results array is created and used is discussed in detail in Appendix B.

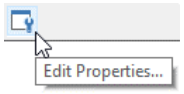
Viewing Distributions of Multiple Outputs

It is often useful to view the distributions of multiple outputs on a single chart or table. Displaying multiple distributions in this way allows you to more directly compare and contrast the results.

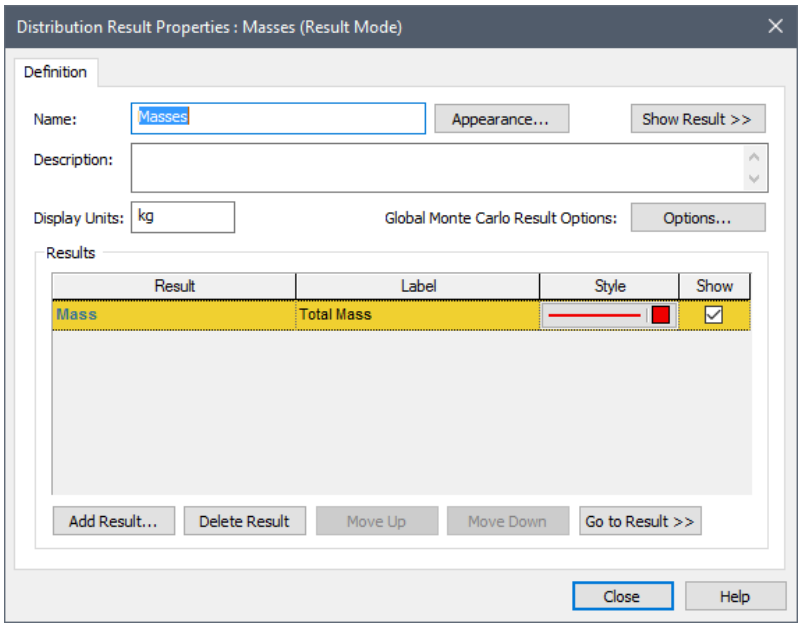
To display multiple results in a Distribution Result, you must first open the Result Properties dialog for the distribution.

Read more: Viewing the Properties of a Distribution Result (page 663).

You can do this by pressing the **Edit Properties…** button in any of the Distribution Result display windows:

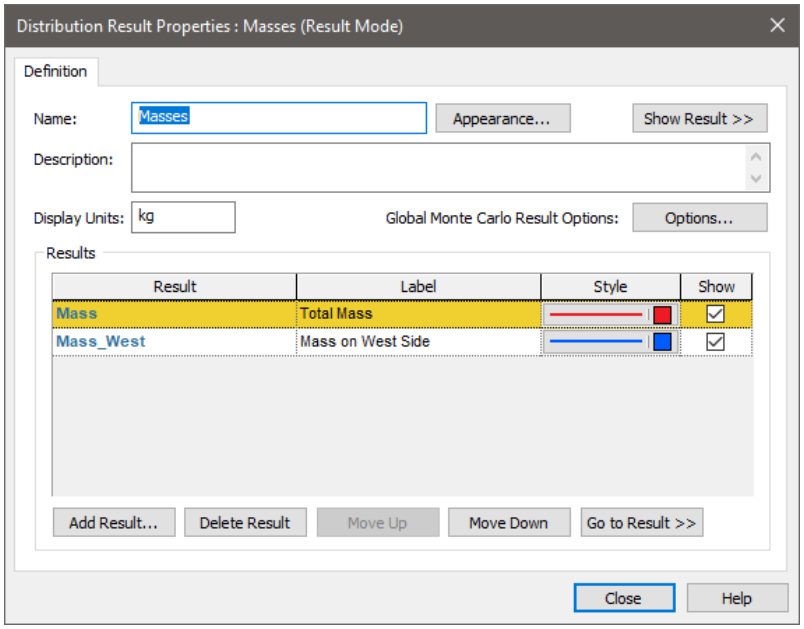


The following dialog will be displayed:



Note that the Label is user-editable and is used in legends and column headers.

To add addition outputs to the result, press the **Add Result…** button. A dialog for selecting an output will be displayed. After you select the output you wish to add to the result display, and press **OK**, the selected outputs are then shown in the Result Properties dialog:



You can show the full path for each result (showing the containment hierarchy) by placing your cursor over the Result item to display a tool-tip.

The following points should be noted regarding the Distribution Result Properties dialog when displaying multiple results:

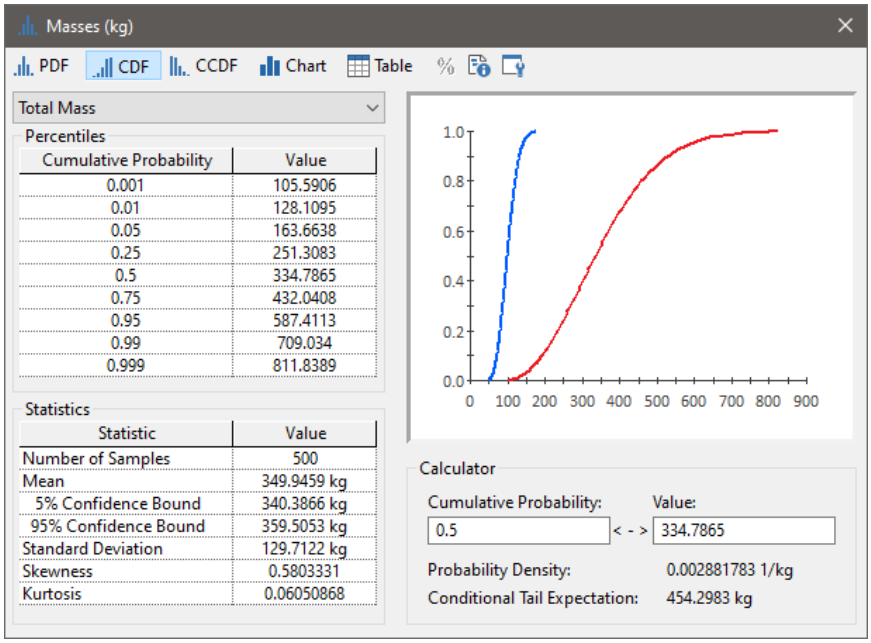
- The units of the results default to the Display Units of the first result added to the list. However, you can change the **Display Units** that are displayed from within the Result Properties dialog.

- You can add as many results as desired to list. Note, however, that all results must have the same dimensions. GoldSim will not allow you to add an output which does not match the dimensions of the existing result(s).
- Only those results in which the **Show** box is checked will be included in displays. Hence, after adding a result to the list, you can temporarily hide it from displays by clearing this box.
- The **Label** is user-editable, and is used in legends and column headers.
- The Style of each line displayed in a Distribution Chart can be edited by clicking on the field (in the **Style** column) corresponding to each result.

Read more: Controlling the Chart Style in Distribution Results (page 691).

Pressing the **Show Result** button displays the multiple output display.

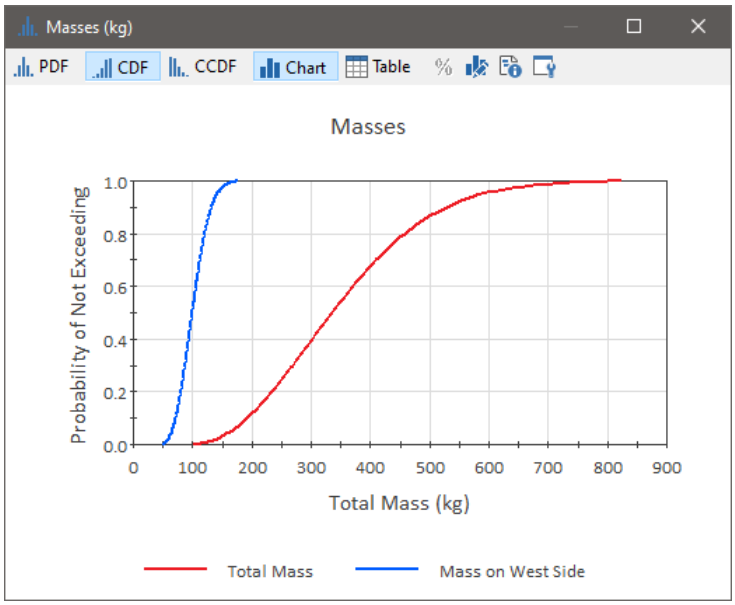
The Distribution Summary looks like this:



Note that although the Preview Pane will show all results, the Distribution Summary can only show Percentiles and Statistics for one result at a time. You can choose which of the results to display from the drop list at the upper left-hand corner of the window.

Read more: Viewing a Distribution Summary (page 666).

A Distribution Chart looks like this:

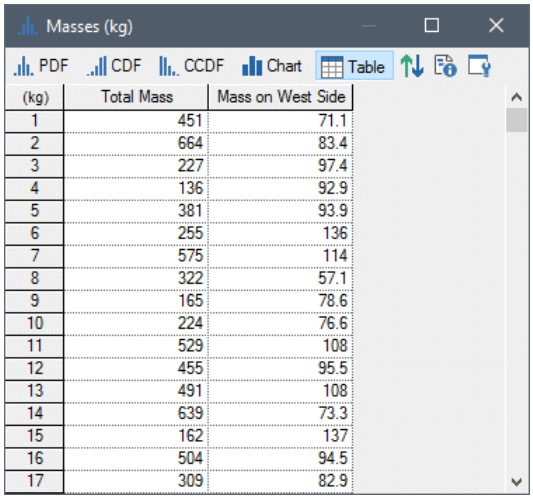


Note that the legend displays the (user-editable) Labels defined for each result.

Read more: Viewing a Distribution Chart (page 670).

Note that a legend is available for Distribution Charts (you may have to turn it on by right-clicking in the chart and selecting to show the legend from the context menu). The Labels specified in the Result Properties dialog are used in the legend to label the different results.

For Distribution Tables, the results are listed in separate columns:



(kg)	Total Mass	Mass on West Side
1	451	71.1
2	664	83.4
3	227	97.4
4	136	92.9
5	381	93.9
6	255	136
7	575	114
8	322	57.1
9	165	78.6
10	224	76.6
11	529	108
12	455	95.5
13	491	108
14	639	73.3
15	162	137
16	504	94.5
17	309	82.9

Note that the column headers are the (user-editable) Labels defined for each result.

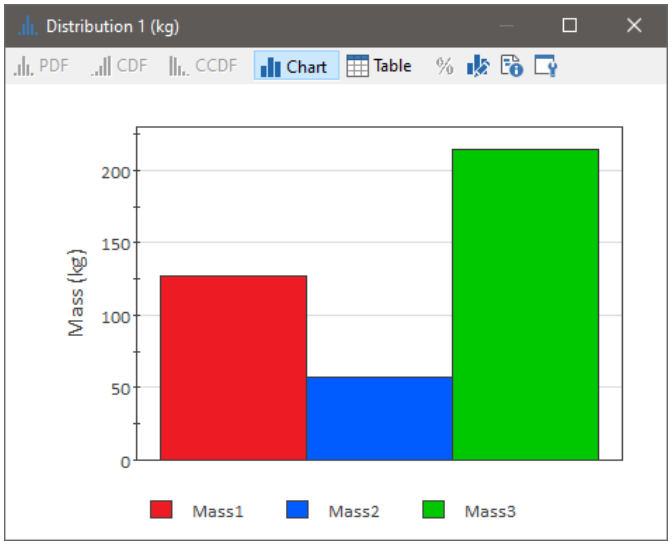
Read more: Viewing a Distribution Table (page 674).

Note: You cannot show Confidence Bounds in the Distribution Chart, Table or the Summary when displaying multiple outputs (the Confidence Bounds button is grayed out).

Viewing Distribution Results for Single Realization Runs

A Distribution Result can also be used to view a single realization simulation.

When displaying Distribution Results after running only a single realization, the Distribution Chart looks like this:

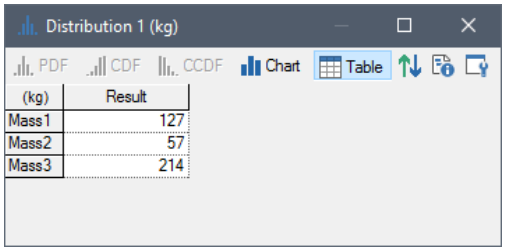


In this example, three results have been added to a Result element via the Properties dialog.Note that the legend displays the (user-editable) Labels defined for each result.

Read more: Viewing a Distribution Chart (page 670).

A legend is available for Distribution Charts (you may have to turn it on by right-clicking in the chart and selecting to show the legend from the context menu). The Labels specified in the Result Properties dialog are used in the legend to label the different results.

For Distribution Tables, the results are listed in separate rows:



Note that the row headers are the (user-editable) Labels defined for each result.

Read more: Viewing a Distribution Table (page 674).

Although using a Distribution Result to view a single realization in this way can be useful if you want to compare different results (or scenarios) in a single display, the Final Value Result provides a much more flexible and powerful way to do this.

Read more: Viewing Final Value Results (page 694).

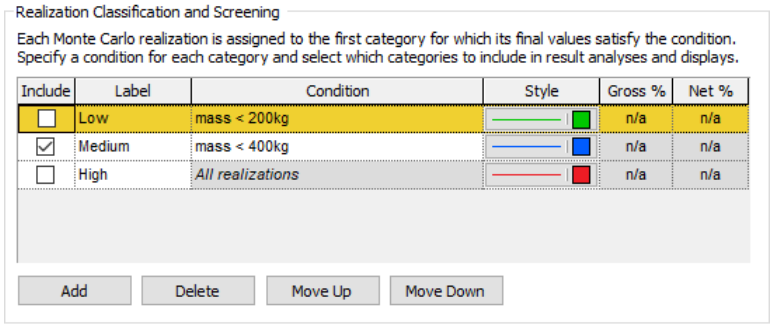
Using Result Classification and Screening in Distribution Results

When carrying out probabilistic simulations, you may often run hundreds or thousands of realizations. In order to analyze the results, it is often quite useful to classify the realizations into *categories*. A category is simply defined by a condition relating one or more outputs in the model (e.g., those realizations in which the discount rate was above 3.5%; those realizations in which the profit

exceeded $1,000,000; those realizations in which the peak concentration was between 1 mg/l and 10 mg/l).

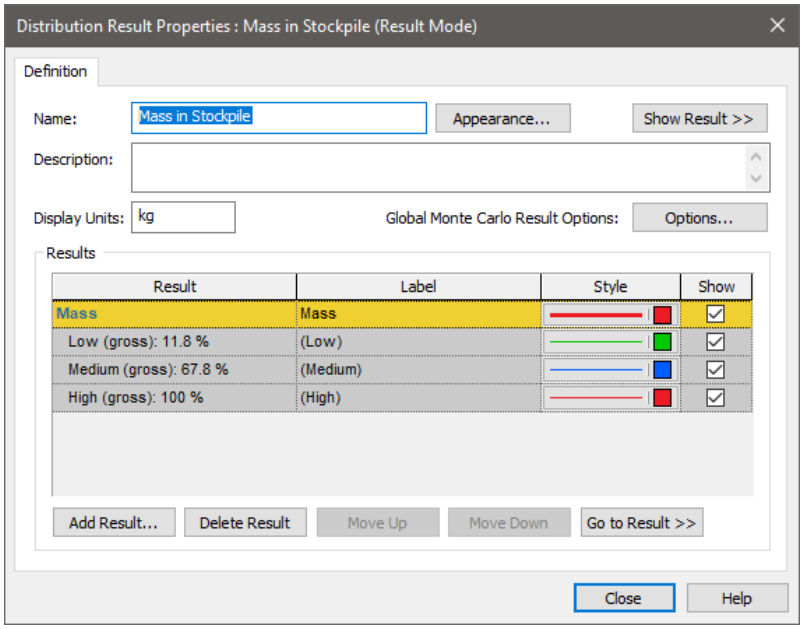
Read more: Classifying and Screening Realizations (page 601).

Classification categories are defined at the bottom of the Monte Carlo Result Display Properties dialog:



This dialog can be accessed from the Monte Carlo tab of the Simulation Settings dialog (via the **Result Options…** button), and is also accessible by pressing the **Options…** button available in the Result Properties dialog of a Distribution Result element.

Once you have defined categories, Distribution results can be displayed by category. The Properties dialog for a Distribution Result with categories defined looks like this:



In addition to showing the result (Mass in this case), the three categories that have been defined are also shown.

Note: Categories are only shown if the Distribution Result contains single result. If you add multiple results, the categories will not be shown.

By default, the categories are not shown in result displays (the **Show** box is cleared). If you want to display the categories, you must check the box.

In this particular example, the net number of realizations falling into each category is as follows: 11.8% of the realizations fall into the Low category, 56% fall into the Medium category, and 32.2% fall into the High category. This information is displayed in the the Monte Carlo Result Display Properties dialog after you run the simulation.

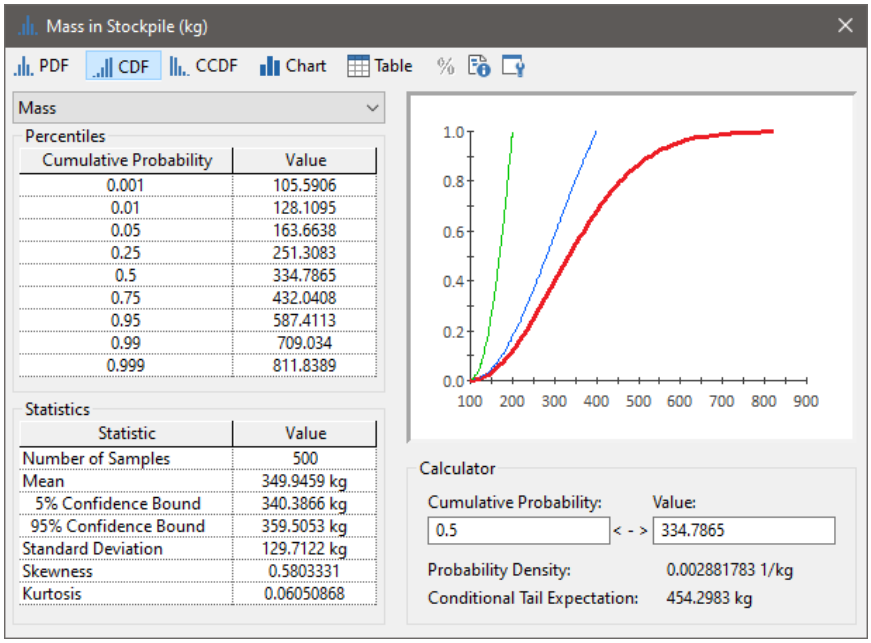
When you display a Distribution Result with categories, however, the results are displayed in terms of the gross number (as indicated in the Result Properties dialog). The gross number represents the percentage of realizations falling into the selected category and all the categories above it. Hence, in this example, 11.8% of the realizations fall into the Low category, 67.8% fall into the Low or Medium category, and 100% fall into the Low, Medium or High category.

If you check the **Show** boxes for all categories, and press the **Show Result** button, the categories will be included in the displays.

Note that for each category, you can edit the **Style** via the Monte Carlo Result Display Properties dialog. (The Style selections for each category are displayed in the Distribution Result Properties dialog, but cannot be edited there.)

Read more: Controlling the Chart Style in Distribution Results (page 691).

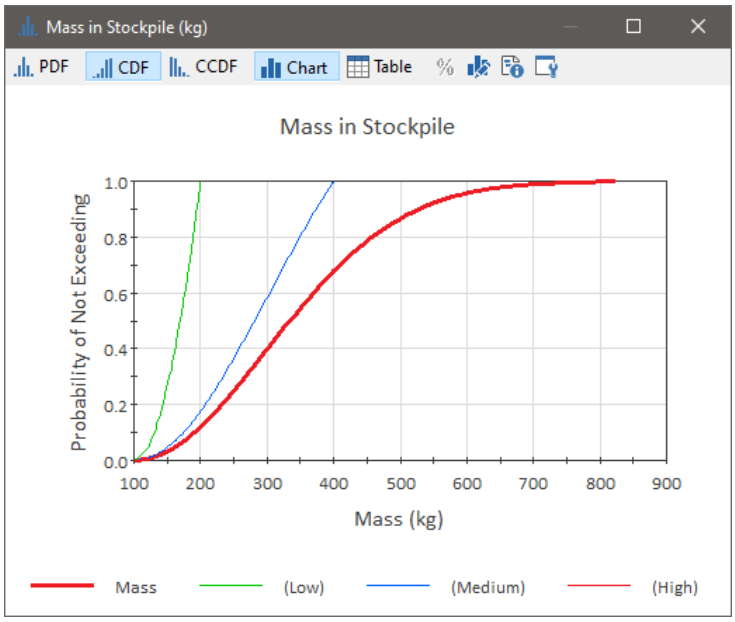
The Distribution Summary with categories looks like this:



Note that although the Preview Pane will show all categories, the Distribution Summary can only show Percentiles and Statistics for one category at a time. You can choose which of the categories to display from the drop list at the upper left-hand corner of the window.

Read more: Viewing a Distribution Summary (page 666).

A Distribution Chart with categories looks like this:



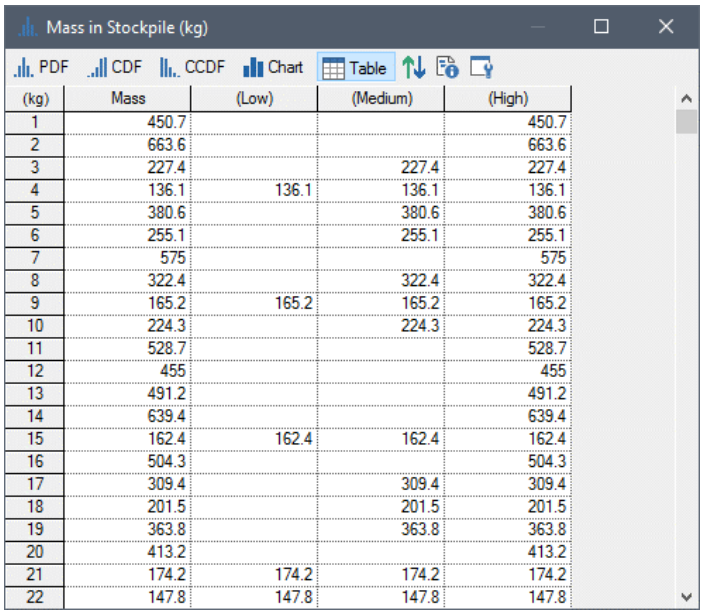
The Labels specified in the Monte Carlo Result Display Properties dialog are used in the legend to label the category results. The label for the result itself (in this case Mass) is specified in the Result element dialog.

Note that a legend is available for Distribution Charts (you may have to turn it on by right-clicking in the chart and selecting to show the legend from the context menu).

Note that because a Distribution Result displays categories in terms of gross numbers, the final category (in this case High) actually includes all realizations, and hence is identical to the display of the result itself.

Read more: Viewing a Distribution Chart (page 670).

For Distribution Tables with categories, the results are listed in separate columns:



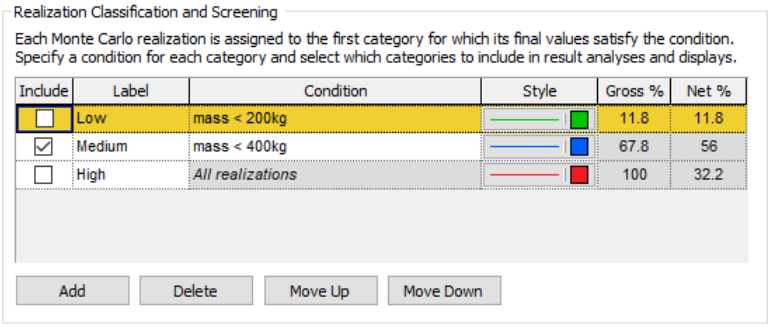
(kg)	Mass	(Low)	(Medium)	(High)
1	450.7			450.7
2	663.6			663.6
3	227.4		227.4	227.4
4	136.1	136.1	136.1	136.1
5	380.6		380.6	380.6
6	255.1		255.1	255.1
7	575			575
8	322.4		322.4	322.4
9	165.2	165.2	165.2	165.2
10	224.3		224.3	224.3
11	528.7			528.7
12	455			455
13	491.2			491.2
14	639.4			639.4
15	162.4	162.4	162.4	162.4
16	504.3			504.3
17	309.4		309.4	309.4
18	201.5		201.5	201.5
19	363.8		363.8	363.8
20	413.2			413.2
21	174.2	174.2	174.2	174.2
22	147.8	147.8	147.8	147.8

Note that only realizations that fall into each category are displayed. If a realization is not in a category, it is blank. Because a Distribution Result displays categories in terms of gross numbers (and categories are displayed in the table from left to right), if a realization falls into a category, it also falls into all category columns to the right.

Read more: Viewing a Distribution Table (page 674).

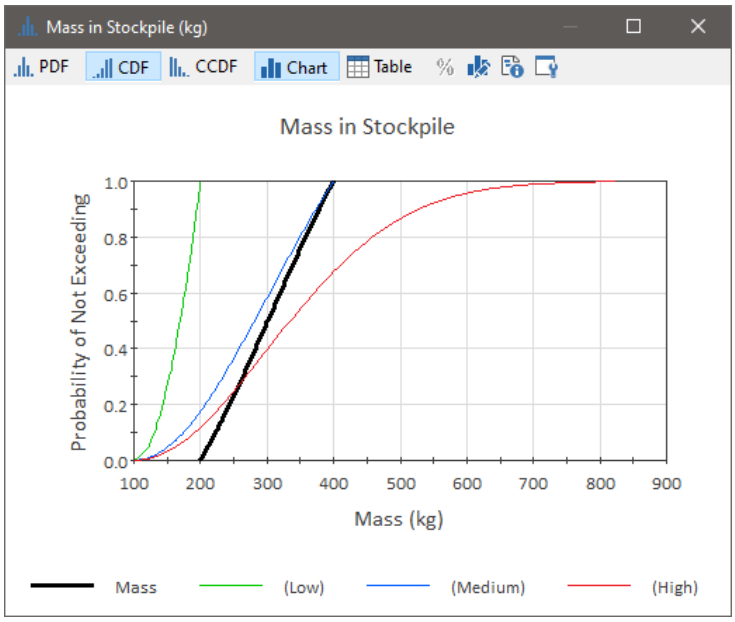
Note: You cannot show Confidence Bounds in the Distribution Chart, Table or the Summary when displaying categories (the Confidence Bounds button is grayed out).

Within all result displays, you can also choose to ***screen*** out one or more categories, so that the results that are shown (in charts and tables) only include those realizations in the categories which you have chosen to include. You can screen a particular category from the results by clearing the **Include** box at the bottom of the Monte Carlo Result Display Properties dialog:



Note: You can edit the **Include** box in Edit Mode, Result Mode Scenario Mode or Run Mode.

Result screening only affects the result itself (if you choose to show categories, the screening does not apply to the category displays). Hence, in the example below, we are screening Low and High categories from the result (labeled Mass), but simultaneously displaying the (gross) category results:



Screened results shown with category results (which are not screened). In most cases, you would likely not show category results when screening.

Note that when screening results, it is the net number of realizations that are screened. Hence, in the example above (in which the Low and High categories are screened), the screened result is based on only those results in the Medium category (56% of the realizations in this example).

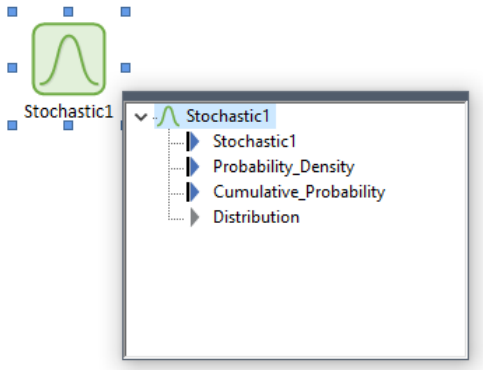
Adding a Distribution Output to a Distribution Result

In most cases, when you add an output to a Distribution Result (via the **Add Result…** button in the Result Properties dialog), you will simply be adding a standard output (such as the output of an Expression element or the the primary output of a Reservoir element). However, several types of elements in GoldSim produce a specialized output referred to as a Distribution output, and this output type can also be added (and viewed) in a Distribution Result.

Distribution outputs are complex outputs that represent all the statistical information necessary to define a probability distribution. They can only be produced by Stochastic elements, SubModels and Spreadsheet elements.

Read more: Stochastic Elements (page 158); Creating the Output Interface to a SubModel (page 1059); Importing Stochastic Element Definitions from a Spreadsheet (page 991).

These outputs can be clearly identified when viewing the output port of an element:



Note the the Distribution output has a different appearance than the other three standard outputs (it is gray rather than blue)

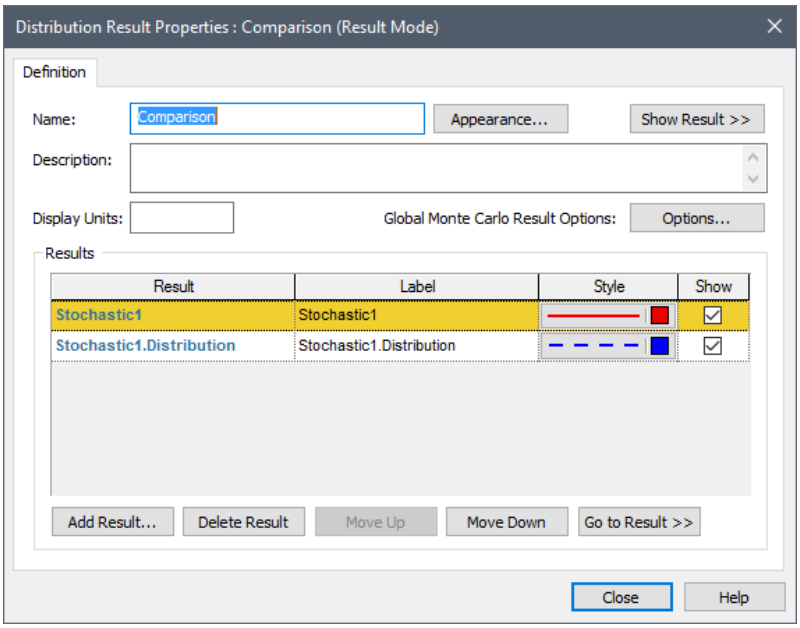
In some situations, you may want to add such an output to a Distribution Result. There are two primary cases where this can be of value:

1. You wish to carry out a nested Monte Carlo simulation (using a SubModel). In order to view the results, you would add a Distribution output from a Monte Carlo SubModel to a Distribution Result element in the parent model.

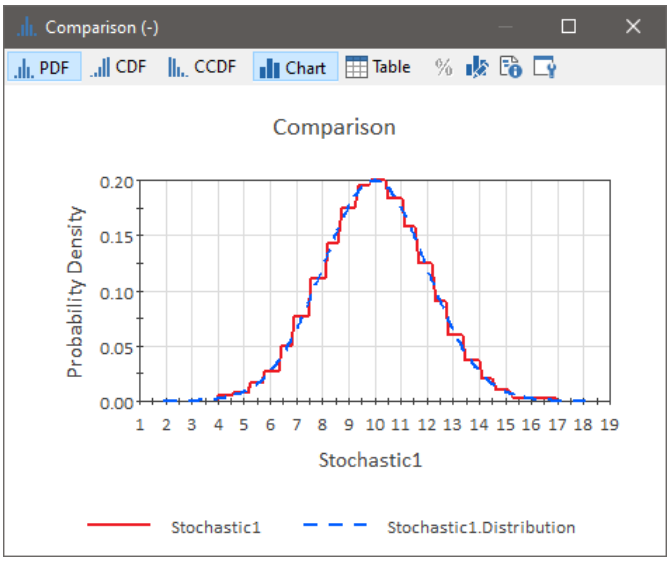
   Read more: Carrying Out Nested Monte Carlo Simulation Using a SubModel (page 1067).

2. You may want to compare a sampled distribution to a specified analytical distribution (e.g., to see how closely the sampled distribution matches a particular distribution such as a Normal or Weibull).

   This is possible because Stochastic elements always have a Distribution output and if you view the Distribution output for a Stochastic in a Distribution Result it will display the analytical distribution (as opposed to the sampled distribution for that Stochastic). In the example below, a Stochastic element is defined (as a Normal) and the model is run for 300 realizations. Two of its outputs are added to a Distribution Result: the primary output and the Distribution output:



The Result display would look like this:



The primary output (Stochastic1) shows the sampled distribution. The Distribution output (Stochastic1.Distribution) shows the analytical distribution shape.

Viewing Scenario Results in Distribution Result Elements

GoldSim's scenario modeling capability allows you to directly compare results generated by different sets of input parameters. In effect, when you use this capability, your model can store (and subsequently compare) multiple sets of results (and inputs).

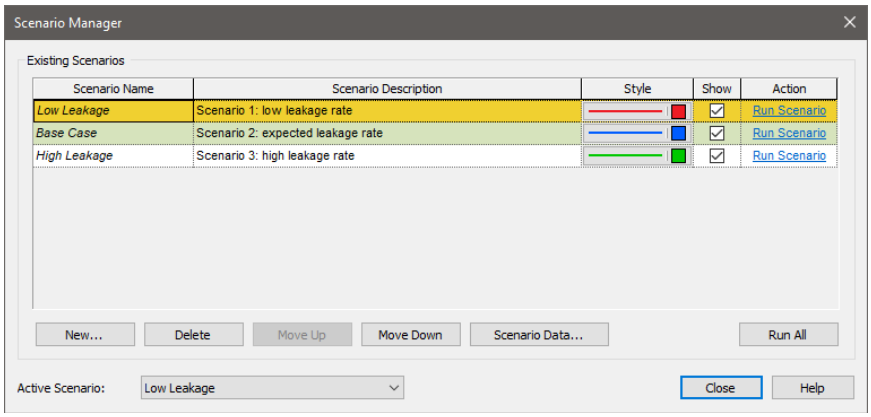
Read more: Creating, Running and Comparing Scenarios (page 525).

When a model is in Scenario Mode, Distribution Result elements can be used to view scenario results.

Note: Scenario results are only shown for the *first result* listed in the Distribution Result element. If the Distribution Result contains multiple results, in Scenario Mode only the first result will be displayed.

Note: Capture Times cannot be viewed in Scenario Mode (i.e., only the Final Result can be viewed). That is, if you are running scenarios and viewing results using Distribution Result elements you cannot view results for scenarios at specified Capture Times. You can only view scenario results for the Final Result.

In order for scenario results to be displayed in a Distribution Result element, the **Show** button must be checked for each scenario to be displayed in the Scenario Manager (accessed from the main menu (**Run | Scenario Manager…**) or by pressing **F7**):



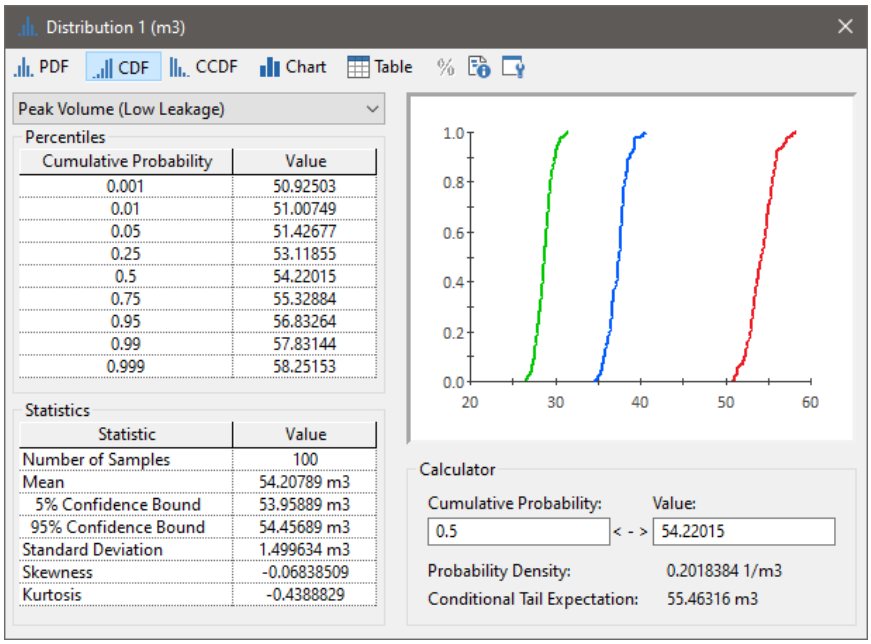
In this example, the Show box is checked for all three scenarios, so all three will be displayed in results.

If you double-click on a Distribution Result element in Scenario Mode, GoldSim displays results for all scenarios for which scenario results have been generated (and for which the **Show** button has been checked from within the Scenario Manager).

Note that for each scenario, within the Scenario Manager you can edit the **Style**, as well as the **Scenario Name**. These affect how the results are labeled in chart and table displays.

Read more: Controlling the Chart Style in Distribution Results (page 691).

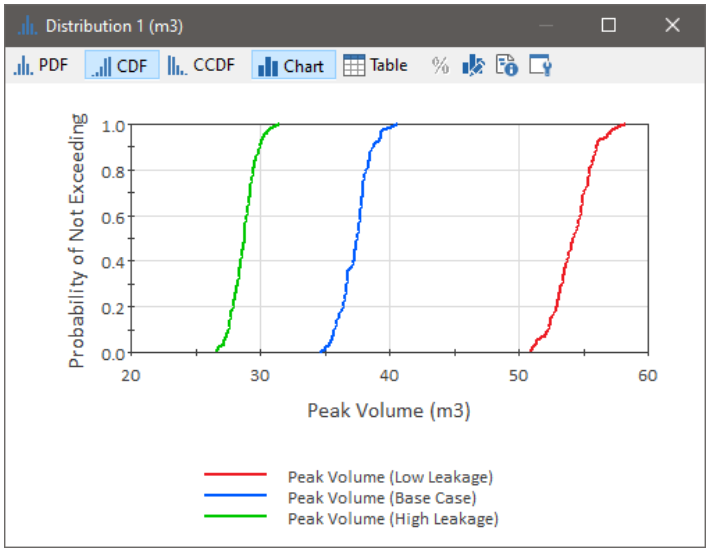
If you have run multiple realizations for the various scenarios (and hence are in Scenario Mode), a Distribution Summary in Scenario Mode looks like this:



Note that although the Preview Pane will show all scenarios, the Distribution Summary can only show Percentiles and Statistics for one scenario at a time. You can choose which of the scenarios to display from the drop list at the upper left-hand corner of the window.

Read more: Viewing a Distribution Summary (page 666).

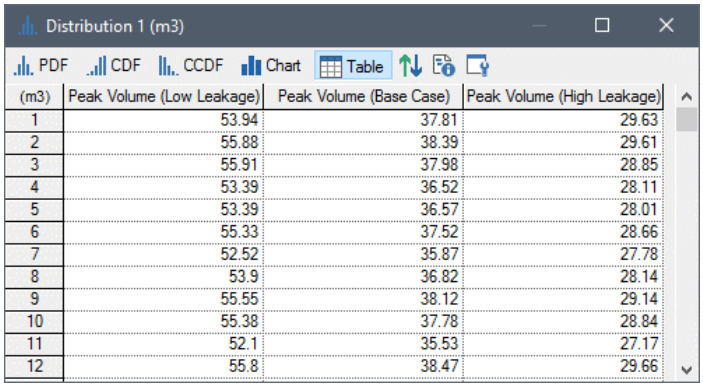
A Distribution Chart in Scenario Mode looks like this:



The Scenario Names specified in the Scenario Manager dialog are used in the legend (in parentheses) after the Result Label (specified in the Result element dialog).

Read more: Viewing a Distribution Chart (page 670).

For Distribution Tables in Scenario Mode, the scenarios are listed in separate columns:

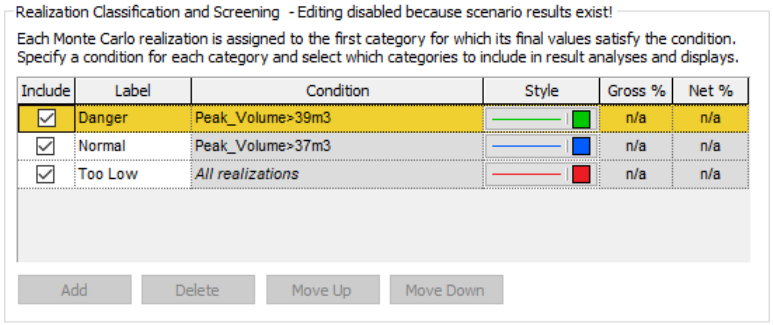


(m3)	Peak Volume (Low Leakage)	Peak Volume (Base Case)	Peak Volume (High Leakage)
1	53.94	37.81	29.63
2	55.88	38.39	29.61
3	55.91	37.98	28.85
4	53.39	36.52	28.11
5	53.39	36.57	28.01
6	55.33	37.52	28.66
7	52.52	35.87	27.78
8	53.9	36.82	28.14
9	55.55	38.12	29.14
10	55.38	37.78	28.84
11	52.1	35.53	27.17
12	55.8	38.47	29.66

Read more: Viewing a Distribution Table (page 674).

Note: You cannot show Confidence Bounds in the Distribution Chart, Table or the Summary in Scenario Mode (the Confidence Bounds button is grayed out).

When viewing a Distribution Result in Scenario Mode, you cannot view results by category (i.e., based on the categories you may have defined at the bottom of the Monte Carlo Result Display Properties dialog):



That is, in Scenario Mode, results are never displayed by category. However, screening by category is active in Scenario Mode. That is, if you have chosen to ***screen*** out one or more categories (by clearing the **Include** box in the dialog above), the scenario results that are shown (in charts and tables) only include those realizations in the categories which you have chosen to include.

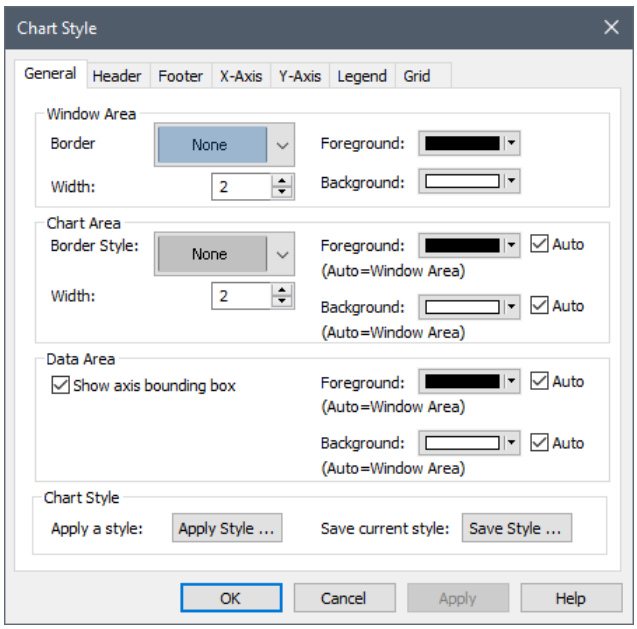
Note: Depending on how you have defined the categories, it is possible for a realization to fall into a different category in different scenarios. Hence, when screening results in Scenario Mode, the number of realizations within each scenario may differ.

Read more: Using Result Classification and Screening in Distribution Results (page 681).

Controlling the Chart Style in Distribution Results

GoldSim has powerful charting capabilities that allow you to customize the appearance of each chart. This includes adding headers and footers, and changing axis scales and labels. Most of these attributes can be edited by pressing the **Chart Style** button at the top of the Distribution Chart window:

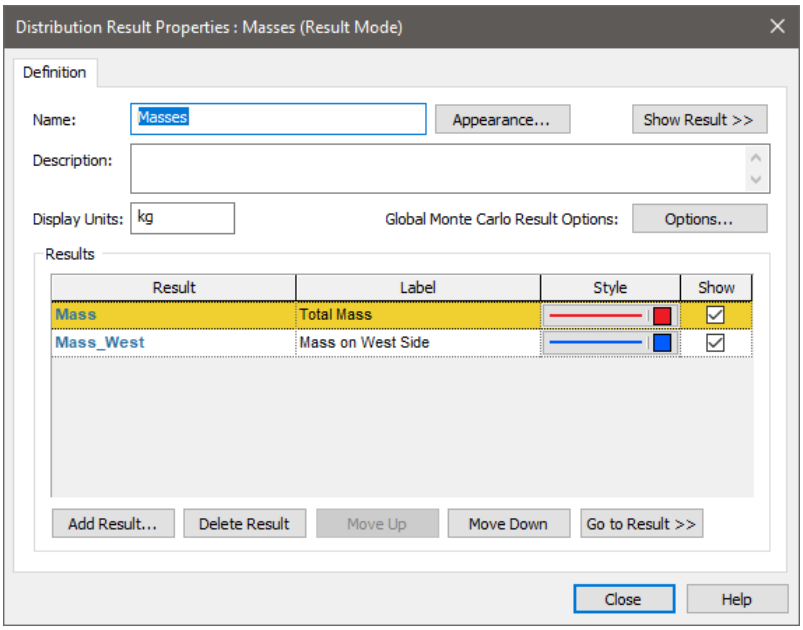
Pressing this button (or right-clicking in a chart and selecting **Edit Chart Style…**) provides access to the following dialog for editing the various chart properties:



This dialog is common to all types of charts, and is discussed elsewhere.

Read more: Editing the Appearance of a Chart (page 768).

In addition to the basic chart attributes controlled by the Chart Style dialog, the Distribution Result Properties dialog itself is used to control some of the attributes of a chart:

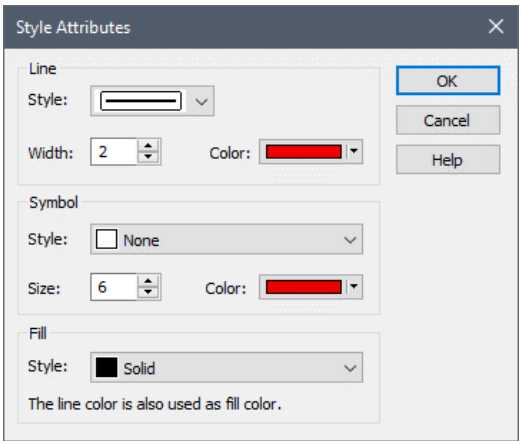


In particular,

- The units of the results default to the Display Units of the first result added to the list. However, you can change the **Display Units** that are displayed from within the Result Properties dialog.
- Only those results in which the **Show** box is checked will be included in displays. Hence, after adding a result to the list, you can temporarily hide it from displays by clearing this box.
- The **Label** is user-editable, and is used in legends (and column headers for tables).

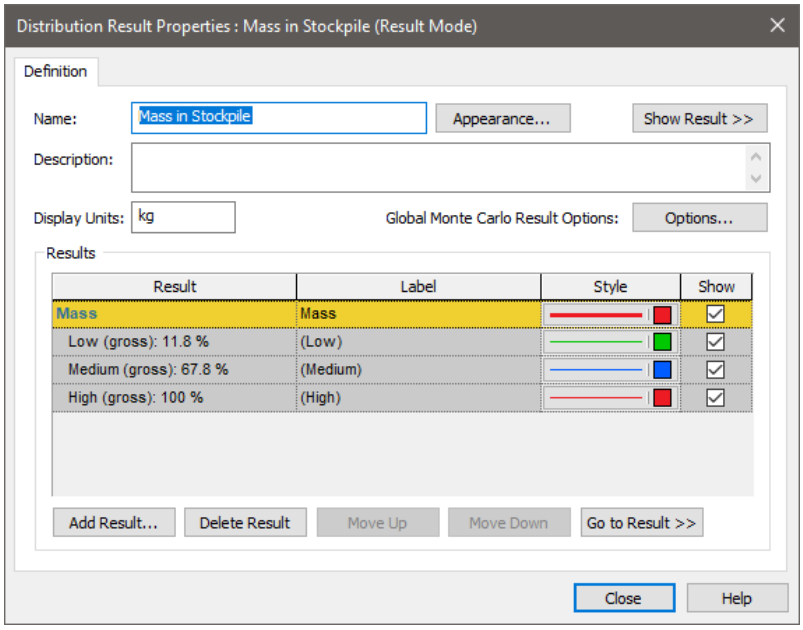
Note: You can hide or show the legend on a chart via the context menu (i.e., accessed by right-clicking in the chart).

- The Style of each line displayed in a Distribution Chart can be edited by clicking on the field (in the **Style** column) corresponding to each result. This provides access to the following dialog for editing the line style (for a distribution) or the fill style (for a single realization display):



Read more: Editing Data Styles (page 776).

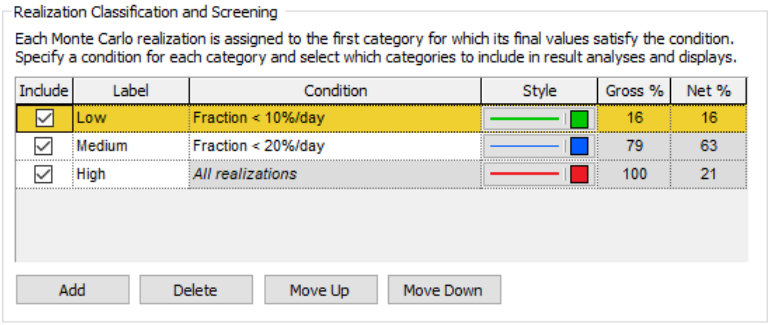
If you have defined realization categories, have run multiple realizations, and a Distribution Result element has only a single result defined, you will note that in addition to showing the result (Mass in the example below), any categories that have been defined are also shown:



Read more: Using Result Classification and Screening in Distribution Results (page 681).

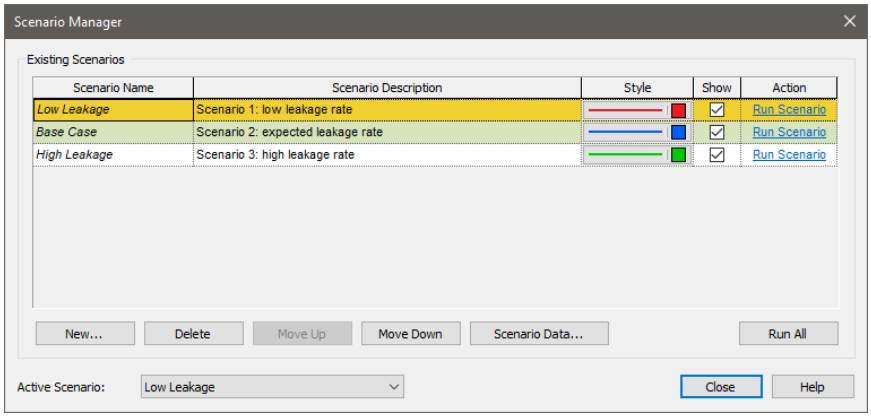
By default, the categories are not shown in result displays (the **Show** box is cleared). If you want to display the categories, you must check the box.

Note that although the Style selections for each category are displayed in the Distribution Result Properties dialog, they cannot be edited there (if you try to do so, you will note that they are grayed out). Instead, the **Style** for each category is controlled via the Monte Carlo Result Display Properties dialog (most easily accessed by pressing the **Options…** button in the Result Properties dialog of a Distribution Result element). The bottom of the Monte Carlo Result Display Properties dialog looks like this:



The Style used for each category displayed in a Distribution Chart can be edited by clicking on the field (in the **Style** column) corresponding to each category.

When a model is in Scenario Mode, Distribution Result elements can be used to view scenario results. In this case, the line style for distribution results for the different scenarios is controlled by the Scenario Manager dialog (accessed from the main menu (**Run | Scenario Manager…**) or by pressing **F7**):



Read more: Viewing Scenario Results in Distribution Result Elements (page 688).

In order for scenario results to be displayed in a Distribution Result element, the **Show** button must be checked for each scenario to be displayed in the Scenario Manager.

Note that for each scenario, you can edit the **Style**, as well as the **Scenario Name**, which is used used in legends (and column headers for tables).

Viewing Final Value Results

Final Value result displays allow you to compare results in the form of bar charts, column charts, pie charts and tables. These results, by default (and as indicated by their name), are those at the end of the simulation. However, by defining Capture Times, you can also display results at a specified time.

Read more: Creating Capture Times for Results (page 488).

If you have saved Final Values for an output, you can display a Final Value result by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Final Value Result…** from the context menu.

Read more: Saving Outputs as Results (page 514).

Note: You cannot view a Final Value result for a condition. Only values can be displayed.

It should be noted, however, that in many cases, the chart that is displayed when you do this will not necessarily be very interesting. This is because the purpose of Final Value result displays is to carry out side-by-side ***comparisons*** of different results (in tabular form or in graphical form as a bar, column or pie chart). As such, in order to use them, you will often need to take some time to carefully specify what you wish to compare and how you want to display that comparison.

What makes Final Value results powerful is the flexibility in the kinds of things that they can be used to compare. Examples include:

- Comparing values (or statistics) of multiple outputs;
- Comparing values of different Monte Carlo statistics (e.g., the mean, 95th percentile) for one or more outputs;
- Comparing values (or statistics) of one or more outputs for different scenarios;
- Comparing values (or statistics) of one or more outputs at different Capture Times; and
- Comparing values (or statistics) for the various items of a vector or a matrix.

Overview of Final Value Results

Because Final Value results are so flexible and can produce a very wide range of different charts and tables, before describing how to actually create and specify the form of these results in detail, it is first worthwhile to briefly provide an overview of the kinds of results that can be displayed.

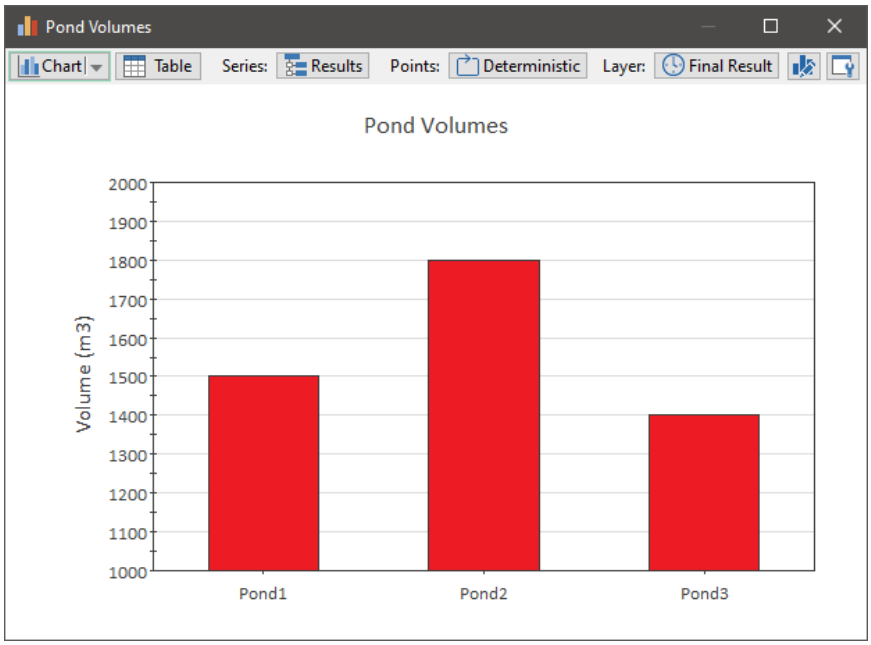
Final Value results are used to carry out side-by-side ***comparisons*** of the final values of outputs for different types of simulations. In order to use them, you need to carefully specify what you wish to compare and how you want to display that comparison. Depending on how your model has been run (e.g., multiple realizations, multiple scenarios, multiple Capture Times) and the outputs you have specified to compare (e.g., one output, multiple outputs, vector results, matrix results), they result displays can have multiple "dimensions" and there can be a large variety of ways to display the comparison. In the sections below, examples of the types of displays that can be created are provided:

- Displays of One-Dimensional Data Sets
- Displays of Two-Dimensional Data Sets
- Displays of Three-Dimensional Data Sets

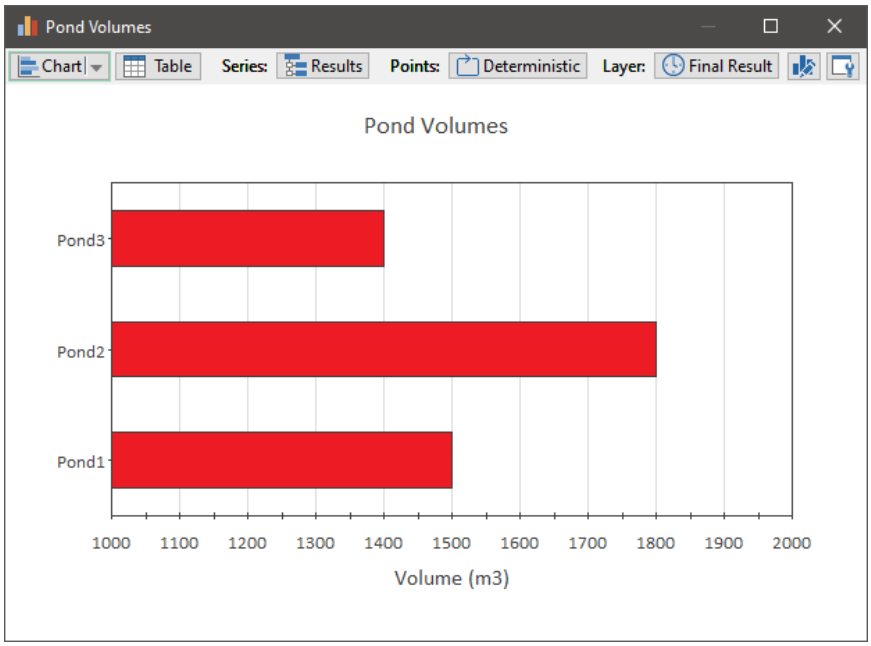
Overview: Displays of One-Dimensional Data Sets

One of the simplest Final Value results you might want to display is simply the comparison of multiple outputs for a deterministic run or a single realization. In effect, this is a "one-dimensional" set of data to display (with the dimension being the different outputs).

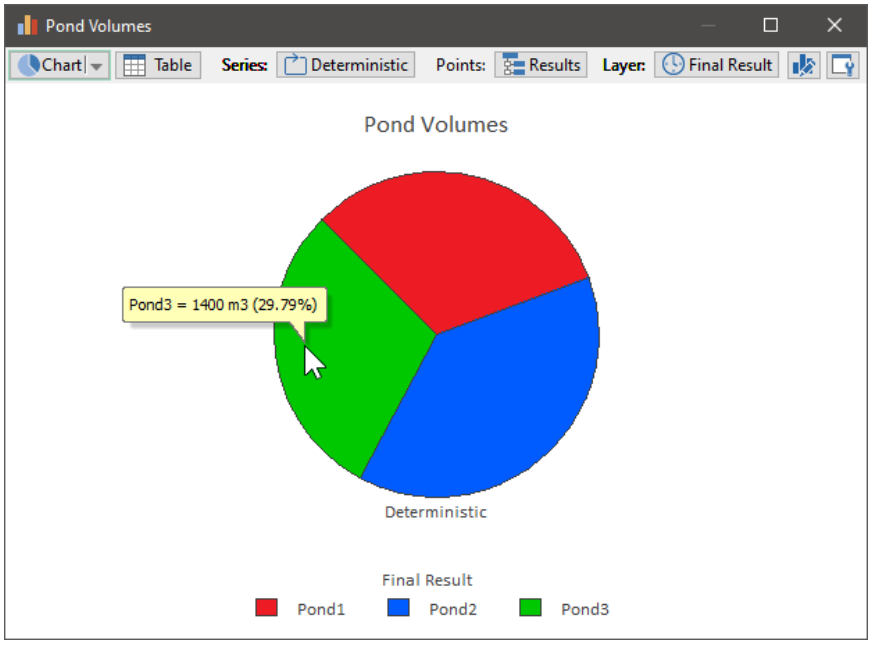
For such a result, there are three meaningful ways that you can choose to display this in a Final Value result. This is a ***column chart***:



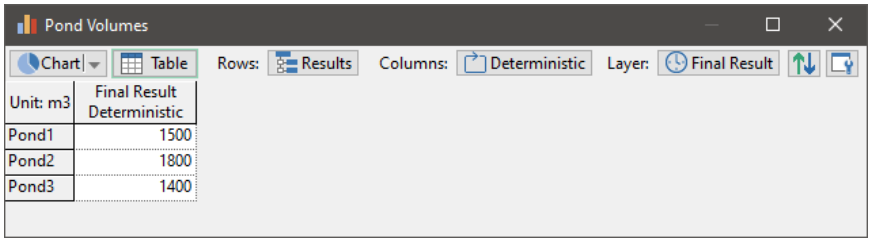
This is a ***bar chart***:

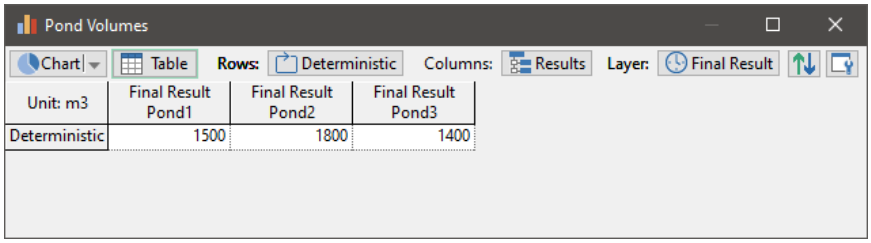


This is a ***pie chart***:



There are two possible ways to view this data in tabular form, either as rows or columns of values:





Overview: Displays of Two-Dimensional Data Sets

We can create a "two-dimensional" data set by running a Monte Carlo simulation. In this case, the final values we would want to look at would likely be statistics (e.g., the mean and some percentiles), although we could also look at all the realizations together (something you would typically not do). The "dimensions" in this case would be the output(s) and the statistic(s) or the output(s) and the realizations. The tabular form of the results (for a Final Value result in which we had three different outputs and were interested in three different statistics) could be viewed in two different ways (since the rows and columns can be switched):

Pond Volumes

Chart | Table | Rows: Results | Columns: Statistics | Layer: Final Result

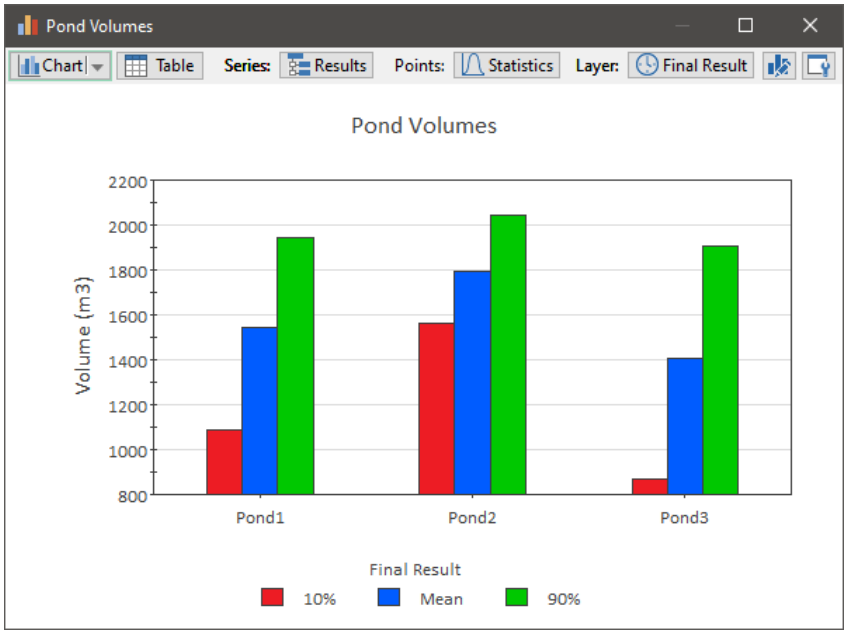
Unit: m3	Final Result 10%	Final Result Mean	Final Result 90%
Pond1	1087.2	1545.5	1946.3
Pond2	1565.5	1796.2	2045.1
Pond3	867.46	1404.7	1908.5

Pond Volumes

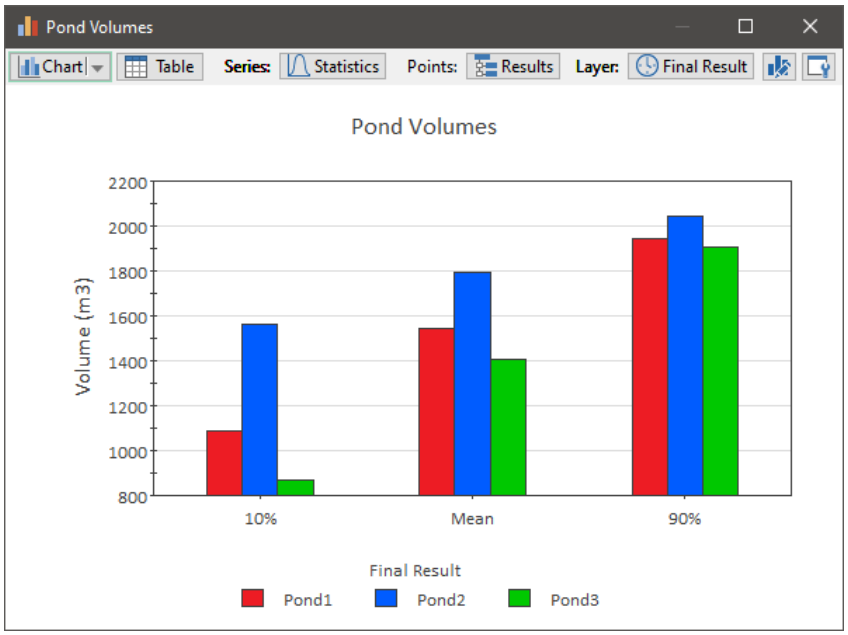
Chart | Table | Rows: Statistics | Columns: Results | Layer: Final Result

Unit: m3	Final Result Pond1	Final Result Pond2	Final Result Pond3
10%	1087.2	1565.5	867.46
Mean	1545.5	1796.2	1404.7
90%	1946.3	2045.1	1908.5

When we move from a "one-dimensional" to a "two-dimensional" data set we can explore and compare the results in more ways. For example, we could produce a ***clustered*** column chart like this:

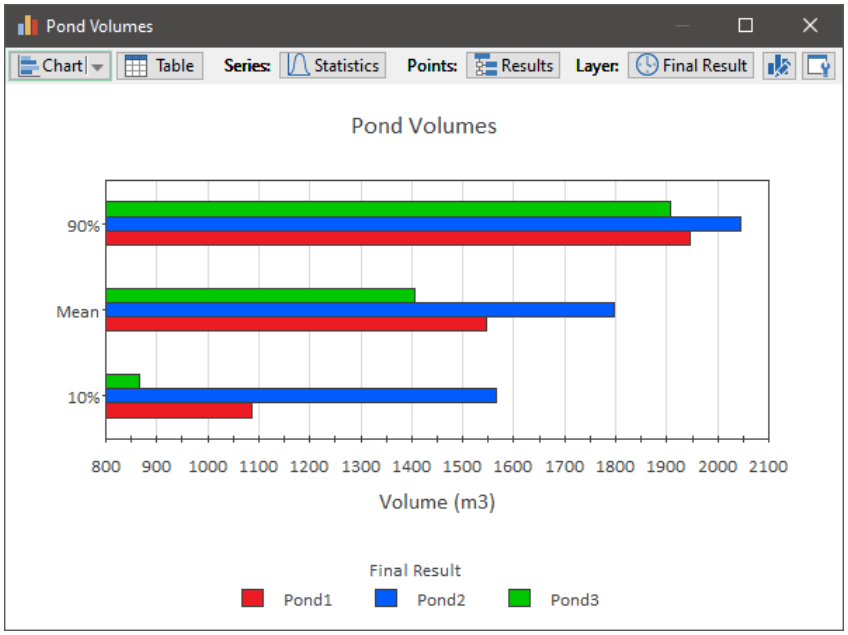


This chart displays three clusters (groups) of columns. Each cluster represents a different output, and each column represents a different statistic for that cluster. The Final Value result, however, can also "flip" how this information is displayed:

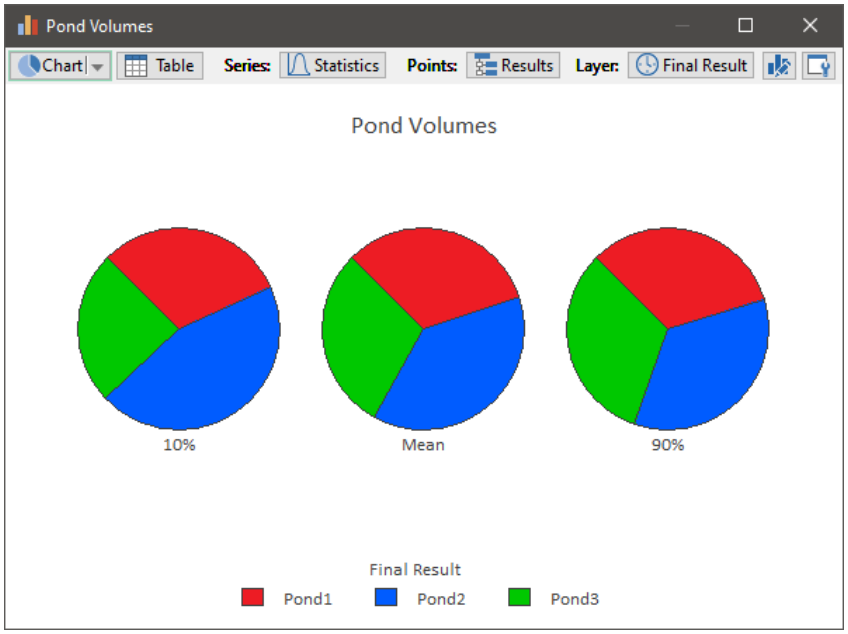


In this case, each group of columns represents a different statistic, and each column represents a different output.

These two displays are in the form of column charts, but we also display bar chart versions of these same results. For example, here is the chart for the same data, shown as a clustered bar chart:

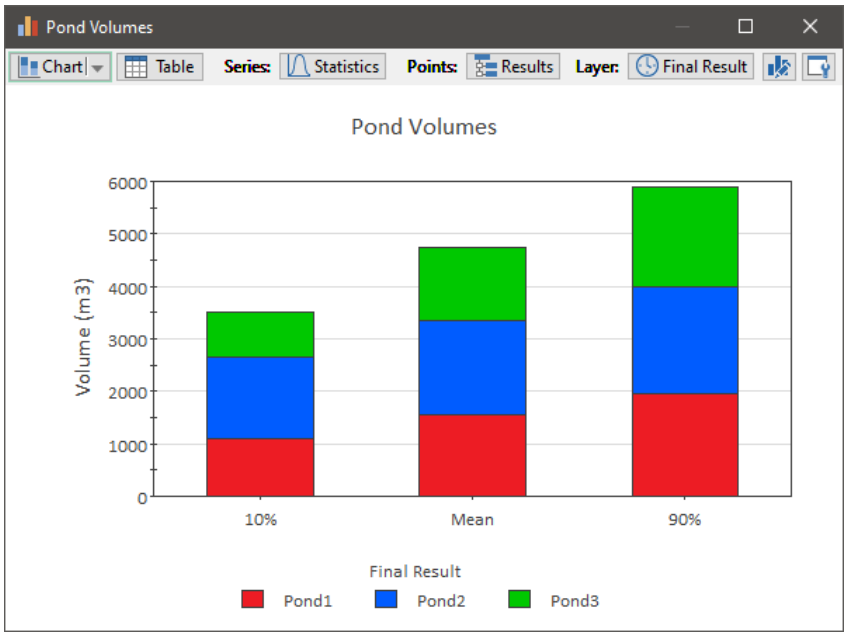


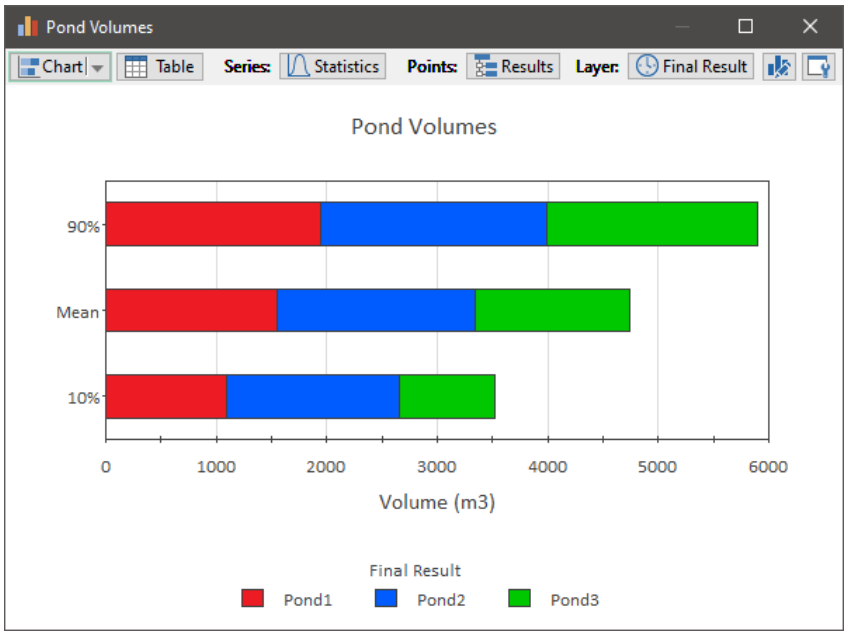
We can also display "two-dimensional" pie charts:



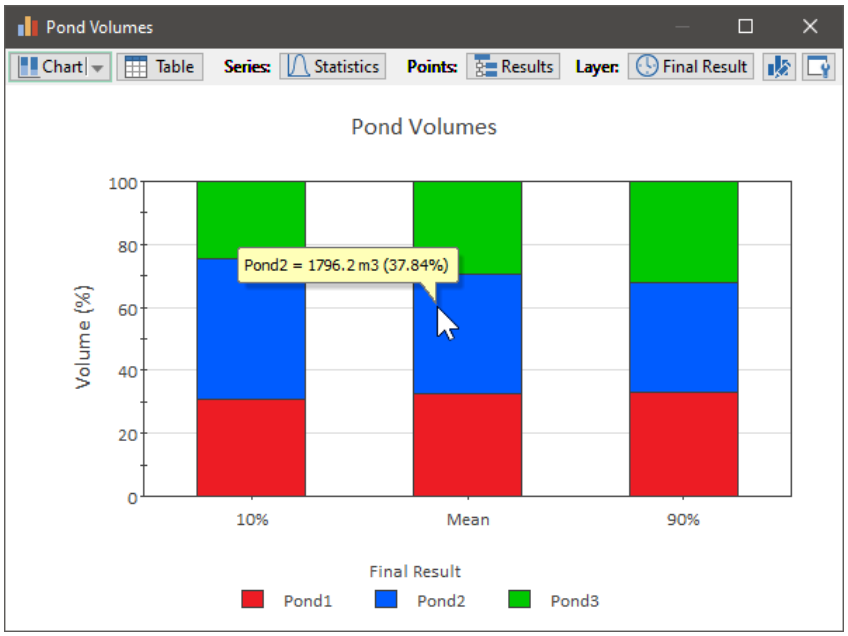
In this case, each pie represents a different statistic, with each pie slice representing a different output. Alternatively, however, we could specify that each pie represents a different output, and each pie slice represents a different statistic.

Finally, having a "two-dimensional" set of data allows us to make use of ***stacked bar*** and ***stacked column*** charts. That is, rather than presenting the data using clusters of columns (or bars), we can present it using stacked columns (or bars):





Stacked bar and column charts can also be displayed as percentages (of all the items in the "stack") rather than values. Here is what the stacked column chart above would look like if displayed as a ***100% stacked column*** chart:

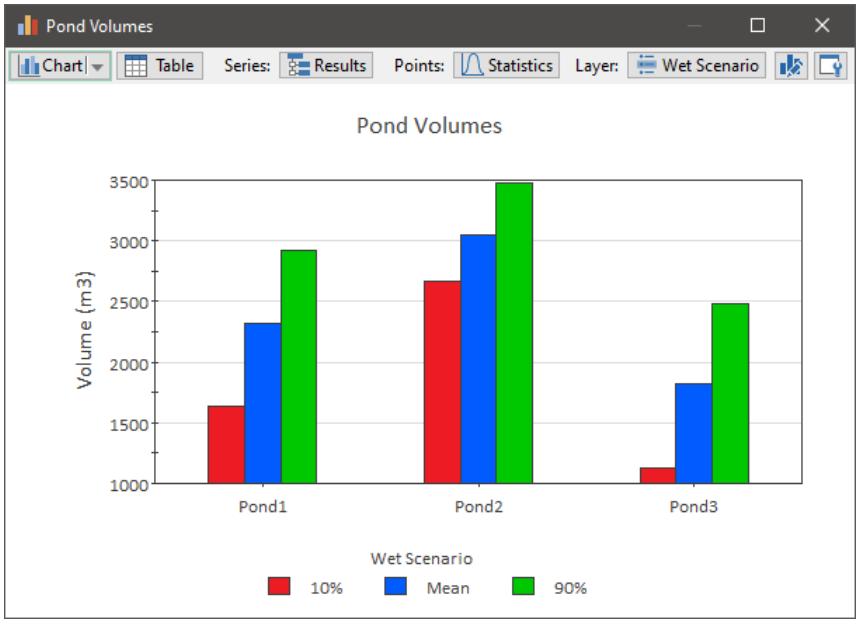


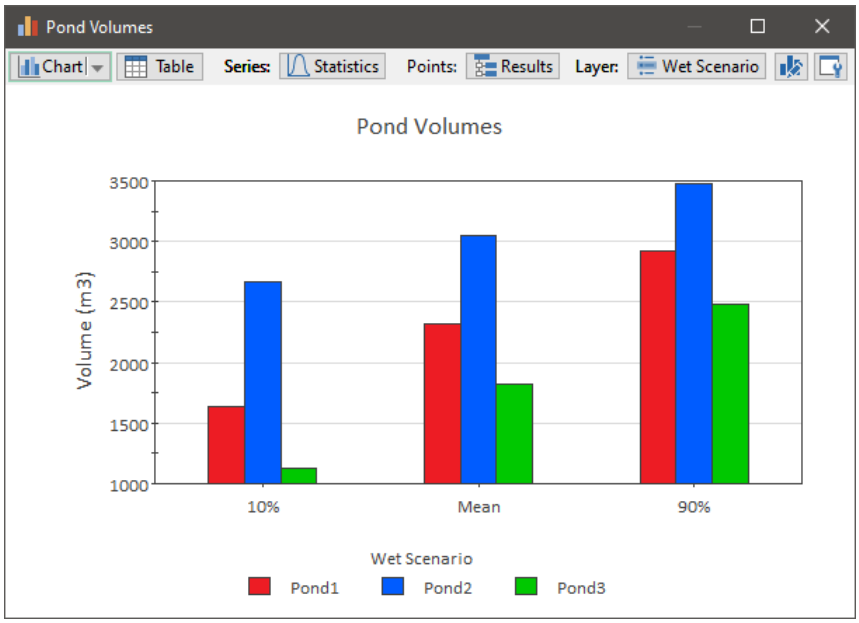
Such a chart is similar to a pie chart (in that all of the sections add to 100%).

Overview: Displays of Three-Dimensional Data Sets

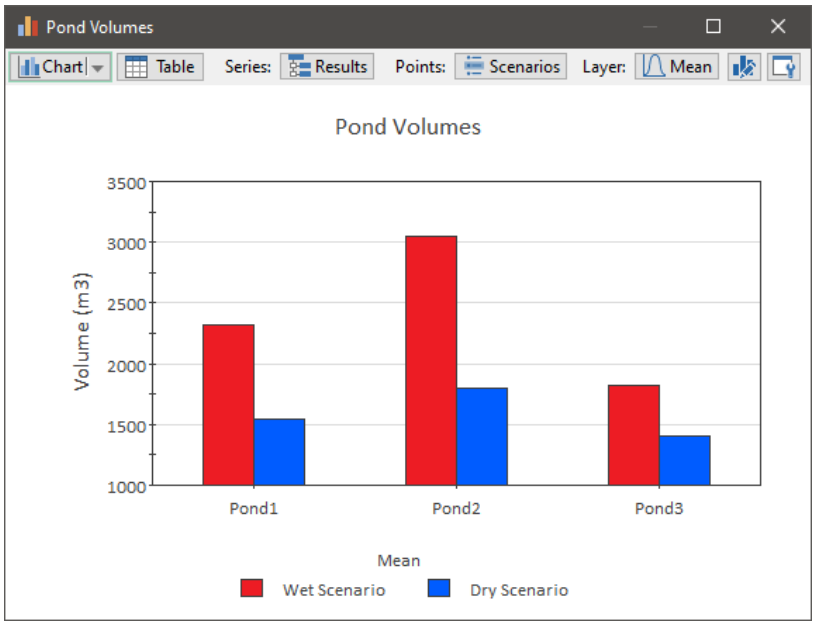
Running a model in different ways can add additional "dimensions" (beyond two) to the set of data that you wish to display. For example, you could run a probablistic model for two different scenarios and display the result for three different outputs. You would then have three "dimensions" of results in the data set (outputs, statistics, scenarios). Charts themselves can not extend beyond "two-dimensions", so when you have three "dimensions" in the set of results, you need to select a single value for one of the dimensions (referred to as the **Layer**) when displaying the chart. But having three dimensions provides great flexibility in how you display the data.

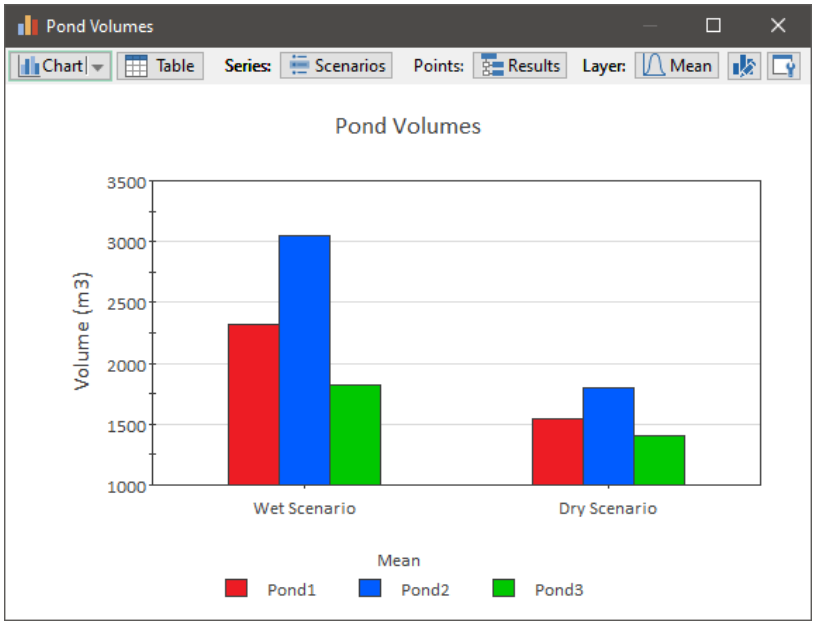
For example, you could choose to display a column chart showing all outputs and all statistics for a particular scenario (in two different ways):



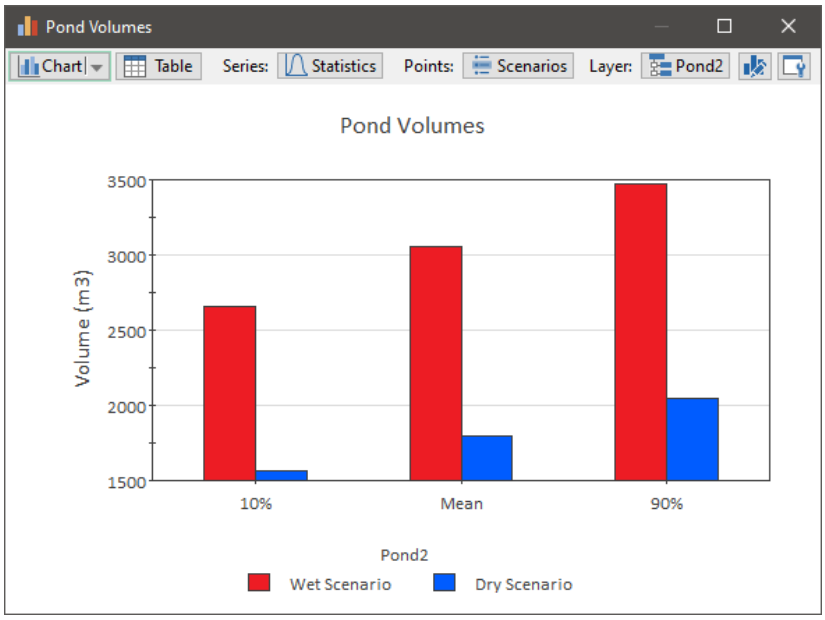


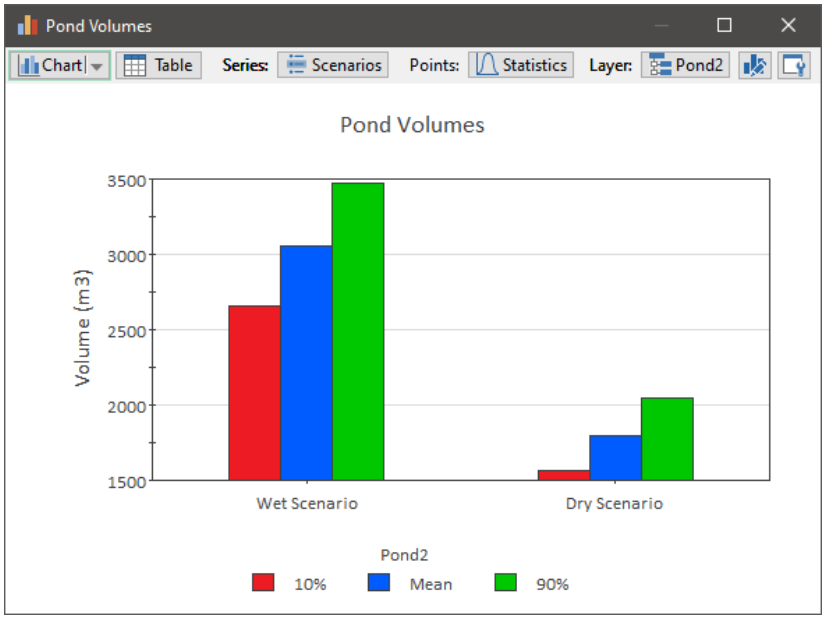
Alternatively, we could choose to display a column chart showing all outputs and all scenarios for a particular statistic (in two different ways):





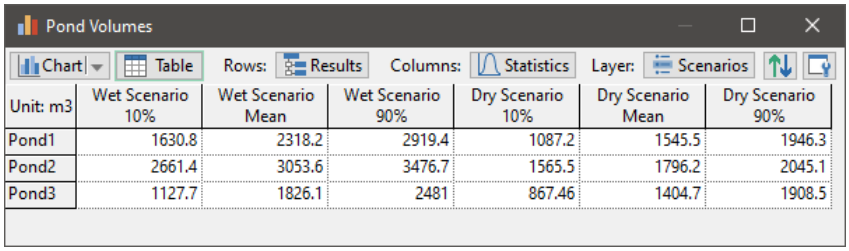
Finally, we could choose to display a column chart showing all scenarios and all statistics for a particular output (in two different ways):





We produced six different column charts displaying the same results in different ways (which allows you to emphasize different aspects of the results). Note that we could have also produced equivalent stacked column charts, bar charts, stacked bar carts, and pie charts (six different charts for each type of display).

The tabular view of this data would look like this (and could also be displayed in multiple ways, by switching what is displayed in the rows and columns):



Unit: m3	Wet Scenario 10%	Wet Scenario Mean	Wet Scenario 90%	Dry Scenario 10%	Dry Scenario Mean	Dry Scenario 90%
Pond1	1630.8	2318.2	2919.4	1087.2	1545.5	1946.3
Pond2	2661.4	3053.6	3476.7	1565.5	1796.2	2045.1
Pond3	1127.7	1826.1	2481	867.46	1404.7	1908.5

In the case of tables, unlike charts, the "third dimension" can be fully displayed (GoldSim simply increases the number of columns).

Overview: Key Features of Final Value Results

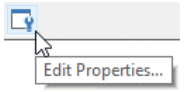
The examples provided in the previous sections do not cover all of the combinations of results that you can display (e.g., we did not show examples of displaying arrays or results for different Capture Times), but what you should conclude from this overview is the following:

- The Final Value result is very flexible, and allows you to produce a variety of charts and tables to display results at the end of the simulation (Final Values) or at defined Capture Times.
- At their most complex level, charts can display up to two "dimensions" of results from higher dimensional data sets (e.g., multiple outputs and multiple statistics for a single scenario; multiple outputs and multiple scenarios for a single statistic, multiple statistics and multiple scenarios for single output).
- Tables can display the full data set selected (by increasing the number of columns).
- The various charts and tables can be displayed and rearranged in a wide variety of ways, giving you great flexibility to emphasize specific aspects of the results.

A simple example file which illustrates the various final value displays (FinalValue.gsm) is in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Viewing the Properties of a Final Value Result

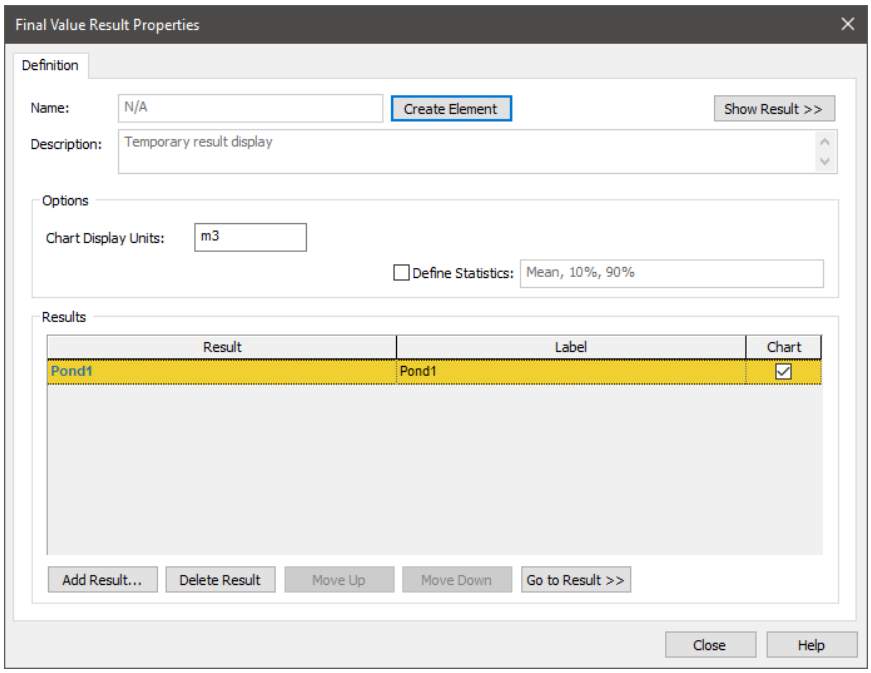
If you create a new Final Value Result element in Edit Mode or you click on the Result Properties button when viewing a Final Value Result chart or table, the Properties dialog for the result will be displayed. The Result Properties button is the furthest button to the right at the top of the display window:



Note that when you press this button while viewing results, it does not close the result display window you were displaying. Both windows are displayed simultaneously (although you can subsequently close one or the other). When viewing results, any changes you make to the Result Properties are immediately represented in the result display.

The Result Properties dialog is always modal. That is, it cannot be minimized, and with the exception of viewing the result display (which can be displayed simultaneously and share the focus with the Properties dialog), it retains the focus while it is displayed. As a result, you must close the Result Properties dialog before you can edit any other part of your GoldSim model.

The Result Properties dialog for an interactive Final Value result looks like this:



At the top of the page is a button to **Create Element**. By pressing this button, a Result element is created. When you do so, the key change that will be noticeable is that the **Name** will now be editable. The **Create Element** button becomes an **Appearance** button (which is used to modify the appearance of the element itself).

Read more: Creating and Using Result Elements (page 593).

The **Show Result >>** button opens a result display window (while keeping the Properties dialog simultaneously open.

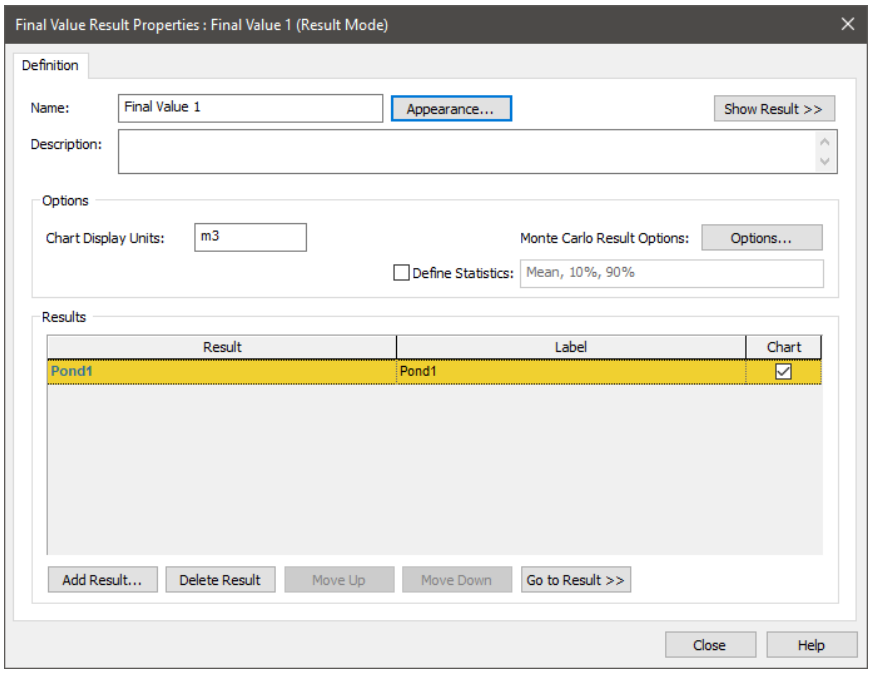
Read more: Displaying Final Value Results (page 712).

In many cases, you will want to compare multiple outputs. The **Add Result…** button allows you to add other results to the chart. Results can be deleted with the **Delete Result** button. The order in which multiple results appear in the list can be changed using the **Move Up** and **Move Down** buttons. Pressing **Go to Result >>** closes the Properties dialog and selects the element associated with the result in the graphics pane.

Note: You cannot add a Condition output to a Final Value result. Only values can be displayed.

For each result in the list, you must specify whether or not the result is to be included when displaying charts (**Chart**). Results do not need to have the same unit dimensions. Results with different dimensions can be displayed in tables. However, all results shown in a chart must have the same dimensions (and units). Hence, if you select the **Chart** box for a result, any other results that are selected but have different dimensions will be automatically deselected. You can also specify the **Chart Display Units** for the result (which overrides the display units specified within the elements property dialogs for the selected results).

The Properties dialog for a Final Value Result element has several differences:

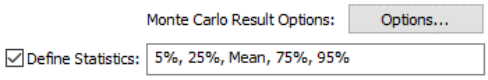


The **Create Element** button is replaced by an **Appearance** button (which is used to modify the appearance of the element itself).

- The **Name** (and **Description**) are editable (since this is an element).
- An **Options…** button is available that provides access to the Monte Carlo Result Display Properties. This is used to define the default statistics displayed for Final Value results for multi-realization simulations (see below).

Read more: Controlling Monte Carlo Result Options (page 500).

If you have run multiple realizations, Final Value results can be used to view and compare ***statistics*** of the result values (e.g., mean, median, specified percentiles). The ***default statistics*** (that appear for all Final Value results in the model) are specified in the Monte Carlo Result Display Properties dialog (accessed via the **Options…** button in the Final Value Result Properties dialog). These default statistics automatically appear (grayed out) in the dialog directly below the **Options…** button. However, you can override these defaults for the specific Final Value Result element you are viewing by checking the **Define Statistics** box. When you do so, you can specify which statistics you wish to view in this Result element:



When defining these statistics, the following should be noted:

- Values can be separated by commas, spaces or semicolons (the latter two are converted to commas).
- Percentiles can be entered as percentages (between 0% and 100% inclusive) or numbers (between 0 and 1 inclusive).
- 50% can also be entered as the word “median”.
- 0% and 100% can be entered as the words “min” and “max”, respectively.

If you clear the **Define Statistics** box, they revert to the default statistics specified in the Monte Carlo Result Display Properties dialog.

Note: Final Value results use the same algorithms as Distribution results to compute statistics These are discussed in detail in Appendix B .

Understanding How Final Value Displays are Specified

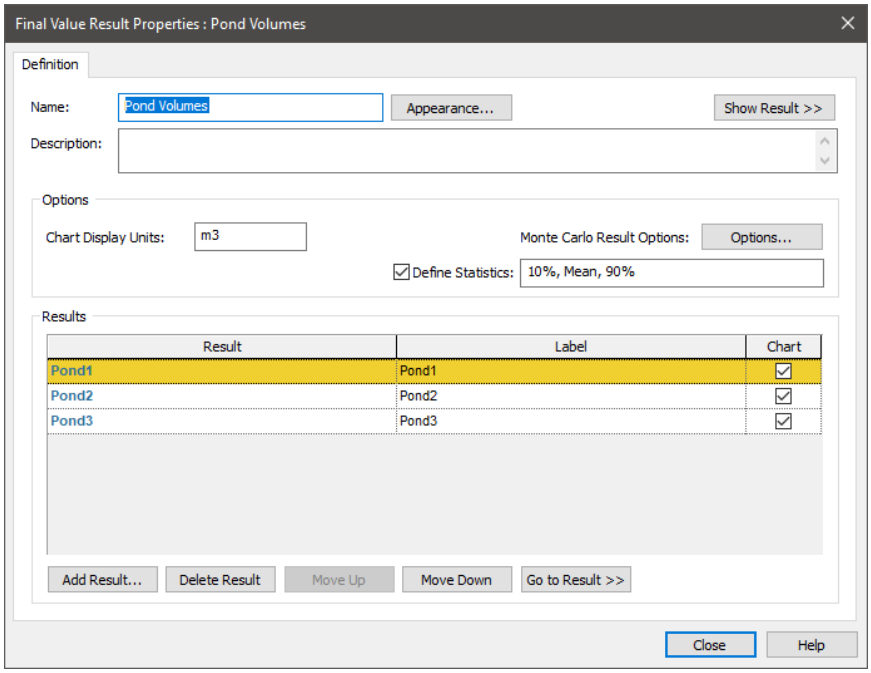
Final Value results are used to carry out side-by-side ***comparisons*** of different types of results. To use them, you need to carefully specify what you wish to compare and how you want to display that comparison. Depending on how your model has been run (e.g., multiple realizations, multiple scenarios, multiple Capture Times) and the outputs you have specified to compare (e.g., one output, multiple outputs, vector items), there can be a large variety of ways to display the comparison.

In order control how Final Value results are displayed, it is important to understand that for any specific type of run and collection of outputs that you have specified for comparison, there are from one to four "dimensions" of date used to create the display.

Final Value results can be viewed as a table, or as one of several different charts (bar, column, stacked bar, stacked column, or pie). The easiest way to understand the various "dimensions" of the results you wish to view in a Final Value result is to first consider the results displayed as tables.

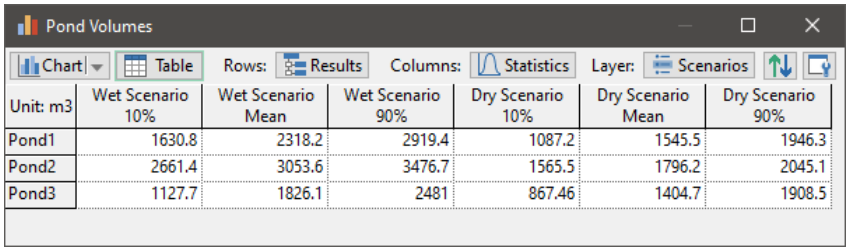
Read more: Overview of Final Value Results (page 695).

Let's consider a Final Value Result element in which we have defined three scalar outputs:



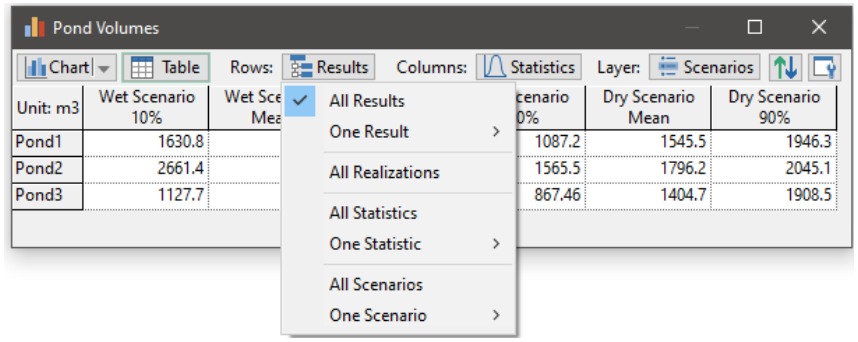
Let's further assume that we have run multiple realizations (and wish to view three statistics, the 10th percentile, the Mean and the 90th percentile), and have run two scenarios. If we were to run all scenarios, we would find that we have a "three dimensional" data set that we wish to view. The three "dimensions" are the outputs, the statistics and the scenarios. We can think of this as a "cube" of

results. The table view of this in a Final Value Result element would look like this:

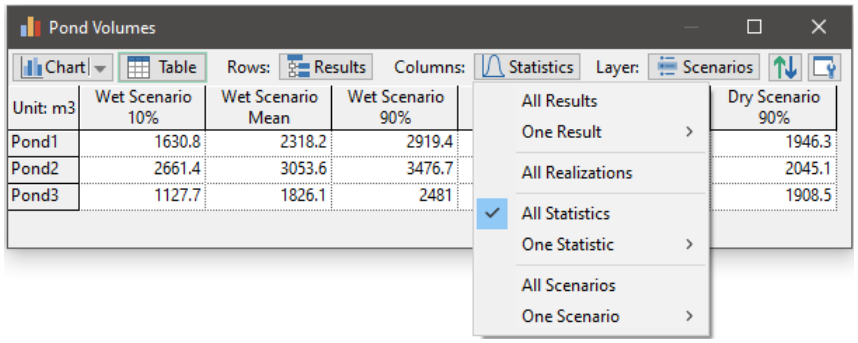


Unit: m3	Wet Scenario 10%	Wet Scenario Mean	Wet Scenario 90%	Dry Scenario 10%	Dry Scenario Mean	Dry Scenario 90%
Pond1	1630.8	2318.2	2919.4	1087.2	1545.5	1946.3
Pond2	2661.4	3053.6	3476.7	1565.5	1796.2	2045.1
Pond3	1127.7	1826.1	2481	867.46	1404.7	1908.5

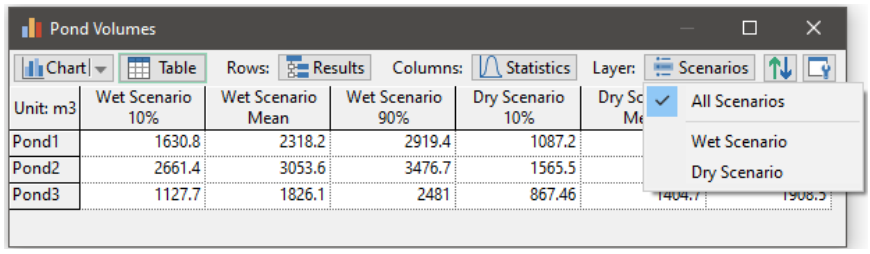
If we click on the **Rows** button, we see that there are a number of options, and what is selected is "All Results":



If we click on the **Columns** button, we see that there are a number of options, and what is selected is "All Statistics":

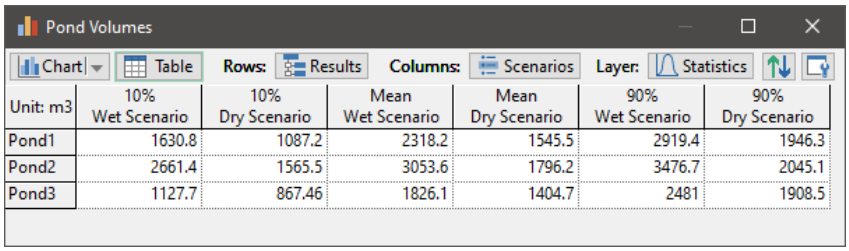


Finally, if we click on the **Layer** button, we see that there are a number of options, and what is selected is "All Scenarios":



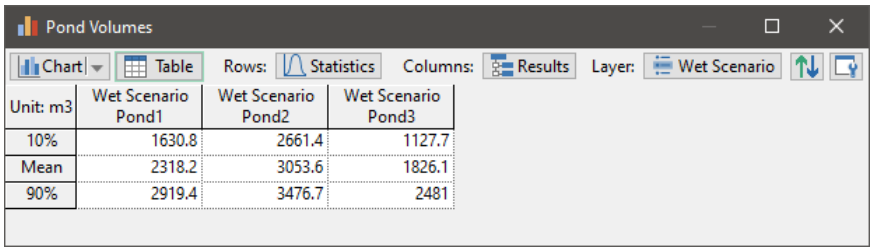
So in this particular table, we are showing all results (a cube of data of dimension 3 x 3 x 2), in which the rows are the outputs, the columns are the statistics and the layers are the scenarios.

We can change how this table is displayed. For example, we could specify that that rows are the results, the columns are the scenarios and the layers are the statistics:



Unit: m3	10% Wet Scenario	10% Dry Scenario	Mean Wet Scenario	Mean Dry Scenario	90% Wet Scenario	90% Dry Scenario
Pond1	1630.8	1087.2	2318.2	1545.5	2919.4	1946.3
Pond2	2661.4	1565.5	3053.6	1796.2	3476.7	2045.1
Pond3	1127.7	867.46	1826.1	1404.7	2481	1908.5

As another example, we could specify that the rows are the statistics, the columns are the outputs, and only one layer (one scenario) is displayed:



Unit: m3	Wet Scenario Pond1	Wet Scenario Pond2	Wet Scenario Pond3
10%	1630.8	2661.4	1127.7
Mean	2318.2	3053.6	1826.1
90%	2919.4	3476.7	2481

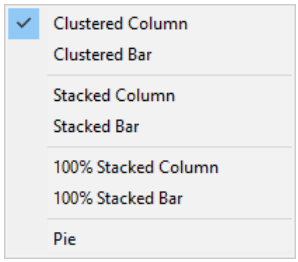
The point here is that you have the ability to assign any of the dimensions (in this example, results, statistics and scenarios) to the rows, columns or layers. Moreover, you can display all of the items in a dimension (i.e., all results, all statistics, all scenarios) or choose to display only one (e.g., a specified result, statistic or scenario). This allows you to emphasize any particular aspect of the results in the table.

Of course, Final Value results also can be displayed as charts. You can switch back and forth between a chart and a table display by pressing the **Chart** or **Table** button, respectively.

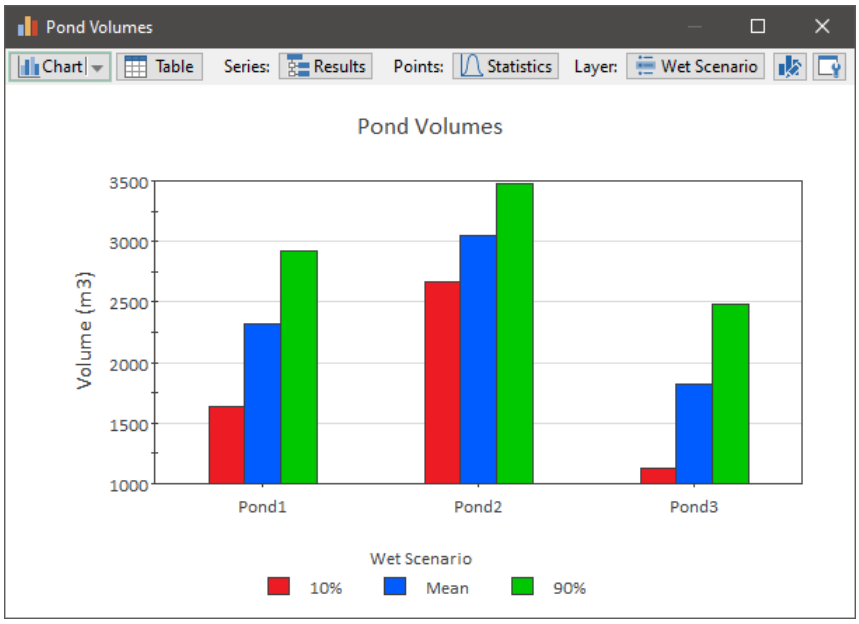
Note: When viewing a Final Value Result element, the element "remembers" the last type of view that was displayed, and displays that view when you double-click on it.

Read more: Creating and Using Result Elements (page 593).

Seven different charts can be selected and displayed (from the **Chart** drop-list):



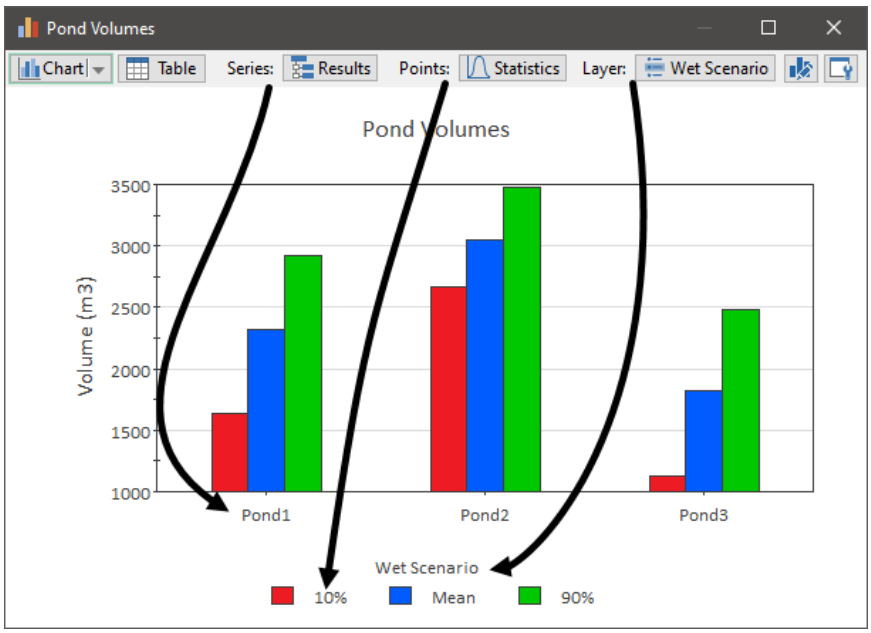
When displaying charts, the **Rows** and **Columns** terminology is no longer applicable (the charts are not presented as rows and columns). Instead, the first "dimension" is referred to as the **Series** and the second "dimension" is referred to as the **Points**:



In this column chart, the **Series** is "All Results" and the **Points** are "All Statistics".

Unlike tables, in a chart, only one **Layer** can be displayed. That is, charts can only display two "dimensions". So in this example, we are displaying a particular scenario (the "Wet Scenario"). As was the case for tables, when viewing charts you have the ability to assign any of the dimensions (in this example, results, statistics and scenarios) to the **Series**, **Points** or **Layer** in order to emphasize a particular aspect of your results.

The figure below illustrates how each of the dimensions is represented in a Final Value chart:



In particular,

- The **Series** is mapped to the label(s) on the axis (X for column charts and Y for bar charts), or for pie charts, the label(s) below the pie(s).
- The **Points** are used to identify to the item(s) in the legend.
- The **Layer** being viewed is identified in the legend title.

Several points should be noted regarding how charts are displayed:

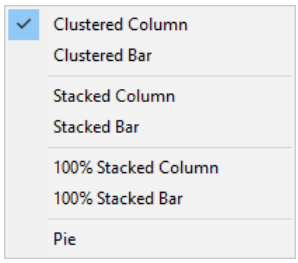
- If you have only a single result, a single realization, no scenarios and no capture times, the result set not very meaningful to display as a Final Value result, as it represents a single data point (and hence there is nothing to compare).
- If you have a "one-dimensional" set of results (e.g., 3 different outputs with a single realization and no Capture Times or scenarios), you can view a bar, column or pie chart, but stacked bar and stacked column charts are not applicable. In this case, there is not a second "dimension" to stack, so a stacked column (or bar chart) would simply look identical to a column (or bar) chart.
- Charts themselves can not extend beyond "two-dimensions", so when you have three "dimensions" in the set of results, you need to select a single value for one of the dimensions (the **Layer**) when displaying the chart.
- Array displays in a Final Value result can actually have "four dimensions". In order to view a chart, multiple dimensions need to be fixed to a single value.

  Read more: Displaying Final Value Results for Vectors (page 725); Displaying Final Value Results for Matrices (page 729).

Displaying Final Value Results

Final Value results can be viewed as a table, or as one of several different charts (bar, column, stacked bar, stacked column, or pie).

In particular, seven different charts can be displayed:



Depending on the type of run and collection of outputs that you have specified for comparison in a Final Value result, there are typically from one to three "dimensions" which you can select from in order to create the display (for array displays, there can be four). These "dimensions" can be defined by:

- The output(s);
- Realization(s) or statistic(s) generated from those realizations;
- Scenario(s);
- Capture Time(s); and
- Result items in an array row or column of a vector or matrix output.

Read more: Understanding How Final Value Displays are Specified (page 708).

In the sections below, the use of each of these various "dimensions" in Final Value result displays is summarized.

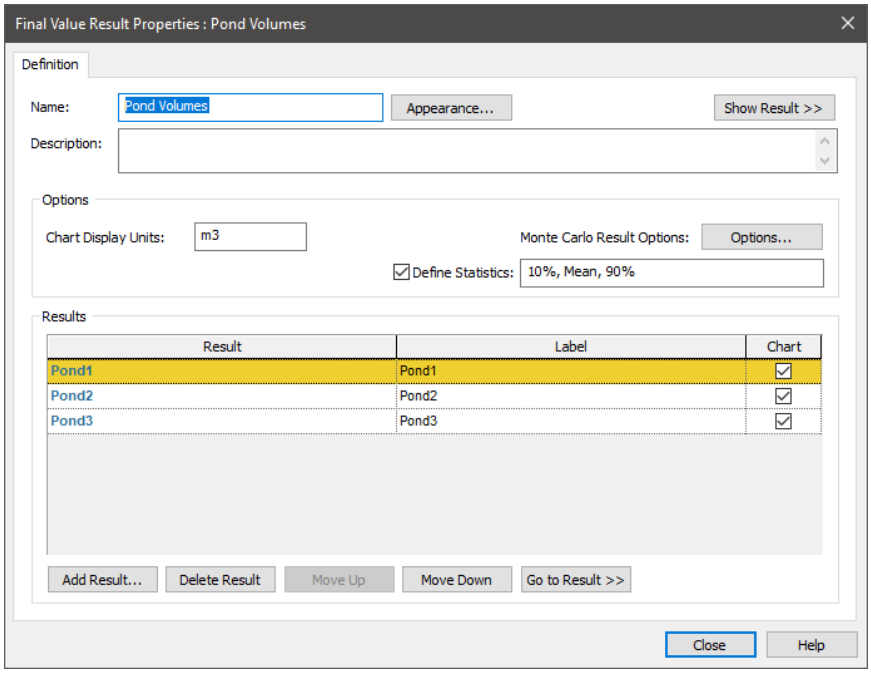
Displaying Multiple Outputs in Final Value Results

One of the most common types of Final Value results you might want to display is simply the comparison of multiple outputs.

To do so, you would need to add the outputs you wished to display using the Properties dialog.

Read more: Viewing the Properties of a Final Value Result (page 705).

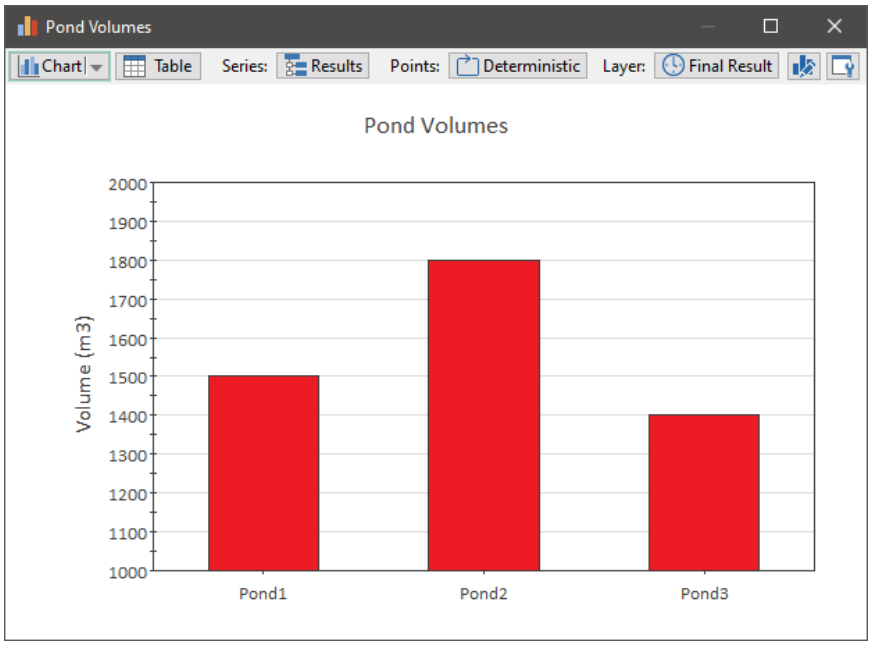
In the example below, there are three scalar outputs specified:

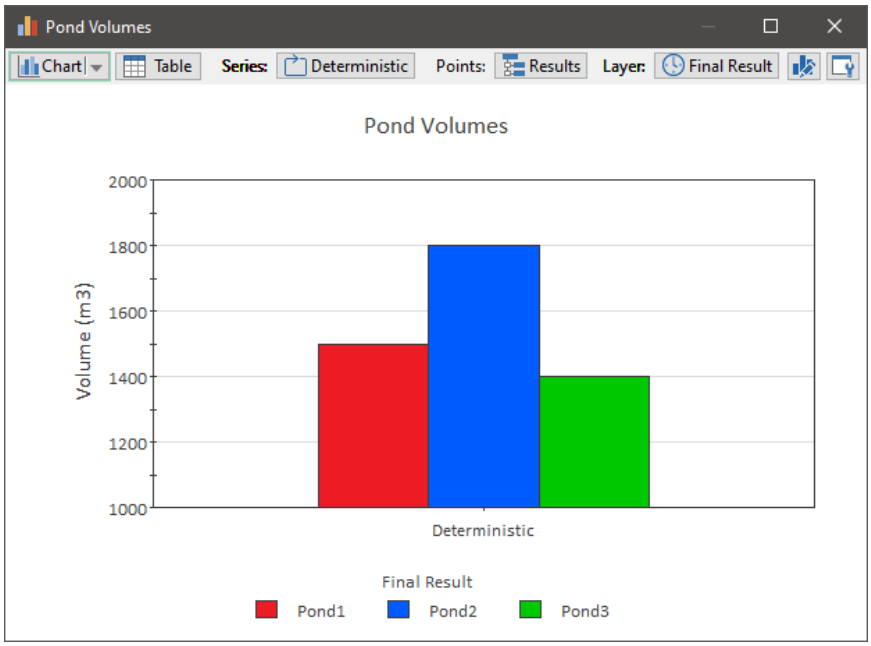


For each result in the list, you can specify whether or not the result is to be included when displaying charts (**Chart**). Results do not need to have the same unit dimensions. Results with different dimensions can be displayed in tables. However, all results shown in a chart must have the same dimensions (and units). Hence, if you select the **Chart** box for a result, any other results that are selected but have different dimensions will be automatically deselected.

When you are viewing a Final Value Result element in a model in which you have defined multiple scalar outputs, when viewing a table you will be able to select "All Results" (or a single result) for the **Rows**, **Columns** or **Layer**. When viewing a chart you will be able to select "All Results" (or a single result) for the **Series** or **Points**, or select a single result for the **Layer**. This provides a great deal of flexibility for displaying results.

For example, if you could choose to display a chart showing all outputs in two different ways:





Of course, we could also display other types of charts (e.g., bar charts, pie charts).

Read more: Overview of Final Value Results (page 695).

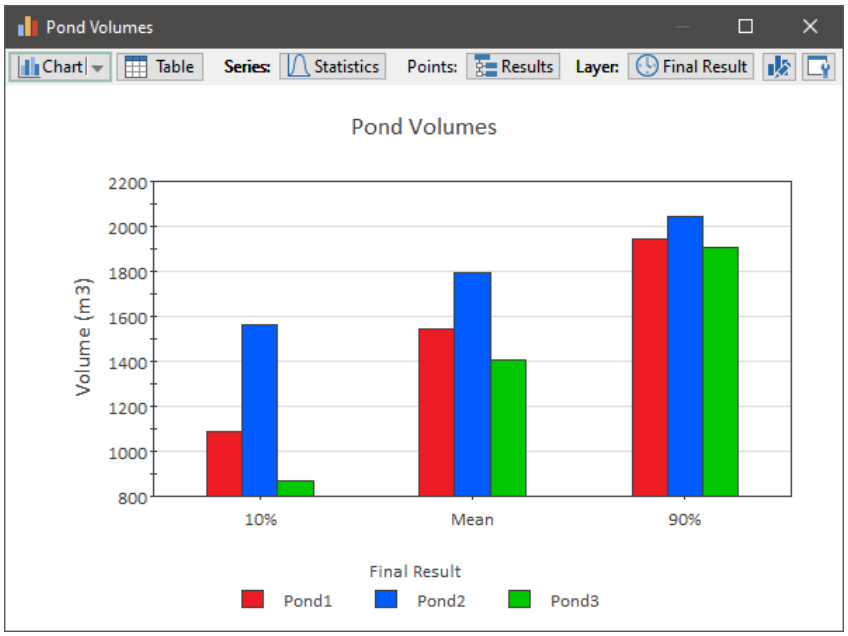
If you added a second (or third) "dimension" to the results (e.g., by running multiple realizations, specifying Capture Times and/or running scenarios), you could display results for a particular Capture Time or scenario, or could display, for example, the statistics and Capture Times for any selected output.

Read more: Displaying Multiple Realizations in Final Value Results (page 715); Displaying Scenarios in Final Value Result Elements (page 717); Displaying Capture Times in Final Value Results (page 722).

Displaying Multiple Realizations in Final Value Results

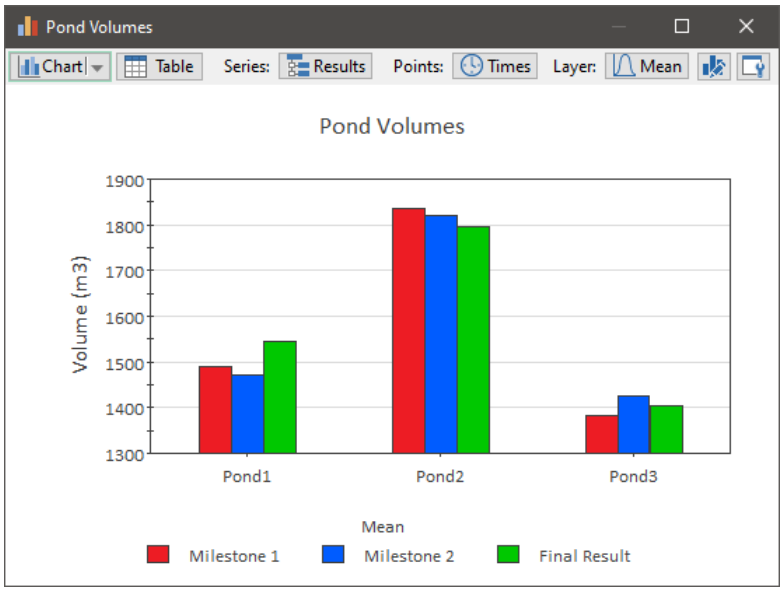
When you are viewing a Final Value result in a model in which you have run multiple realizations, when viewing a table or chart you can view probabilistic results by selecting "All Realizations", "All Statistics" or a single statistic for the **Rows/Series** or **Columns/Points**. This provides a great deal of flexibility for displaying probabilistic results in a Final Value display.

For example, if you were viewing multiple outputs and ran multiple realizations, you could choose to display a chart showing all outputs and all statistics in two different ways:



Note: You could also view "All Realizations", but while the table display may be useful, this typically would not produce a very meaningful chart display.

If you added a third "dimension" to the results (e.g., by specifying Capture Times or running scenarios), you could display these results for a particular Capture Time or scenario, or could display, for example, all the outputs and Capture Times for any selected statistic:



Read more: Displaying Scenarios in Final Value Result Elements (page 717); Displaying Capture Times in Final Value Results (page 722).

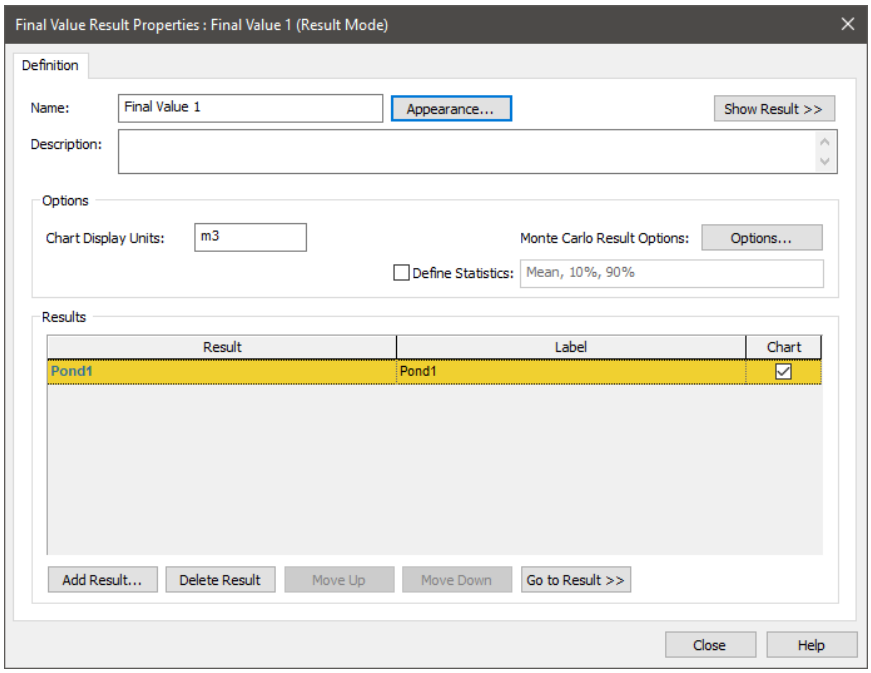
Of course, we could also display other types of charts (bar charts, stacked bar or column charts, or pie charts).

Read more: Overview of Final Value Results (page 695).

The statistics that can be displayed for multiple realization runs can be specified in two different ways: using ***default statistics*** or local statistics. Default statistics (that appear for all Final Value results in the model) are specified in the Monte Carlo Result Display Properties dialog (accessed via the **Options…** button in the Final Value Result Properties dialog).

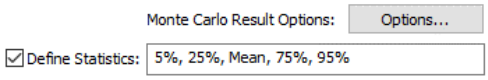
Read more: Viewing the Properties of a Final Value Result (page 705).

These default statistics automatically appear (grayed out) in the dialog directly below the **Options…** button in the Final Value Result Properties dialog (in the example below, Mean, 10% and 90% are the default statistics):



Read more: Controlling Monte Carlo Result Options (page 500).

However, you can override these defaults for the specific Final Value Result element you are viewing by checking the **Define Statistics** box to define the statistics locally. When you do so, you can specify which statistics you wish to view in this Result element. For example:



When defining these statistics, the following should be noted:

- Values can be separated by commas, spaces or semicolons (the latter two are converted to commas).
- Percentiles can be entered as percentages (between 0% and 100% inclusive) or numbers (between 0 and 1 inclusive).
- 50% can also be entered as the word “Median”.
- 0% and 100% can be entered as the words “Min” and “Max”, respectively.

If you clear the **Define Statistics** box, they revert to the default statistics specified in the Monte Carlo Result Display Properties dialog.

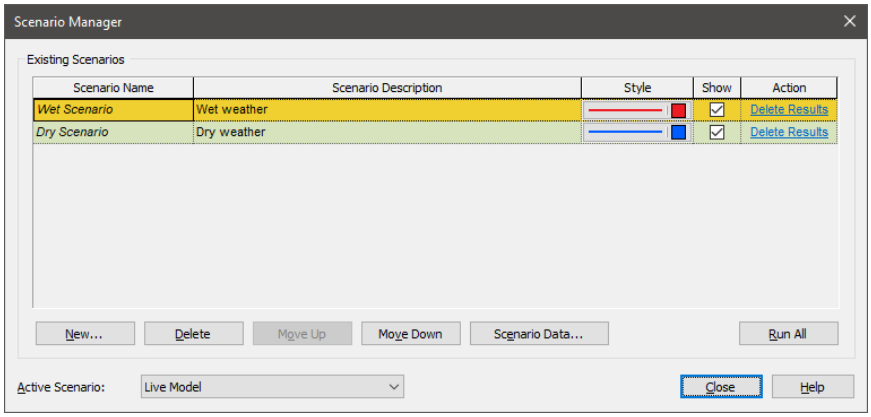
Note: Final Value results use the same algorithms as Distribution results to compute statistics These are discussed in detail in Appendix B .

Displaying Scenarios in Final Value Result Elements

GoldSim’s scenario modeling capability allows you to directly compare results generated by different sets of input parameters. In effect, when you use this capability, your model can store (and subsequently compare) multiple sets of results (and inputs).

Read more: Creating, Running and Comparing Scenarios (page 525).

When a model is in Scenario Mode, Final Value Result elements can be used to view scenario results as one of the "dimensions". In order for scenario results to be displayed in a Final Value Result element, the **Show** button must be checked for each scenario to be displayed in the Scenario Manager (accessed from the main menu (**Run | Scenario Manager…**) or by pressing **F7**):

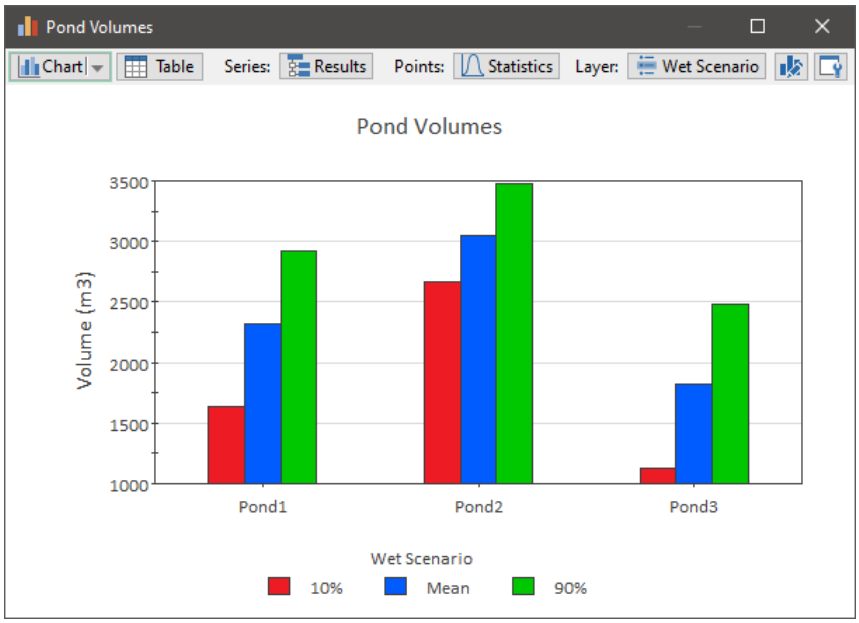


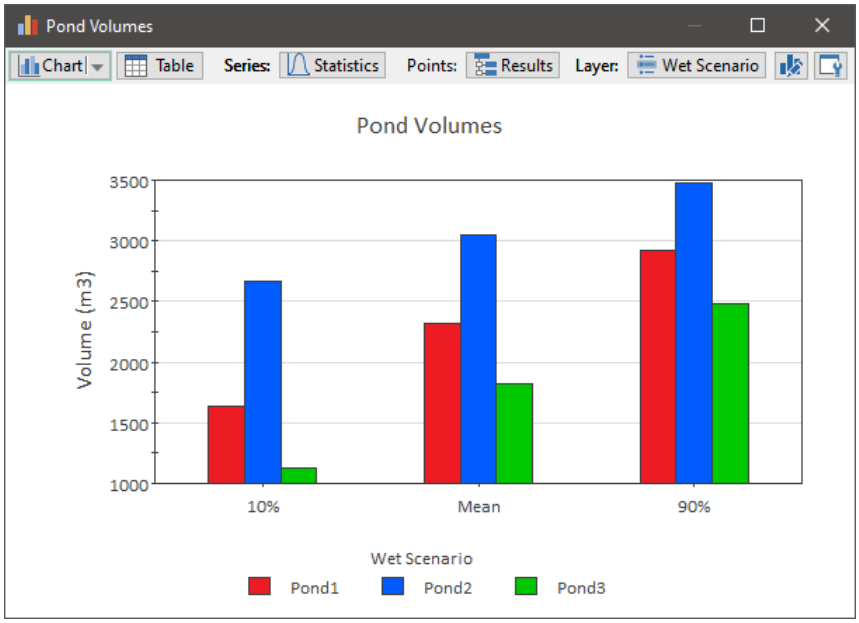
In this example, the **Show** box is checked for both scenarios, so bothe will be displayed in results.

Note: Capture Times cannot be viewed in Scenario Mode (i.e., only the Final Result can be viewed). That is, if you are running scenarios and viewing results using Final Value Result elements you cannot view results for scenarios at specified Capture Times. You can only view scenario results for the Final Result.

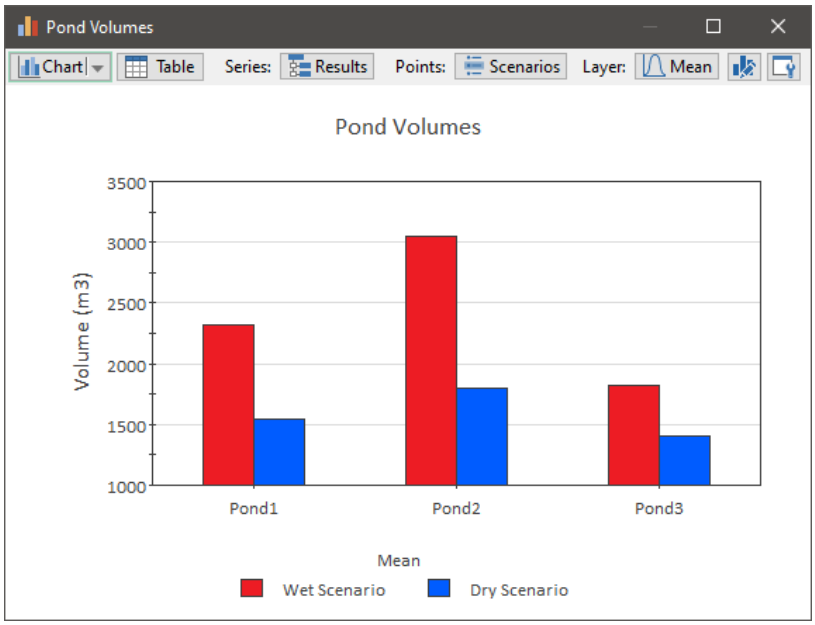
When you are viewing a Final Value Result element in Scenario Mode, when viewing a table you will be able to select "All Scenarios" (or a single scenario) for the **Rows**, **Columns** or **Layer**. When viewing a chart you will be able to select "All Scenarios" (or a single scenario) for the **Series** or **Points**, or select a single scenario for the **Layer**. This provides a great deal of flexibility for displaying scenario results.

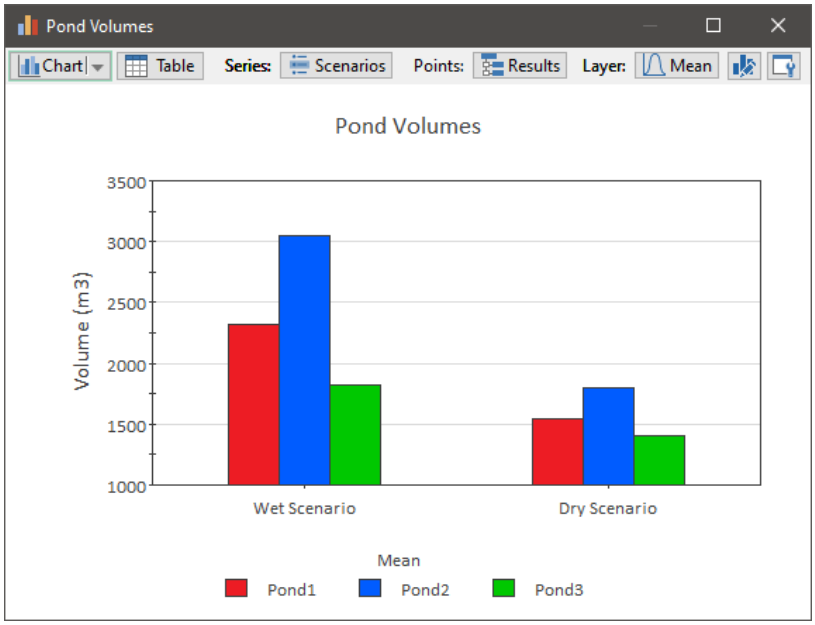
For example, if you were viewing multiple outputs and multiple realizations, you could choose to display a chart showing all outputs and all statistics for a particular scenario (in two different ways):



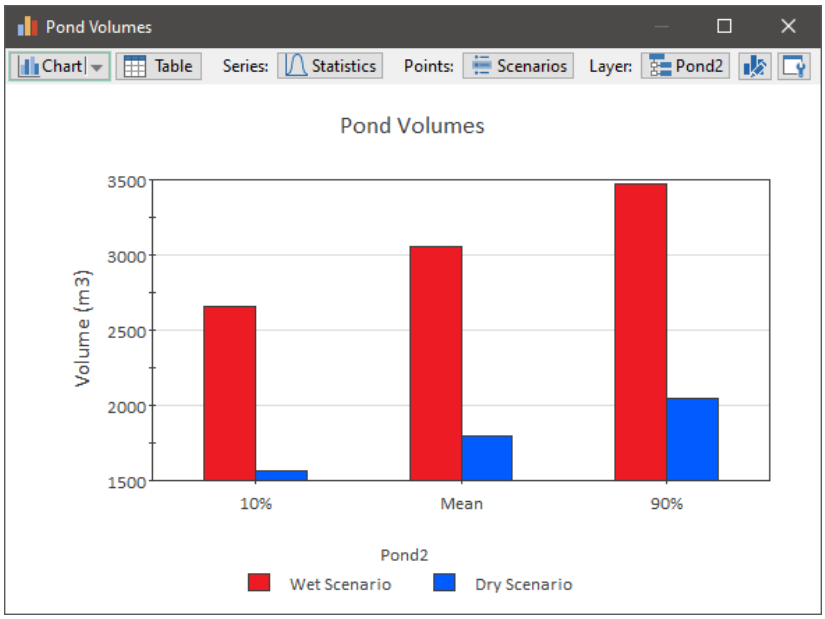


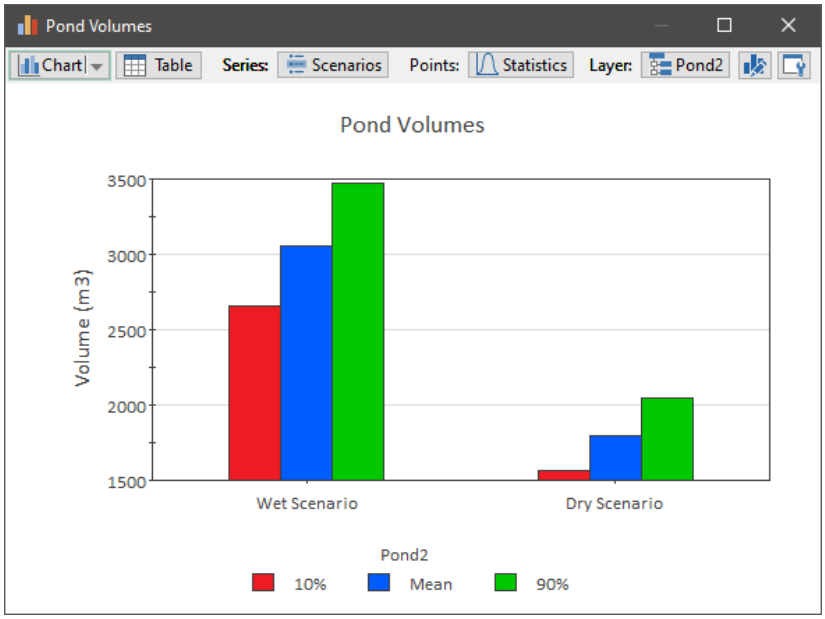
Alternatively, you could choose to display a chart showing all outputs and all scenarios for a particular statistic (in two different ways):





Finally, you could choose to display a chart showing all scenarios and all statistics for a particular output (in two different ways):





Of course, we could also display other types of charts (bar charts, stacked bar or column charts, or pie charts).

Read more: Overview of Final Value Results (page 695).

Note: When you define a scenario in the Scenario Manager you can specify a **Style**. When viewing other types of results (Time History, Distribution) these are used to define the color and style of the items (e.g., lines) representing that scenario in the chart. However, this does not apply for Final Value results. The colors of the bars, columns or pie slices in a Final Value chart are auto-selected and cannot be controlled by the user.

Displaying Capture Times in Final Value Results

As their name indicates, Final Value results operate on Final Values. That is, they allow you to view and compare values at the end of each realization.

In some cases, however, you may also want to view and compare results at other times in the simulation (rather than just the end of the simulation). This can be useful, for example, if you wanted to compare the value of different outputs at several different "snapshots" in time during a simulation. GoldSim facilitates this by allowing you to create ***Capture Times*** at which these results are also made available. In particular, Final Value Result elements allow the Capture Time to be specified as one of the "dimensions".

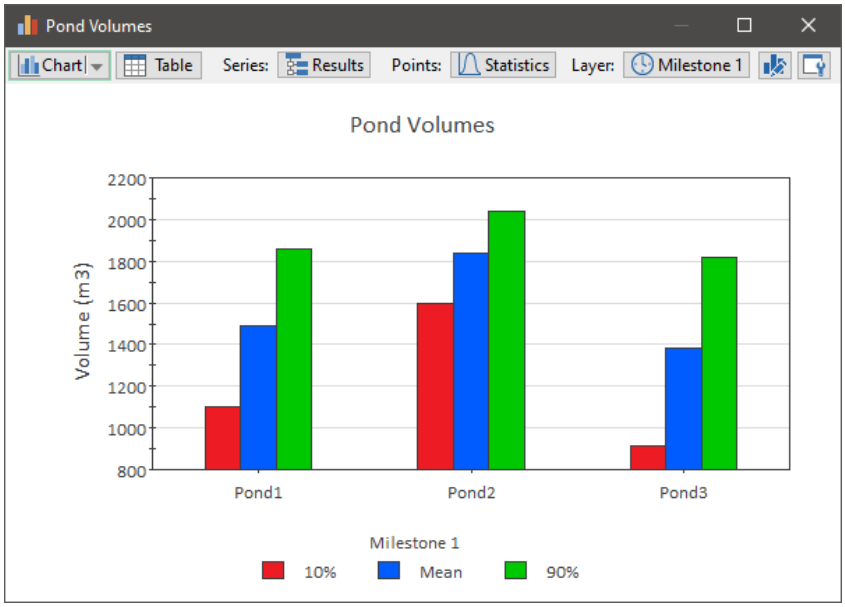
Read more: Creating Capture Times for Results (page 488).

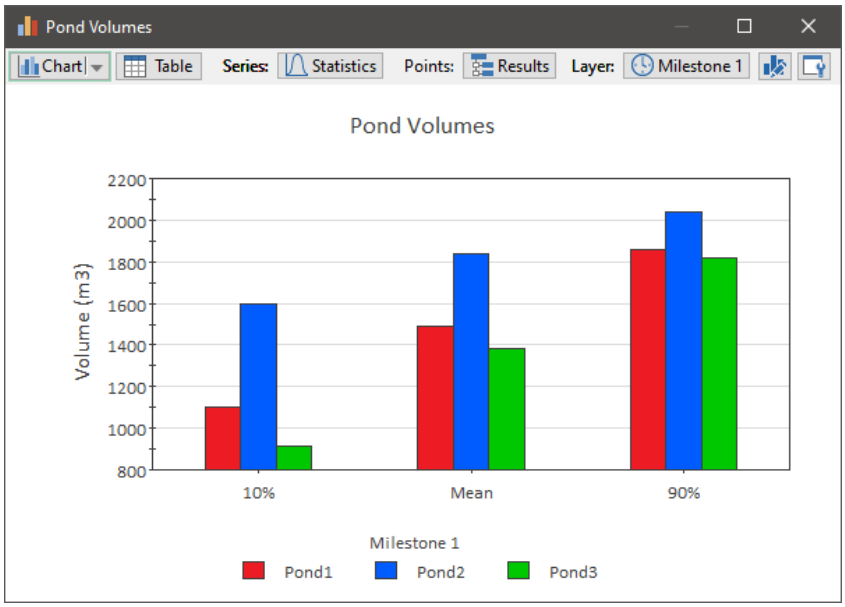
Note: Capture Times cannot be viewed in Scenario Mode (i.e., only the Final Result can be viewed). That is, if you are running scenarios and viewing results using Final Value Result elements you cannot view results for scenarios at specified Capture Times. You can only view scenario results for the Final Result.

Read more: Creating, Running and Comparing Scenarios (page 525).

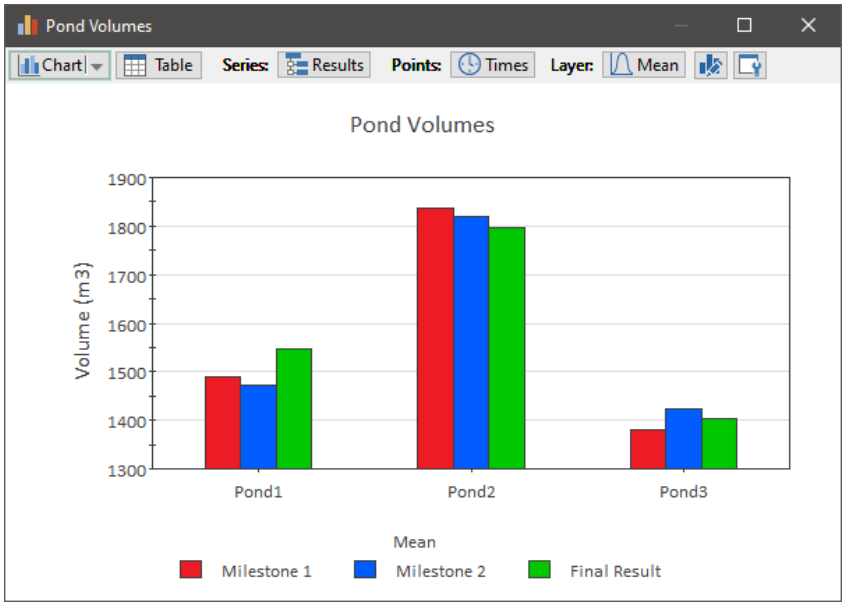
When you are viewing a Final Value result in a model in which you have defined Capture Times, when viewing a table you will be able to select "All Capture Times" (or a single Capture Time) for the **Rows**, **Columns** or **Layer**. When viewing a chart you will be able to select "All Capture Times" (or a single Capture Time) for the **Series** or **Points**, or select a single Capture Time for the **Layer**. This provides a great deal of flexibility for displaying Capture Time results.

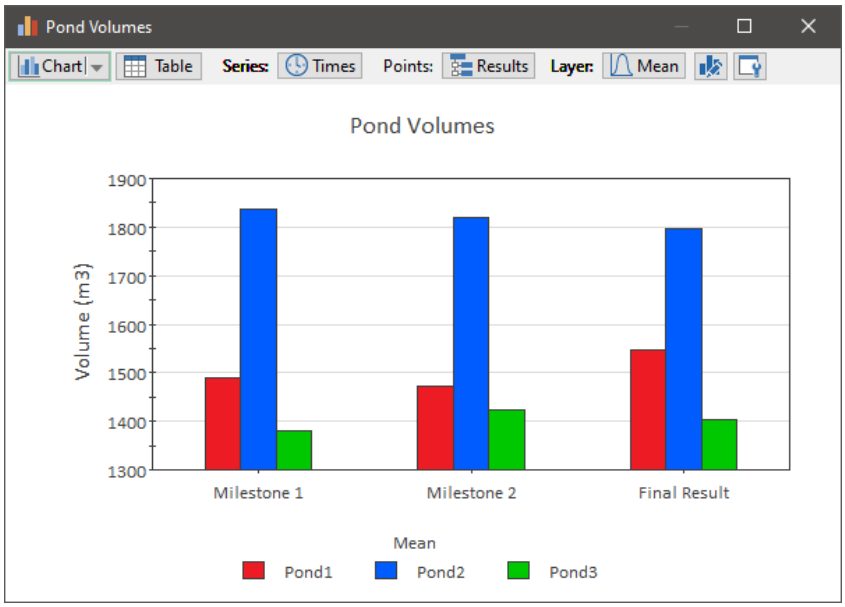
For example, if you were viewing multiple outputs and multiple realizations, you could choose to display a chart showing all outputs and all statistics for a particular Capture Time (in two different ways):



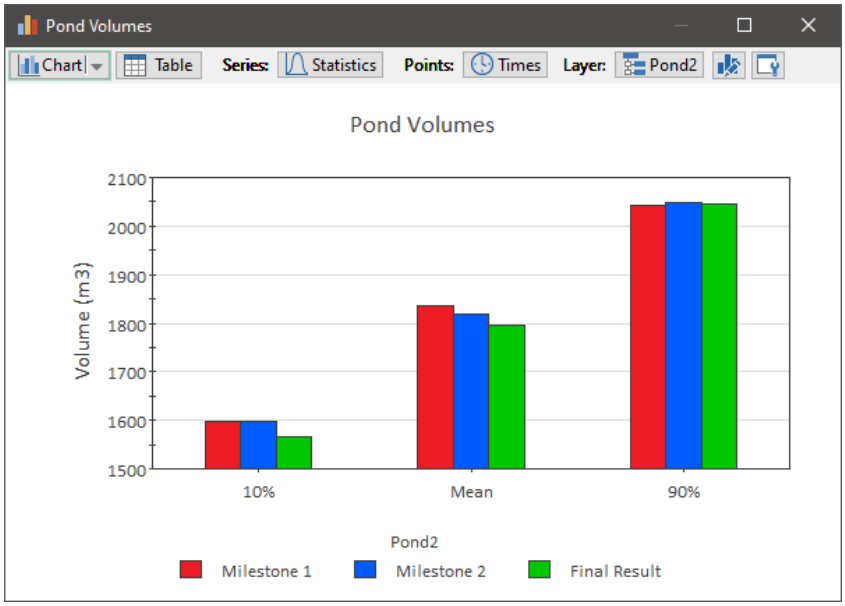


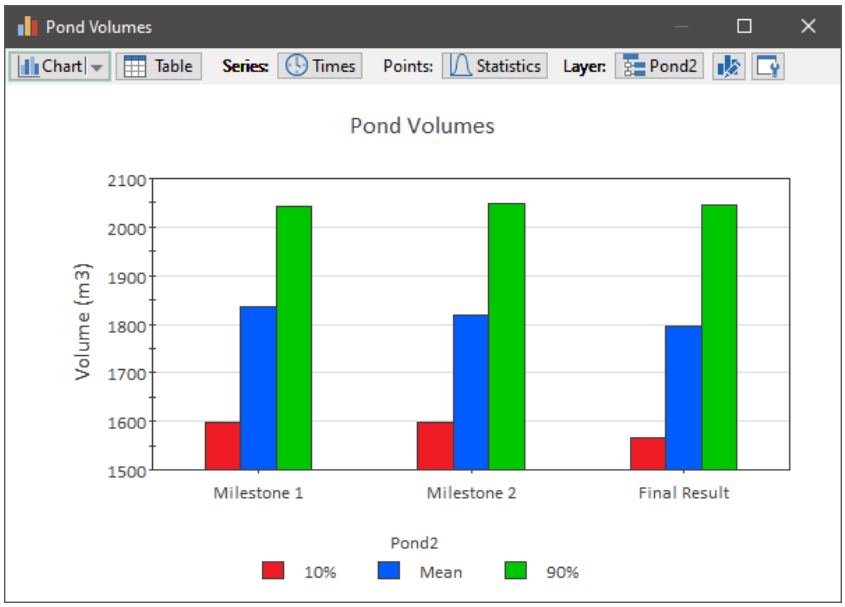
Alternatively, we could choose to display a chart showing all outputs and all Capture Times for a particular statistic (in two different ways):





Finally, you could choose to display a column chart showing all Capture Times and all statistics for a particular output (in two different ways):





Of course, we could also display other types of charts (bar charts, stacked bar or column charts, or pie charts).

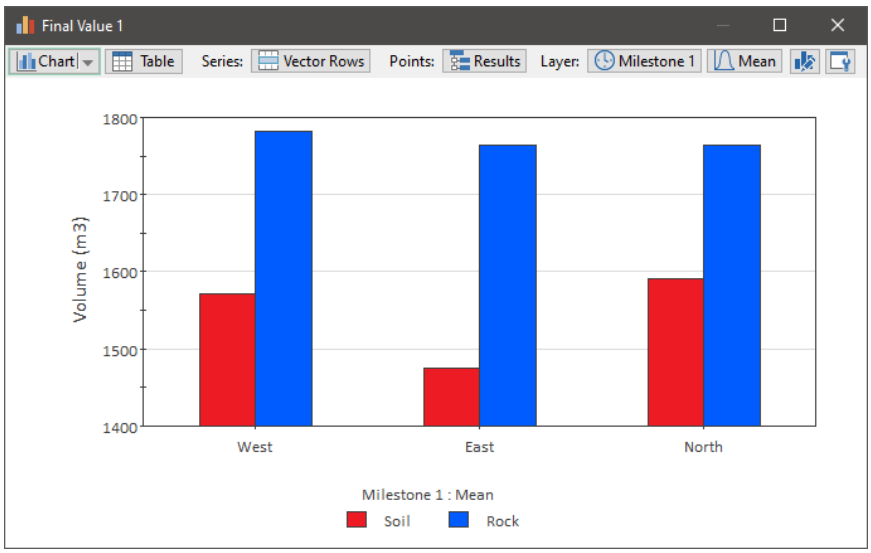
Read more: Overview of Final Value Results (page 695).

Displaying Final Value Results for Vectors

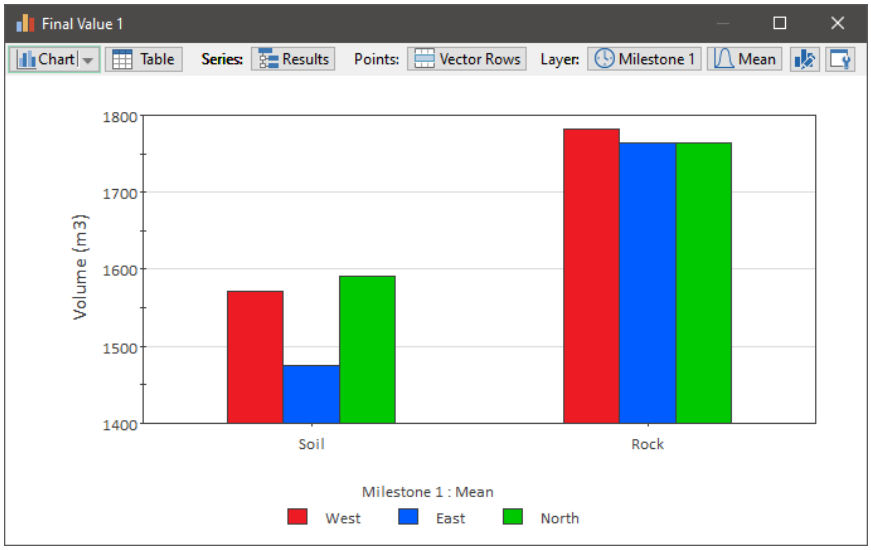
Final Value results can display vectors.

Read more: Using Vectors and Matrices (page 848).

When you are displaying Final Value results for a vector (or multiple vectors), if viewing a table or a chart you will be able to select "Vector Rows" for the **Rows/Series** or **Columns/Points**. In the example below, the model has been run for multiple realizations and multiple Capture Times, two vectors named Soil and Rock (of the same Array Label set) are being displayed and the **Series** is defined as "Vector Rows" (with vector items labeled "West", "East" and "North"):



In this chart, the **Points** are defined as "Vector Rows":



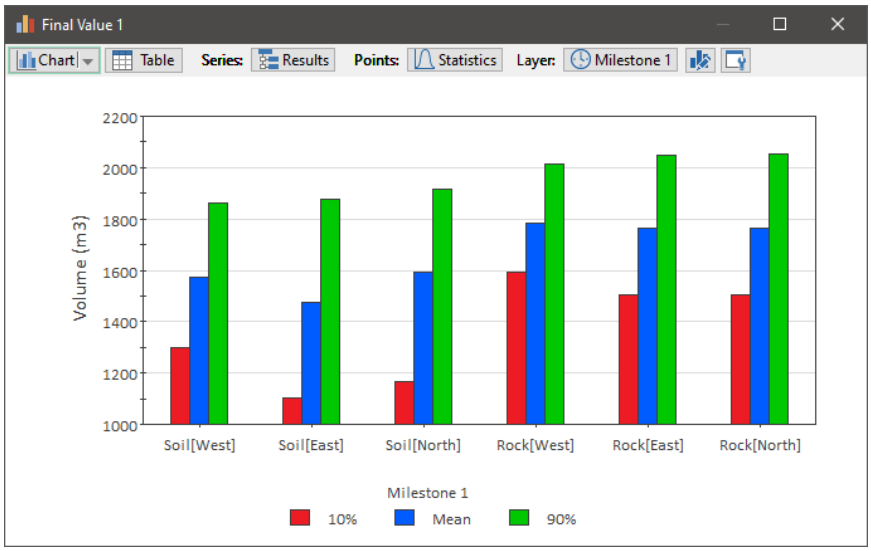
Of course, we could also display other types of charts (bar charts, stacked bar or column charts, or pie charts).

Read more: Overview of Final Value Results (page 695).

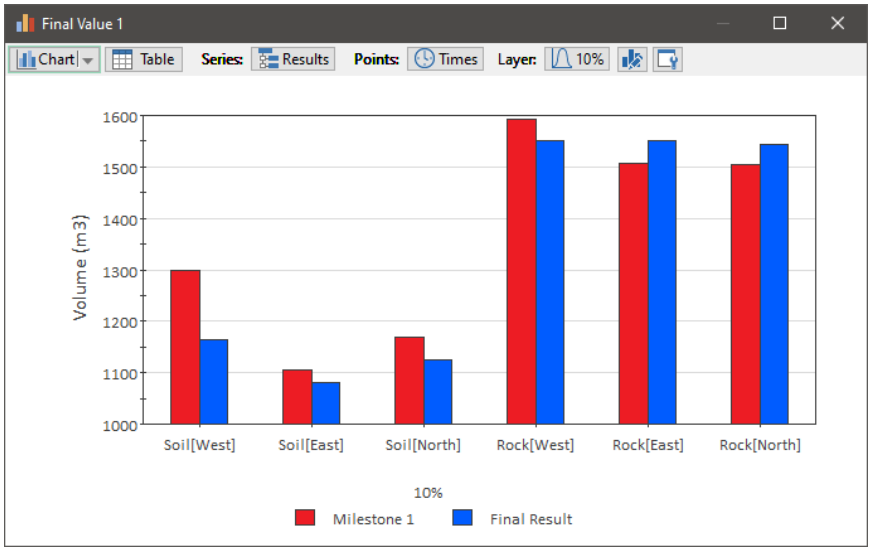
Note that in these charts, there are actually four "dimensions": vector rows, the output, the Capture Time and the statistic. Because we have selected "Vector Rows" for one of the dimensions, for two of the remaining dimensions only one item can be selected (in this example, the Capture Time named "Milestone 1" and the statistic "Mean").

If you select "Vector Rows" for the **Rows/Series**, the **Columns/Points** must be specified to view the entire vector(s) or a single item of a vector. You cannot select, for example, Capture Times, Scenarios or Statistics for the **Columns/Points**. Similarly, If you select "Vector Rows" for the **Columns/Points**, the **Rows/Series** must be specified to view the entire vector(s) or a single item of a vector. This means that if you wish for statistics, Capture Times or scenarios to be assigned to the **Rows/Series** or **Columns/Points**, then "Vector Rows" can no longer be assigned to a dimension.

For example, in the chart below (using the same data as above), we are displaying "All Results" as the **Series** and "All Statistics" for the **Points**. In this case, every vector item for every output is displayed (on the x axis) for a specified Capture Time. For each result item, three statistics are displayed for the selected Capture Time. Since there are two outputs, three vector items and three statistics, there are 2*3*3 = 18 different results displayed:

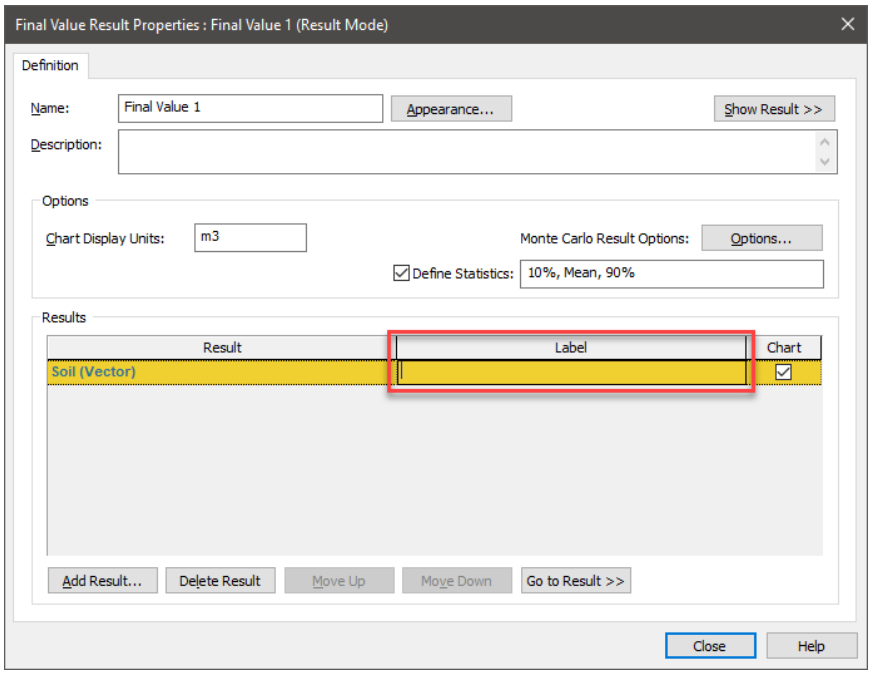


Alternatively, in the chart below (using the same data as above), we are displaying "All Results" as the **Series** and "All Capture Times" for the **Points**. In this case, every vector item for every output is displayed (on the x axis) for a specified statistic. For each result item, three statistics are displayed for the selected statistic. Since there are two outputs, three vector items and two Capture times, there are 2*3*2 = 12 different results displayed:

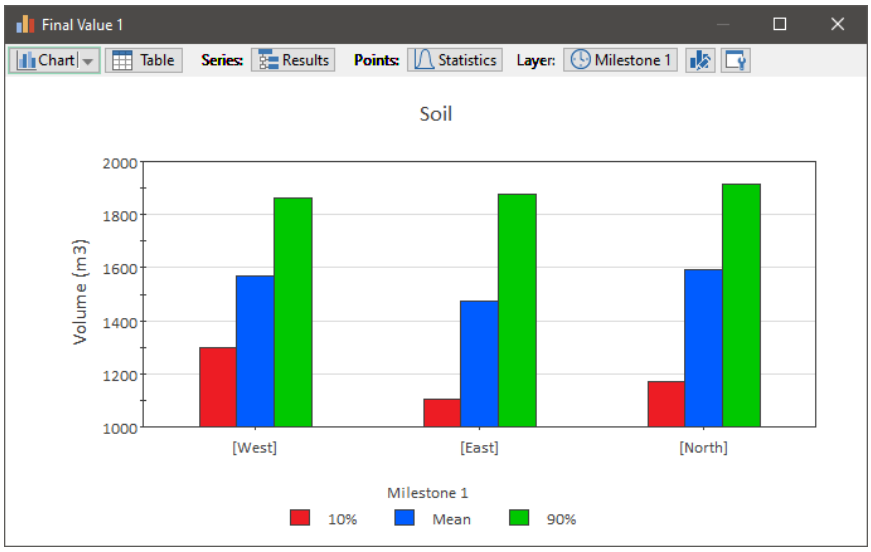


Note: If you assign multiple vectors to a Final Value result they do not need to have the same array label sets or dimensions (i.e., units). Vectors with different array label sets and different dimensions can be displayed in tables. However, if either the **Series** or the **Points** are defined as "Vector Rows", then to be shown in a chart, all results must have the same array label sets and the same dimensions. Hence, if you select the **Chart** box for a vector, any other vectors that are selected but have different array label sets or different dimensions will be automatically deselected. If neither the **Series** nor the **Points** are defined as "Vector Rows", then vectors with different array label sets can be shown in a chart as long as they have the same dimensions. In this case, if you select the **Chart** box for a vector, any other vectors that are selected but have different dimensions will be automatically deselected.

If you were displaying just a single vector and wanted to produce a chart as above (in which "All Statistics" or "All Capture Times" are assigned to the **Series** or **Points**), you could choose to simplify the labels on the axis (so they don't repeat the vector name) by making the label blank in the Properties dialog:



Of course, you could not do this if you were plotting multiple vectors (as you would not be able to identify the items), but with a single vector you could add the vector name to the header to make what you were plotting clear:



Note: Vectors can also be viewed using an Array result display. However, Final Value results are more flexible for viewing arrays and for the most part make Array result displays redundant (i.e., they are a legacy feature). Array results do have two minor features not available in Final Value elements (the ability to sum rows and columns and the ability to produce 3D charts), but for most applications Final Value displays are much more powerful.

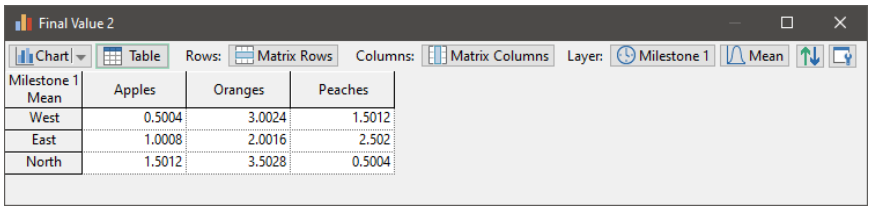
Read more: Viewing Array Results (page 754).

Displaying Final Value Results for Matrices

Final Value results can display matrices.

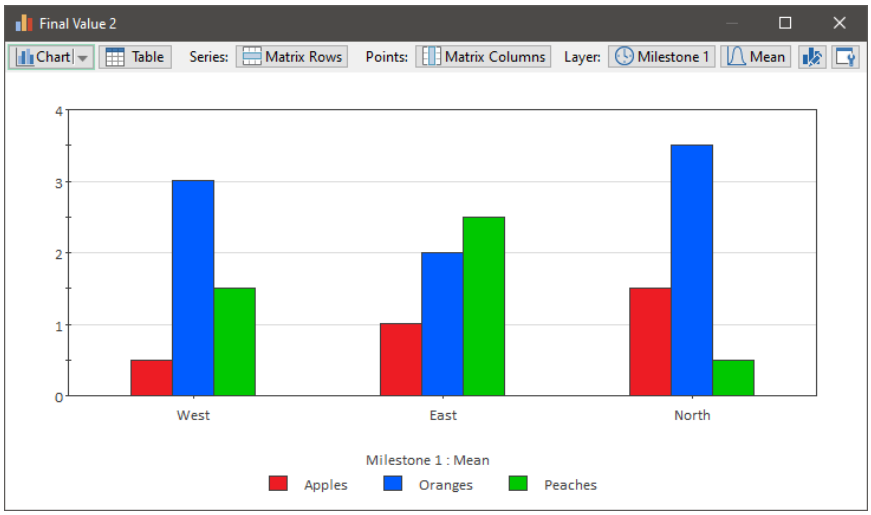
Read more: Using Vectors and Matrices (page 848).

When you are displaying a Final Value result for a single matrix, when viewing a table or a chart you will be able to select "Matrix Rows" for the **Rows/Series** or **Columns/Points**. If you select "Matrix Rows" (or "Matrix Columns") for one of these, GoldSim automatically selects "Matrix Columns" (or "Matrix Rows") for the other. In the example below, the model has been run for multiple realizations and multiple Capture Times, and there is a matrix with three rows (with items labeled "West", "East" and "North") and three columns (with items labeled "Apples", "Oranges" and "Peaches") being displayed. The table view of this would look like this:

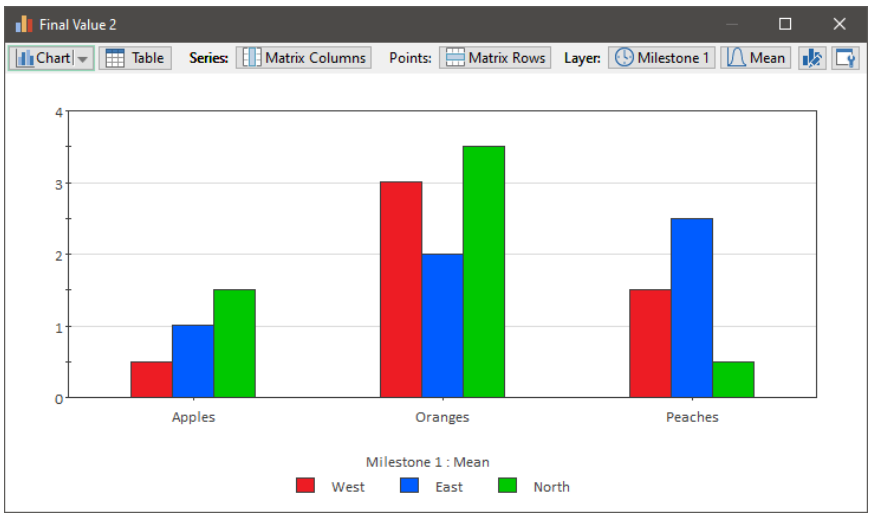


Milestone 1 Mean	Apples	Oranges	Peaches
West	0.5004	3.0024	1.5012
East	1.0008	2.0016	2.502
North	1.5012	3.5028	0.5004

The chart view would look like this:



We could also "flip" the rows and columns:



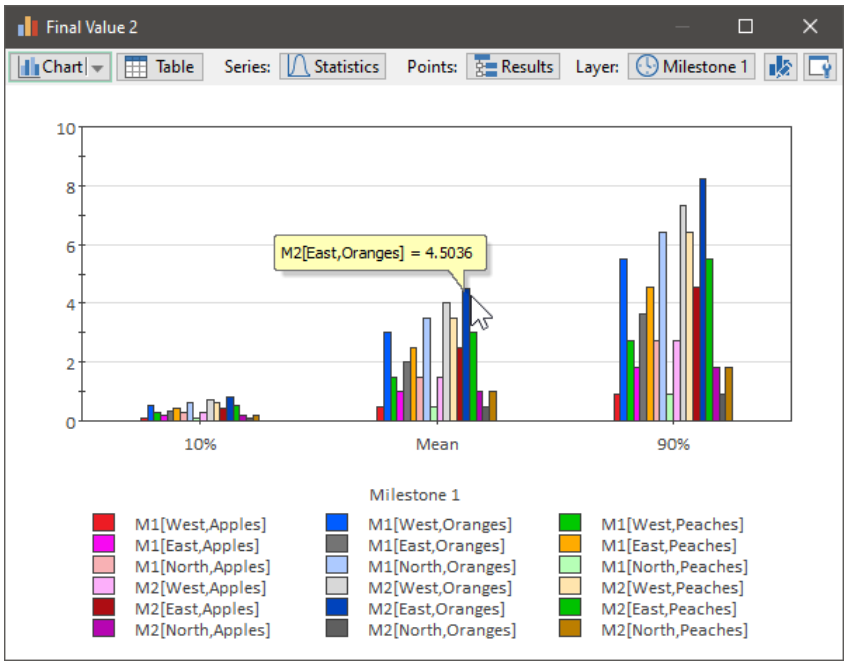
Of course, we could also display other types of charts (bar charts, stacked bar or column charts, or pie charts).

Read more: Overview of Final Value Results (page 695).

Note that in these charts, there are actually four "dimensions": matrix rows, matrix columns, the Capture Time and the statistic. Because we have selected "Matrix Rows" and "Matrix Columns" for two of the dimensions, for the other two dimensions only one item can be selected (in this case, the Capture Time named "Milestone 1", and the statistic "Mean").

"Matrix Rows" and "Matrix Columns" are not available if you wish to view multiple matrices in the same Final Value result display. These are only available when viewing a single matrix. Of course, unless the matrices are very small, a chart displaying multiple matrices will likely be very complex (and likely difficult to interpret).

In the chart below, we are displaying "All Statistics" as the **Series** and "All Results" as the **Points** for two different matrices (each with 3 rows and 3 columns):



In this case, every matrix item for both outputs is displayed (as a separate column and identified in the legend) for a particular Capture Time. Since there are two matrices, nine items for each matrix and three statistics, there are 2*9*3 = 54 different results displayed.

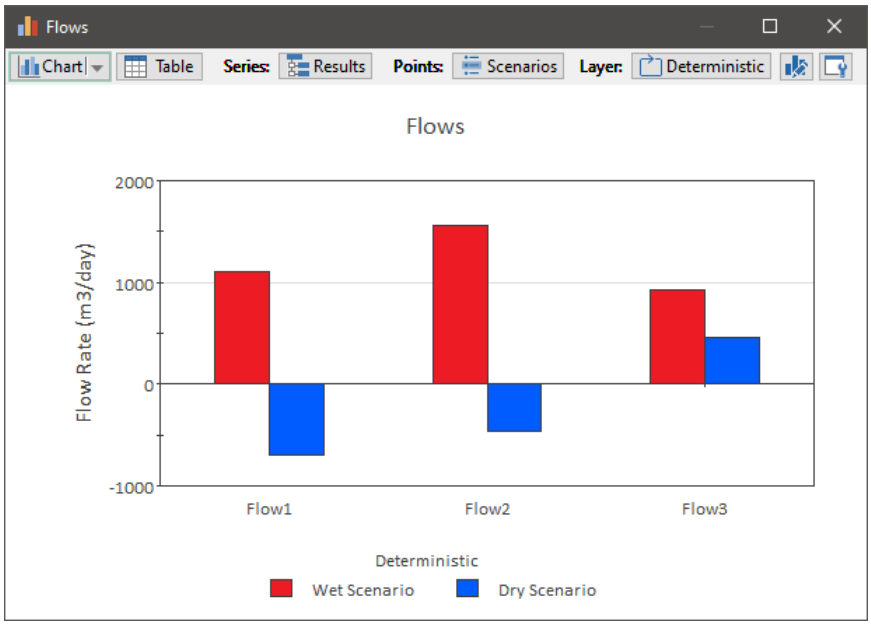
Note: If you assign multiple matrices to a Final Value result they do not need to have the same array label sets or dimensions (i.e., units). Matrices with different array labels can be displayed in tables and charts (since all the items are displayed separately). However, all results shown in a chart must have the same dimensions. Hence, if you select the **Chart** box for a matrix, any other matrices that are selected but have different dimensions will be automatically deselected.

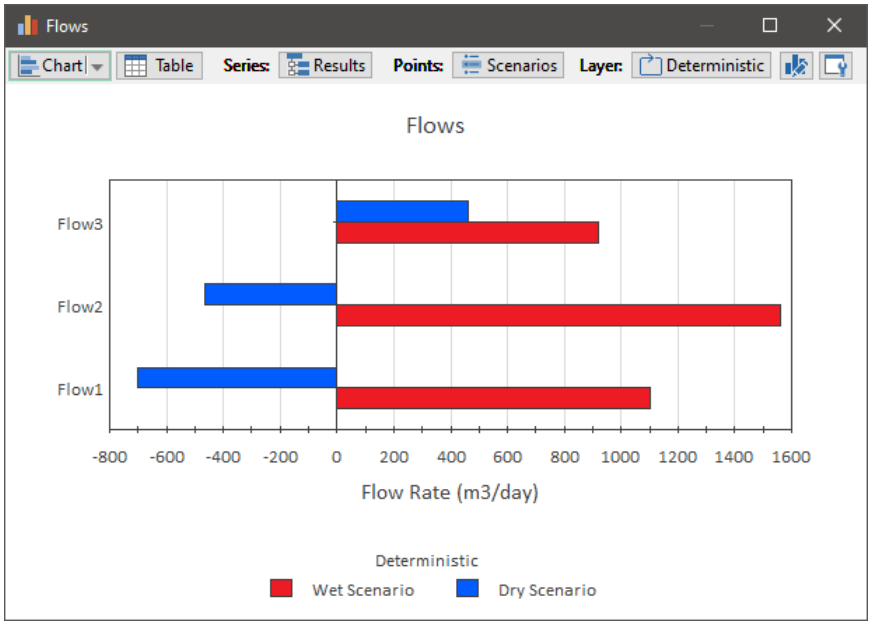
Note: Matrices can also be viewed using an Array result display. However, Final Value results are more flexible for viewing arrays and for the most part make Array result displays redundant (i.e., they are a legacy feature). Array results do have two minor features not available in Final Value elements (the ability to sum rows and columns and the ability to produce 3D charts), but for most applications Final Value displays are much more powerful.

Read more: Viewing Array Results (page 754).

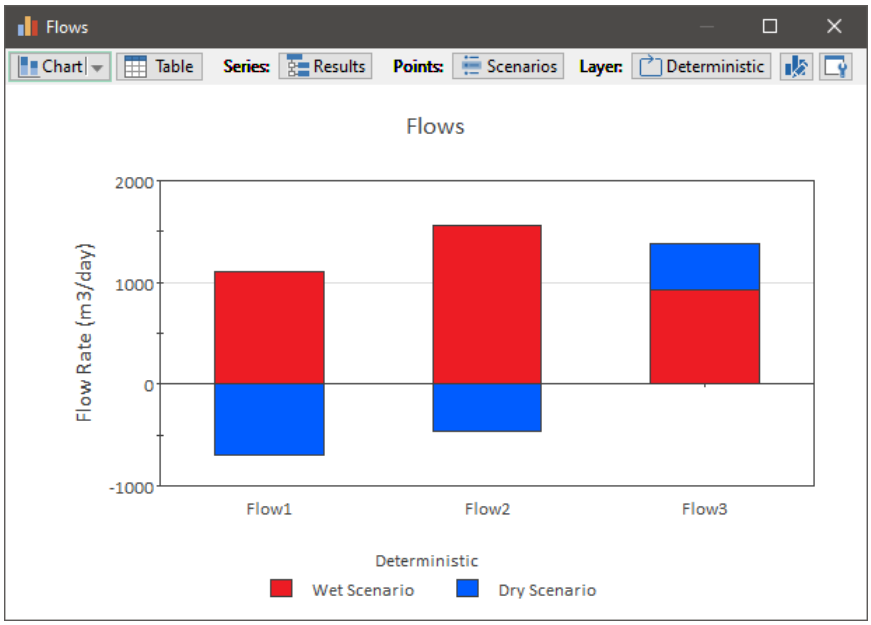
Displaying Final Value Results for Negative Numbers

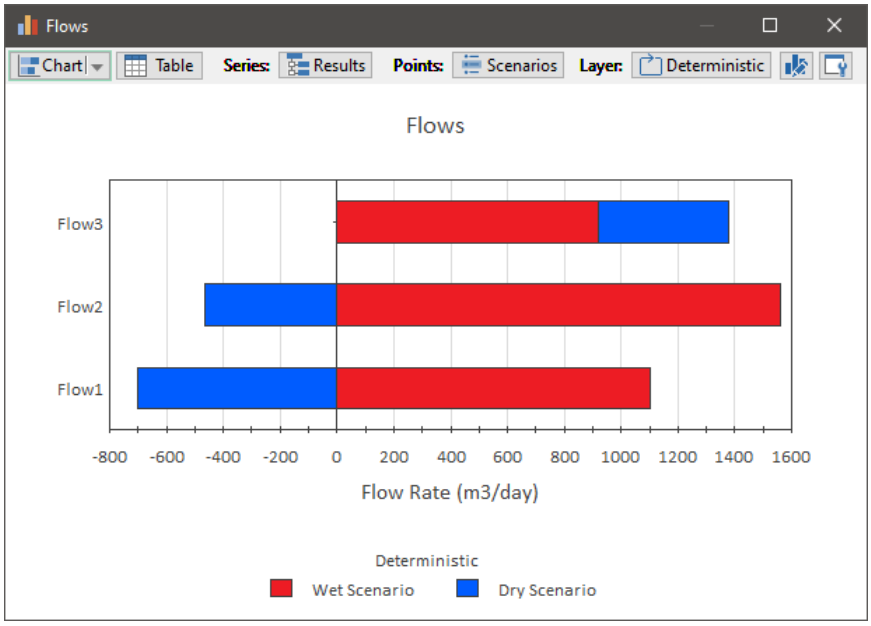
When displaying bar or column charts that include negative values, GoldSim always displays negative values below the zero axis for columns charts and to the left of the zero axis for bar charts:





Stacked bar and column charts are also displayed in this way:





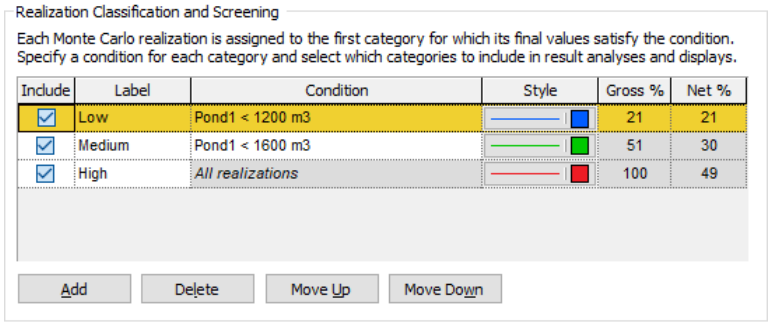
Note: Pie charts cannot display negative values (since a pie "slice" cannot have a negative area. Negative values are treated as zero.

Using Result Classification and Screening in Final Value Results

When carrying out probabilistic simulations, you may often run hundreds or thousands of realizations. In order to analyze the results, it is often quite useful to classify the realizations into ***categories***. A category is simply defined by a condition relating one or more outputs in the model (e.g., those realizations in which the discount rate was above 3.5%; those realizations in which the profit exceeded $1,000,000; those realizations in which the peak concentration was between 1 mg/l and 10 mg/l).

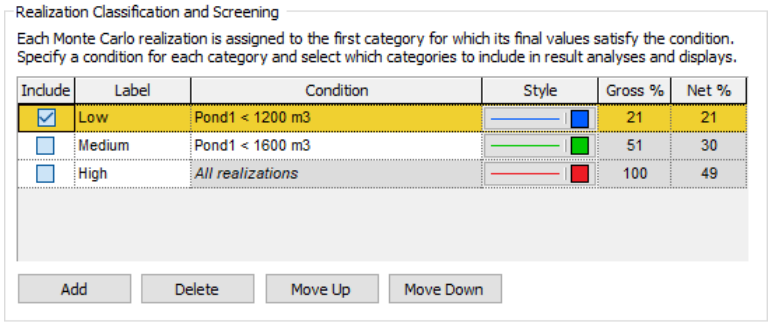
Read more: Classifying and Screening Realizations (page 601).

Classification categories are defined at the bottom of the Monte Carlo Result Display Properties dialog:

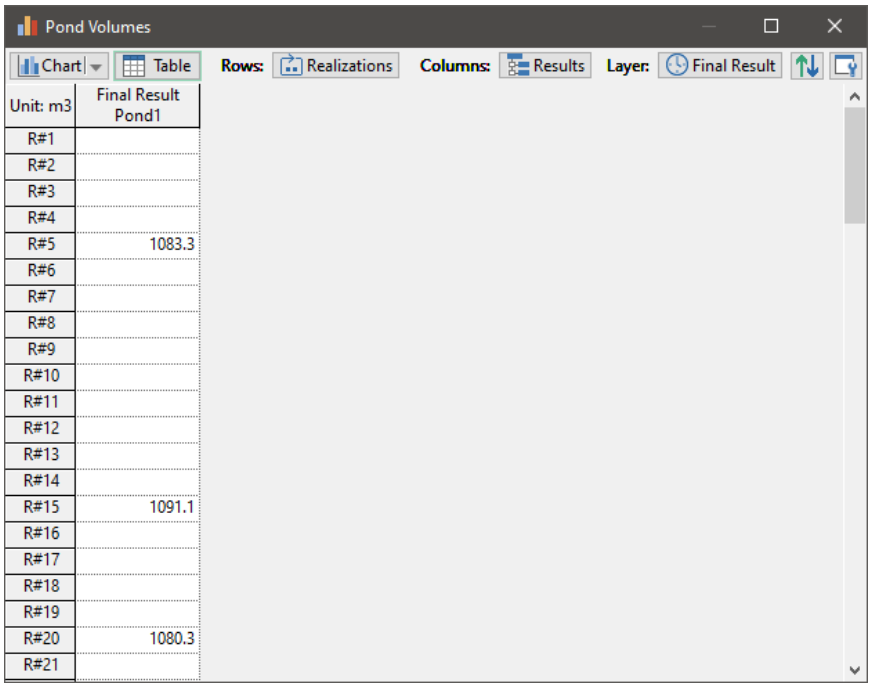


This dialog can be accessed from the **Monte Carlo** tab of the Simulation Settings dialog (via the **Result Options…** button), and is also accessible by pressing the **Options…** button available in the Result Properties dialog of a Final Value Result element.

When viewing a Final Value result in which you have run multiple realizations and have defined more than one category, you can choose to ***screen*** out one or more categories (by clearing the **Include** box in the dialog above). In the example below, we have screened out the "Medium" and "High" categories (which are defined based on the value of Pond1):

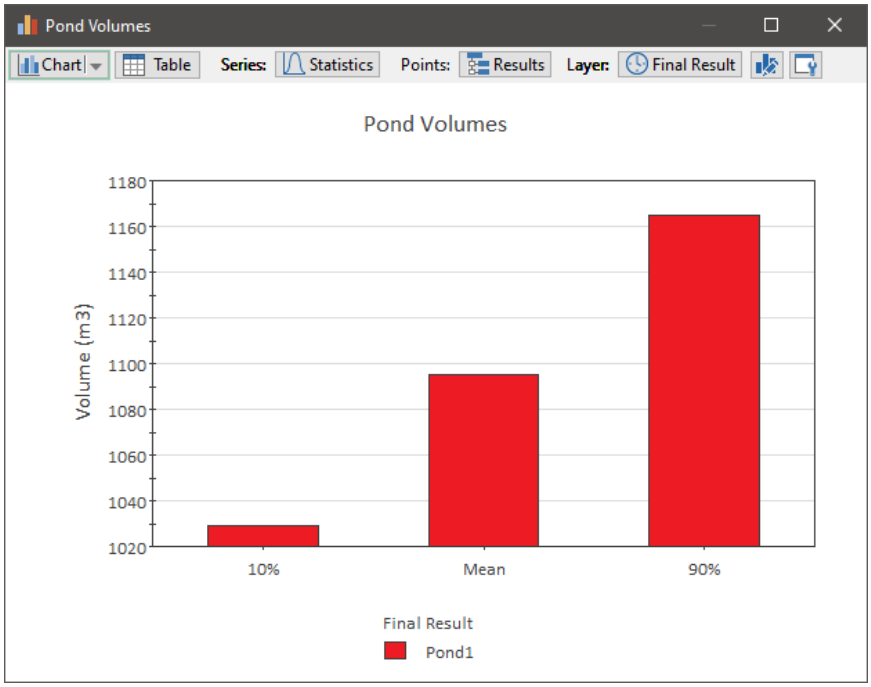


If you then view the results, realizations falling into the Medium and High categories are screened (omitted from consideration). For example, a table view of the results (showing all realizations) would look like this:



Unit: m3	Final Result Pond1
R#1	
R#2	
R#3	
R#4	
R#5	1083.3
R#6	
R#7	
R#8	
R#9	
R#10	
R#11	
R#12	
R#13	
R#14	
R#15	1091.1
R#16	
R#17	
R#18	
R#19	
R#20	1080.3
R#21	

Note that some of the realizations are blank, since these results have been screened out. More importantly, if you were to view statistics, they would be computed based only on the unscreened realizations:

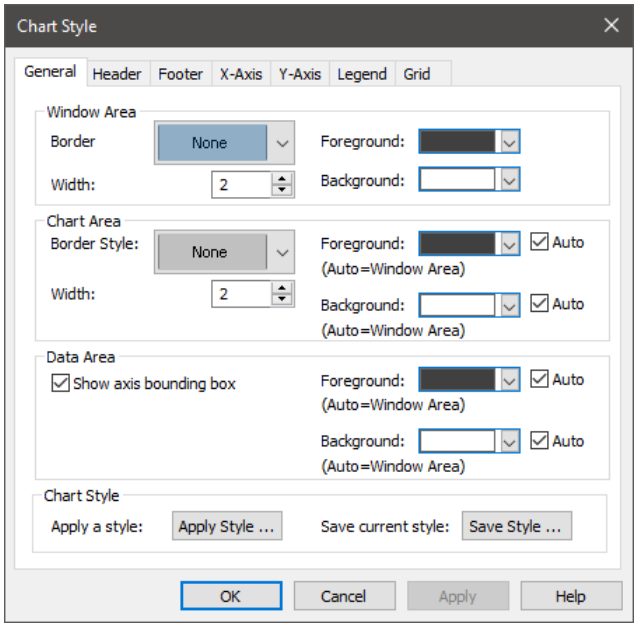


Note that that the "Low" Category only contained values for Pond1 that were less than 1200 m3, and this is reflected in the statistics displayed in this chart.

Controlling the Chart Style in Final Value Results

GoldSim has powerful charting capabilities that allow you to customize the appearance of each chart. This includes adding headers and footers, and changing axis scales and labels. Most of these attributes can be edited by pressing the **Chart Style** button at the top of the Final Value Chart window:

Pressing this button (or right-clicking in a chart and selecting **Edit Chart Style…**) provides access to the following dialog for editing the various chart properties:

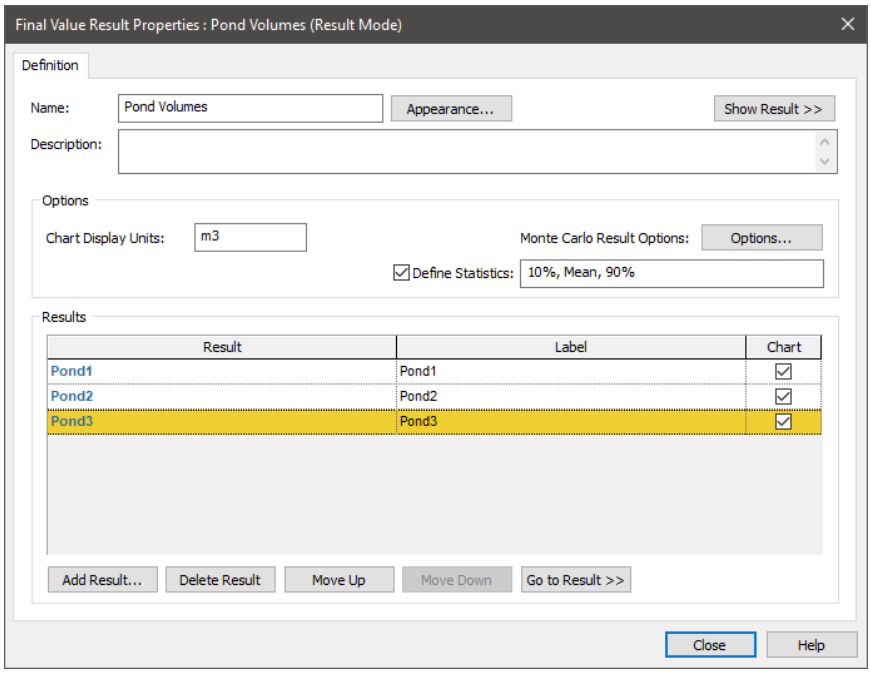


This dialog is common to all types of charts, and is discussed elsewhere.

Read more: Editing the Appearance of a Chart (page 768).

Unlike most other result types in GoldSim, however, the colors of the bars, columns and pie slices in a Final Value chart are auto-selected and cannot be controlled by the user.

In addition to the basic chart attributes controlled by the Chart Style dialog, the Final Value Result Properties dialog itself is used to control some of the attributes of a chart:



In particular,

- The units of the results default to the Display Units of the first result added to the list. However, you can change the **Chart Display Units** that are displayed from within the Result Properties dialog.
- Only those results in which the **Chart** box is checked will be included in chart displays. Hence, after adding a result to the list, you can temporarily hide it from chart displays by clearing this box. In addition, all items that are to be displayed in charts must be consistent (e.g., in terms of dimensions, and in some cases array labels) in order for the **Chart** box to be checked simultaneously.
- The **Label** is user-editable.

Read more: Viewing the Properties of a Final Value Result (page 705).

Viewing Multi-Variate Results

Multi-Variate results allow you to analyze and compare multiple outputs in graphical or tabular form. That is, by definition, a Multi-Variate result display requires at least two separate output variables (i.e., results). A Multi-Variate result display provides a mechanism for creating scatter plots, as well as carrying out sensitivity and correlation analysis among the selected outputs.

To view Multi-Variate results, you must select a specific output that you are interested in, along with one or more additional outputs that may have affected that result.

Five types of Multi-Variate result displays are available:

- 2D scatter plots;
- 3D scatter plots;
- Sensitivity analyses;
- Correlation analyses; and

- "Raw" Data display.

Note: Multi-Variate results are not available in Scenario Mode. They can only be viewed in Result Mode.

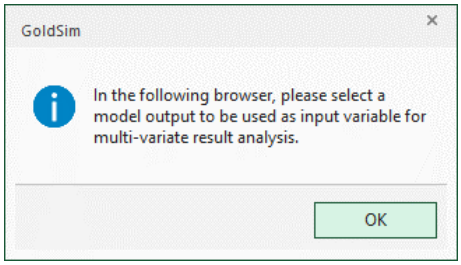
Read more: Understanding Simulation Modes (page 517).

Selecting Outputs for a Multi-Variate Result Display

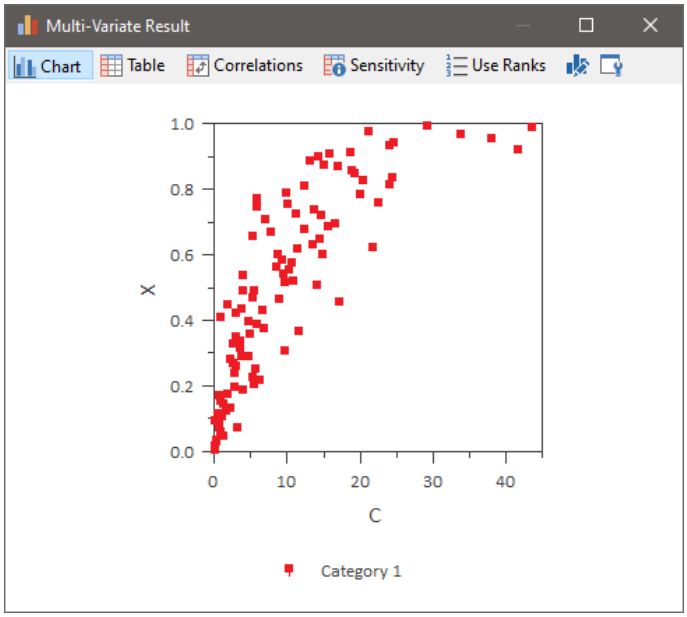
Unlike other result types, a Multi-Variate results requires specification of at least two outputs. If you have saved Final Values for an output, you can display a Multi-Variate result by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Multi-Variate Result…** from the context menu.

Read more: Saving Outputs as Results (page 514).

The output that you selected will be defined as the result to evaluate. You will then be prompted to select an input variable (i.e., some other output in the model) upon which you wish to base your analysis (multi-variate result displays require at least one variable to be selected):



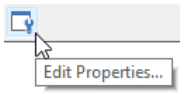
A browser will then appear allowing you to select a variable (i.e., another output in the model). After doing so, the default display for a Multi-Variate result (a 2D scatter plot) is displayed:



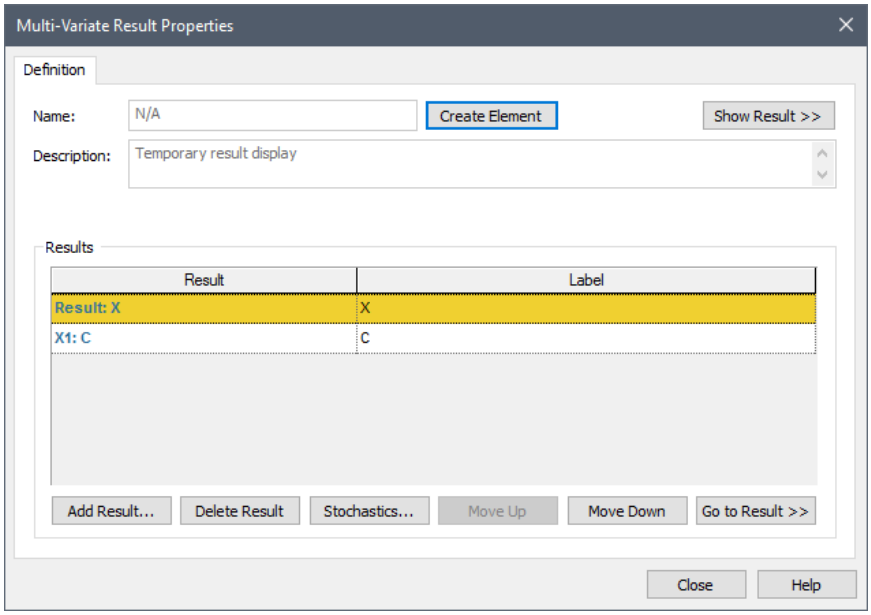
Note: By default, a legend will be turned on, labeling the different categories into which the realizations have been classified. If you have not defined categories, you will want to hide the legend (by right-clicking in the chart and and clearing **View | Show Legend**).

Read more: Using Result Classification and Screening in Multi-Variate Results (page 751).

To add additional outputs to the the Multi-Variate result, you must then press the Result Properties button. The Result Properties button is the furthest button to the right at the top of the display window:



When you do so, the Result Properties dialog for the Mult-Variate result will be displayed:



Read more: Viewing the Properties of a Multi-Variate Result (page 740).

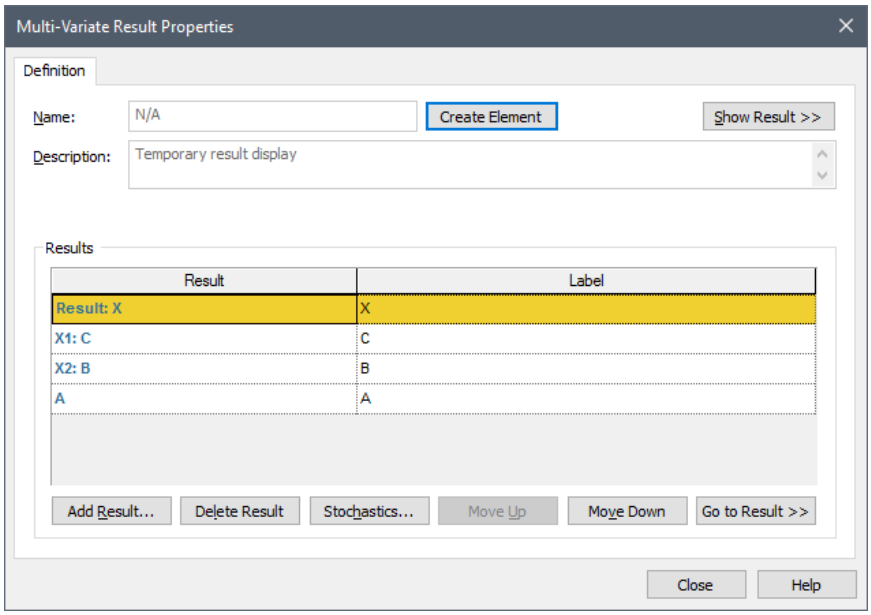
From this dialog, you can add additional variables (or delete variables) using the **Add Result…** and **Delete Result** buttons.

Note: If you delete variables such that you have less than two, you will not be able to display any results at all (since a Multi-Variate result requires at least two variables).

The **Stochastics…** button adds all Stochastic elements in the model to the list of variables. This is often of value, since when carrying out sensitivity or uncertainty analyses, the variables of interest are typically the Stochastics in your model.

For the purpose of creating scatter plots, the variables must be assigned to specific axes. The result (the output from which you selected **Multi-Variate**

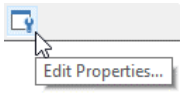
Result…) is assigned to the Y-axis (i.e., the "Result" axis). The first variable that you select is assigned to the X1-axis, and the second variable you select is assigned to the X2-axis. Additional variables are not assigned to any axis. This is indicated in the Result column of the dialog:



You can subsequently reassign these axes by moving variables up and down in the list using the **Move Up** and **Move Down** buttons. Pressing **Go to Result >>** closes the Properties dialog and selects the element associated with the result in th graphics pane.

Viewing the Properties of a Multi-Variate Result

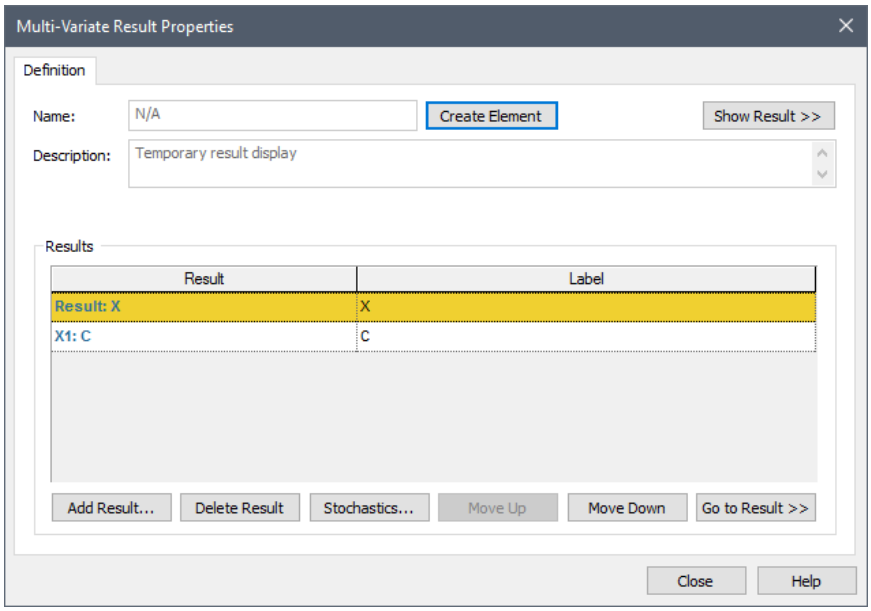
If you create a new Mult-Variat Result element in Edit Mode or you click on the Result Properties button when viewing a Multi-Variate Result chart or table, the Properties dialog for the result will be displayed. The Result Properties button is the furthest button to the right at the top of the display window:



Note that when you press this button while viewing results, it does not close the result display window you were displaying. Both windows are displayed simultaneously (although you can subsequently close one or the other). When viewing results, any changes you make to the Result Properties are immediately represented in the result display.

The Result Properties dialog is always modal. That is, it cannot be minimized, and with the exception of viewing the result display (which can be displayed simultaneously and share the focus with the Properties dialog), it retains the focus while it is displayed. As a result, you must close the Result Properties dialog before you can edit any other part of your GoldSim model.

The Result Properties dialog for an interactive Multi-Variate result looks like this:



At the top of the page is a button to **Create Element**. By pressing this button, a Result element is created. When you do so, the key change that will be noticeable is that the **Name** will now be editable. The **Create Element** button becomes an **Appearance** button (which is used to modify the appearance of the element itself).

Read more: Creating and Using Result Elements (page 593).

The **Show Result** >> button opens a result display window (while keeping the Properties dialog simultaneously open.

Read more: Viewing a 2D Scatter Plot (page 742); Viewing a 3D Scatter Plot (page 744); Viewing a Sensitivity Analysis Table (page 746); Viewing a Correlation Matrix Table (page 748); Viewing a Raw Multi-Variate Data Table (page 749).

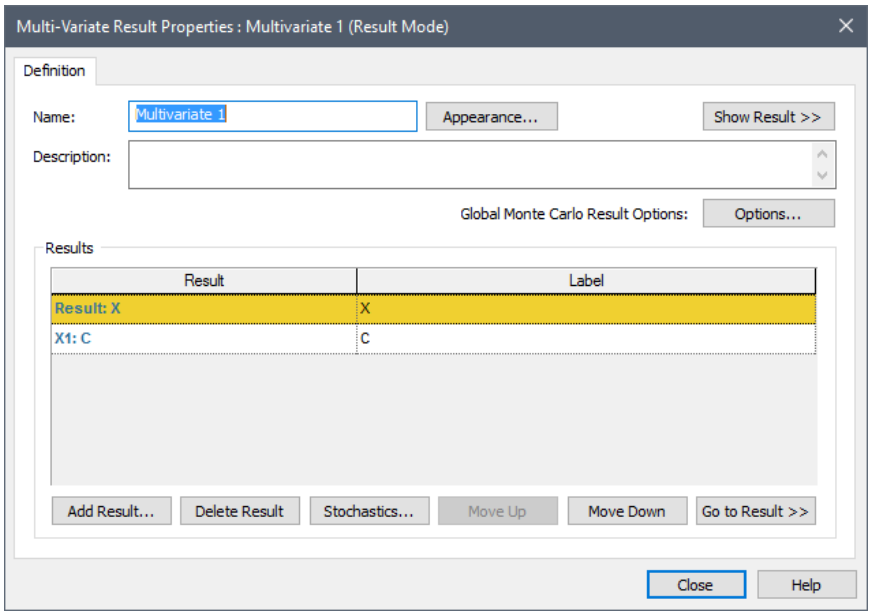
The **Add Result…** button allows you to add other results to the chart. Results can be deleted with the **Delete Result** button.The order in which multiple results appear in the list can be changed using the **Move Up** and **Move Down** buttons. Pressing **Go to Result** >> closes the Properties dialog and selects the element associated with the result in the graphics pane.

The **Stochastics…** button adds all Stochastic elements in the model to the list of variables. This is often of value, since when carrying out sensitivity or uncertainty analyses, the variables of interest are typically the Stochastics in your model.

For the purpose of creating scatter plots, the variables must be assigned to specific axes. The first result in the list is assigned to the Y-axis (i.e., the "Result" axis). The second result is assigned to the X1-axis, and the third result is assigned to the X2-axis. Additional variables are not assigned to any axis. This is indicated in the Result column of the dialog.

Read more: Selecting Outputs for a Multi-Variate Result Display (page 738).

The Properties dialog for a Multi-Variate Result element has several differences:



- The **Create Element** button is replaced by an **Appearance** button (which is used to modify the appearance of the element itself).
- The **Name** (and **Description**) are editable (since this is an element).
- An **Options…** button is available that provides access to the Monte Carlo Result Display Properties.

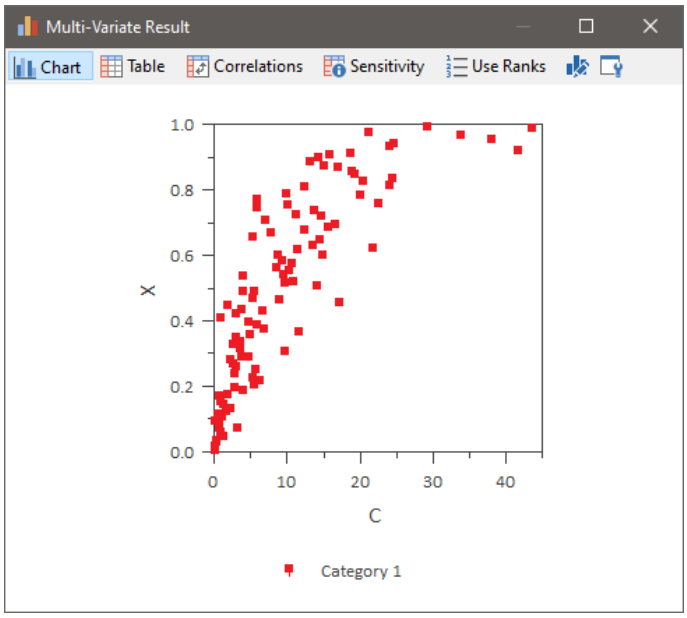
Read more: Controlling Monte Carlo Result Options (page 500).

Viewing a 2D Scatter Plot

A 2D Scatter Plot can provide a powerful visual image of the relationship between two variables.

If you have saved Final Values for an output, you can display a 2D Scatter Plot by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Multi-Variate Result…** from the context menu. The output that you selected will be defined as the result to evaluate. You will then be prompted to select an input variable (i.e., some other output in the model) upon which you wish to base your analysis (multi-variate result displays require at least one variable to be selected)

A browser will then appear allowing you to select a variable (i.e., another output in the model). After doing so, the default display for a Multi-Variate result (a 2D scatter plot) is displayed:



If you are viewing a different type of display (either a chart or table), you can view a 2D Scatter Plot by pressing the **Chart** or **2D Chart** button at the top of the display.

Note: By default, a legend will be turned on, labeling the different categories into which the realizations have been classified. If you have not defined categories, you will want to hide the legend (by right-clicking in the chart and and clearing **View | Show Legend**).

Note: If only two variables are listed in the Result Properties dialog, only a 2D Chart can be shown, and hence only one button will be available (**Chart**). If three or more variables are present in the Result Properties dialog, buttons for both a **2D Chart** and a **3D Chart** become available.

Note: When viewing a Multi-Variate Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

For the purpose of creating scatter plots, the variables must be assigned to specific axes. The first result in the list of results in the Result Properties dialog is assigned to the Y-axis (i.e., the "Result" axis). The second result is assigned to the X1-axis, and the third result is assigned to the X2-axis. Additional variables are not assigned to any axis. This is indicated in the Result column of the Result Properties dialog. The order in which multiple results appear in the list can be changed using the **Move Up** and **Move Down** buttons in that dialog.

Read more: Selecting Outputs for a Multi-Variate Result Display (page 738).

The **Use Ranks** button determines whether the display uses ranks of the values or the actual values. By default, this button is not pressed, and the display uses actual values.

You can copy the chart to the clipboard by right-clicking in the chart, and selecting **Copy** from the context menu. Alternatively, you can press **Ctrl+C** while viewing the chart. To export a chart, right-click in the chart, and select **Export…** from the context menu.

Read more: Copying a Chart or Table (page 800); Exporting a Chart (page 801).

By default, Multi-Variate results operate on Final Values. That is, the display uses the values at the end of each realization. However, by defining Capture Times, you can display values at any specified time. If you have created Capture Times, an additional drop-list is added to the display window to allow you to select the set of data (i.e., the values at the specified Capture Time) that you would like to display.

Read more: Viewing Results at Capture Times (page 592).

If you are using Result Classification, the plots points will be displayed in a different color for each category that has been defined.

Read more: Using Result Classification and Screening in Multi-Variate Results (page 751).

Viewing a 3D Scatter Plot

A 3D Scatter Plot (or a Cloud Plot) allows you to visualize the relationship between three variables.

The default view for a Multi-Variate result is a 2D Scatter Plot.

Read more: Viewing a 2D Scatter Plot (page 742).

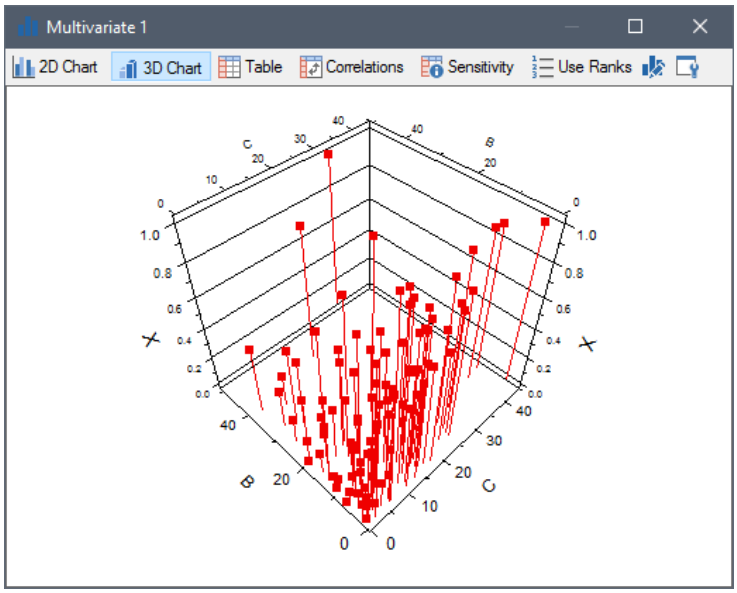
If you are viewing a 2D Scatter Plot (or a different type of Multi-variate display), you can view a 3D Scatter Plot by pressing the **3D Chart** button at the top of the display.

Note: Depending on how many variables you have defined in the Result Properties dialog, the 3D Chart button may not be available. In particular, in order to display a 3D Scatter Plot, you must have at least three results defined.

Read more: Viewing the Properties of a Multi-Variate Result (page 740).

Note: When viewing a Multi-Variate Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

A 3D Scatter Plot looks like this:



For the purpose of creating scatter plots, the variables must be assigned to specific axes. The first output in the list of results in the Result Properties dialog is assigned to the Y-axis (i.e., the "Result" axis). The second output is assigned to the X1-axis, and the third output is assigned to the X2-axis. Additional variables are not assigned to any axis. This is indicated in the Result column of the Result Properties dialog. The order in which multiple results appear in the list can be changed using the **Move Up** and **Move Down** buttons in that dialog.

Read more: Selecting Outputs for a Multi-Variate Result Display (page 738).

The **Use Ranks** button determines whether the display uses ranks of the values or the actual values. By default, this button is not pressed, and the display uses actual values.

You can rotate the three dimensional image by holding down the left mouse button and dragging within the chart. You can also use the Up, Down Left and Right cursor keys.

In addition, 3D Scatter Plots have several hot-keys which can be used to modify the plot:

Keys	Action
Ctrl+D	Toggles the drop lines (the lines drawn from each point to the base of the axis) on and off.
Ctrl+S	Toggles between a 3D scatter plot and a 2D scatter plot.

These options are also available from the context menu for the chart.

You can copy the chart to the clipboard by right-clicking in the chart, and selecting **Copy** from the context menu. Alternatively, you can press **Ctrl+C** while viewing the chart. To export a chart, right-click in the chart, and select **Export…** from the context menu.

Read more: Copying a Chart or Table (page 800); Exporting a Chart (page 801).

By default, Multi-Variate results operate on Final Values. That is, the display uses the values at the end of each realization. However, by defining Capture Times, you can display values at any specified time. If you have created Capture

Times, an additional drop-list is added to the display window to allow you to select the set of data (i.e., the values at the specified Capture Time) that you would like to display.

Read more: Viewing Results at Capture Times (page 592).

If you are using Result Classification, the plots points will be displayed in a different color for each category that has been defined.

Read more: Using Result Classification and Screening in Multi-Variate Results (page 751).

Viewing a Sensitivity Analysis Table

One of the most powerful options for analyzing multi-variate results is to carry out a sensitivity analysis. GoldSim provides a number of statistical sensitivity analyses through the multi-variate result display option.

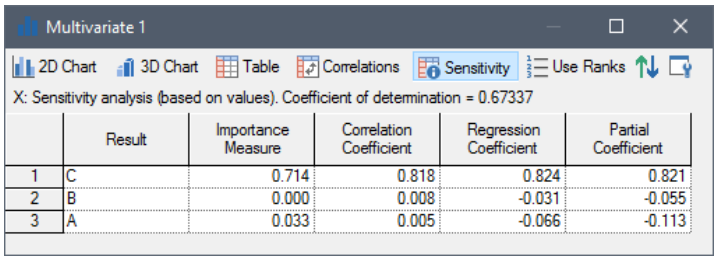
The default view for a Multi-Variate result is a 2D Scatter Plot.

Read more: Viewing a 2D Scatter Plot (page 742).

If you are viewing a 2D Scatter Plot (or a different type of Multi-variate display), you can view a Sensitivity Analysis Table by pressing the **Sensitivity** button at the top of the display.

Note: When viewing a Multi-Variate Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

A Sensitivity Analysis Table looks like this:



	Result	Importance Measure	Correlation Coefficient	Regression Coefficient	Partial Coefficient
1	C	0.714	0.818	0.824	0.821
2	B	0.000	0.008	-0.031	-0.055
3	A	0.033	0.005	-0.066	-0.113

This table displays measures of the sensitivity of the first output in the list of results in the Result Properties dialog (listed at the top of the dialog) to the selected input variables (all the other outputs in the list of results in the Result Properties dialog). In the example above, the analysis is being carried out on the result R1, and the other results whose impact on R1 is being measured are A, B, C and W.

Note: If some of your Stochastics are triggered repeatedly during a simulation, selecting them for sensitivity analysis is likely not to produce meaningful results.

The order in which results appear in the list in the Result Properties dialog can be changed using the **Move Up** and **Move Down** buttons in that dialog, such that any variable in the list can be specified as the result for which the sensitivity analysis is being carried out.

Read more: Selecting Outputs for a Multi-Variate Result Display (page 738).

Each of the measures computed in the Sensitivity Analysis Table is described below:

Coefficient of determination: This coefficient varies between 0 and 1, and represents the fraction of the total variance in the result that can be explained based on a linear (regression) relationship to the input variables (i.e., Result = aX + bY + cZ + …). The closer this value is to 1, the better the relationship between the result and the variables can be explained with a linear model.

Importance Measure: This measure varies between 0 and 1, and represents the fraction of the result's variance that is explained by the variable. This measure is useful in identifying nonlinear, non-monotonic relationships between an input variable and the result (which conventional correlation coefficients may not reveal). The importance measure is a normalized version of a measure discussed in Saltelli and Tarantola (2002).

Correlation Coefficient: Rank (Spearman) or value (Pearson) correlation coefficients range between -1 and 1, and express the extent to which there is a linear relationship between the selected result and an input variable.

SRC (Standardized Regression Coefficient): Standardized regression coefficients range between -1 and 1 and provide a normalized measure of the linear relationship between variables and the result. They are the regression coefficients found when all of the variables (and the result) are transformed and expressed in terms of the number of standard deviations away from their mean. GoldSim's formulation is based on Iman et al (1985).

Partial Correlation Coefficient: Partial correlation coefficients vary between -1 and 1, and reflect the extent to which there is a linear relationship between the selected result and an input variable, after removing the effects of any linear relationships between the other input variables and both the result and the input variable in question. For systems where some of the input variables may be correlated, the partial correlation coefficients represent the "unique" contribution of each input to the result. GoldSim's formulation is based on Iman et al (1985).

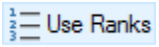
A more detailed discussion of how these measures are computed (along with full references) is presented in Appendix B.

You can copy the contents of a sensitivity analysis table to the clipboard. To do so, you must first select the entire table (by double-clicking on the empty cell in the upper left-hand corner of the table. After you do so, you can copy the table to the clipboard by **Ctrl+C**. You can subsequently paste the table into another application (such as a spreadsheet).

Like all result tables in GoldSim, this table can be sorted in ascending or descending order by selecting a column and pressing the **Sort** button:

Read more: Sorting Values in Result Tables (page 590).

The **Use Ranks** button determines whether the calculations use ranks of the values or the actual values. By default, this button is not pressed, and the calculations are based on actual values.



By default, Multi-Variate results operate on Final Values. That is, the analysis applies to the values at the end of each realization. However, by defining Capture Times, you can carry out the analysis at any specified time. If you have created Capture Times, an additional drop-list is added to the display window to allow you to select the set of data (i.e., the values at the specified Capture Time) that you would like to analyze.

Read more: Viewing Results at Capture Times (page 592).

Note: The sensitivity analyses presented here are statistical measures computed by analyzing multiple realizations of the model in which all of the Stochastic variables are simultaneously sampled each realization. GoldSim also provides a second type of sensitivity analysis in which you can vary one variable at a time, while holding all other variables constant.

Read more: Running Sensitivity Analyses (page 560).

Note: If you need to carry out more advanced sensitivity analyses, you can do so by exporting all results and using a third party analysis tool.

Read more: Exporting Final Value Results for Multiple Outputs and Multiple Realizations (page 799).

Viewing a Correlation Matrix Table

A Correlation Matrix tabulates the statistical correlation between two or more variables.

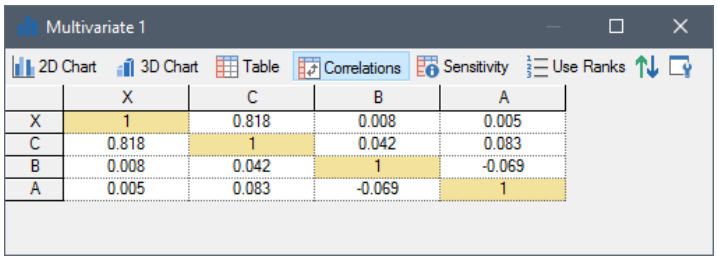
The default view for a Multi-Variate result is a 2D Scatter Plot.

Read more: Viewing a 2D Scatter Plot (page 742).

If you are viewing a 2D Scatter Plot (or a different type of Multi-variate display), you can view a Correlation Matrix Table by pressing the **Correlations** button at the top of the display.

Note: When viewing a Multi-Variate Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

A Correlation Matrix Table looks like this:



	X	C	B	A
X	1	0.818	0.008	0.005
C	0.818	1	0.042	0.083
B	0.008	0.042	1	-0.069
A	0.005	0.083	-0.069	1

The correlation matrix consists of a table whose column and row headers are identical, and consist of all of the selected variables. The table entry for a particular row/column pair is the correlation coefficient for that pair of variables.

The correlation coefficient takes on a value between –1 and 1, 1 being a perfect positive correlation, -1 being a perfect negative correlation.

This is the same analysis presented in the Sensitivity Analysis Table (in the Correlation Coefficient column), but is presented in terms of a matrix here, showing how all variables are correlated to each of the others. The Sensitivity Analysis table simply shows how a single result variable is correlated to the others (i.e., it shows one column of the matrix).

Read more: Viewing a Sensitivity Analysis Table (page 746).

A detailed discussion of how correlation coefficients are computed is presented in Appendix B .

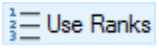
You can increase or decrease the width of a column by dragging the line separating columns to the right or to the left, respectively. If the column is too narrow to display the contents of a cell, holding the cursor over the cell displays a tool-tip with the contents.

You can copy the contents of a correlation matrix table to the clipboard. To do so, you must first select the entire table (by double-clicking on the empty cell in the upper left-hand corner of the table. After you do so, you can copy the table to the clipboard by **Ctrl+C**. You can subsequently paste the table into another application (such as a spreadsheet).

Like all result tables in GoldSim, this table can be sorted in ascending or descending order by selecting a column and pressing the **Sort** button.

Read more: Sorting Values in Result Tables (page 590).

The **Use Ranks** button determines whether the calculations use ranks of the values or the actual values. By default, this button is not pressed, and the calculations are based on actual values.



By default, Multi-Variate results operate on Final Values. That is, the analysis applies to the values at the end of each realization. However, by defining Capture Times, you can carry out the analysis at any specified time. If you have created Capture Times, an additional drop-list is added to the display window to allow you to select the set of data (i.e., the values at the specified Capture Time) that you would like to analyze.

Read more: Viewing Results at Capture Times (page 592).

Viewing a Raw Multi-Variate Data Table

In some situations, it is valuable to simply view a "raw" table of all the data values (i.e., for each realization) for each output specified in a Multi-Variate result.

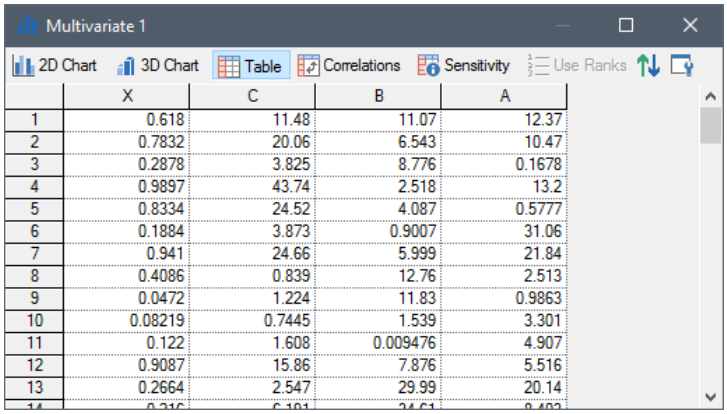
The default view for a Multi-Variate result is a 2D Scatter Plot.

Read more: Viewing a 2D Scatter Plot (page 742).

If you are viewing a 2D Scatter Plot (or a different type of Multi-variate display), you can view a Multi-Variate Data Table by pressing the **Table** button at the top of the display.

Note: When viewing a Multi-Variate Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

A Multi-Variate Data Table looks like this:



	X	C	B	A
1	0.618	11.48	11.07	12.37
2	0.7832	20.06	6.543	10.47
3	0.2878	3.825	8.776	0.1678
4	0.9897	43.74	2.518	13.2
5	0.8334	24.52	4.087	0.5777
6	0.1884	3.873	0.9007	31.06
7	0.941	24.66	5.999	21.84
8	0.4086	0.839	12.76	2.513
9	0.0472	1.224	11.83	0.9863
10	0.08219	0.7445	1.539	3.301
11	0.122	1.608	0.009476	4.907
12	0.9087	15.86	7.876	5.516
13	0.2664	2.547	29.99	20.14

Each row of the table is a different realization, while the columns show the values of the selected outputs.

You can increase or decrease the width of a column by dragging the line separating columns to the right or to the left, respectively. If the column is too narrow to display the contents of a cell, holding the cursor over the cell displays a tool-tip with the contents.

Like all result tables in GoldSim, this table can be sorted in ascending or descending order by selecting a column and pressing the **Sort** button.

Read more: Sorting Values in Result Tables (page 590).

You can copy the contents of the table to the clipboard. To do so, you must first select the entire table (by double-clicking on the empty cell in the upper left-hand corner of the table. After you do so, you can copy the table to the clipboard by **Ctrl+C**. You can subsequently paste the table into another application (such as a spreadsheet).

Note: You can control the number of significant figures displayed in tables from the Results tab of the Options dialog (accessed via **Model |Options…** from the main menu).

Read more: Controlling Significant Figures and Scientific Notation in Result Displays (page 591).

By default, Multi-Variate results operate on Final Values. That is, the display applies to the values at the end of each realization. However, by defining Capture Times, you can display values at any specified time. If you have created Capture Times, an additional drop-list is added to the display window to allow you to select the set of data (i.e., the values at the specified Capture Time) that you would like to display.

Read more: Viewing Results at Capture Times (page 592).

In some cases, you may want to export all of the data in a Multi-Variate Data Table to a file so that it can be read into another program (e.g., a statistical post-processor). GoldSim provides a mechanism to do this directly from the table by pressing a key combination.

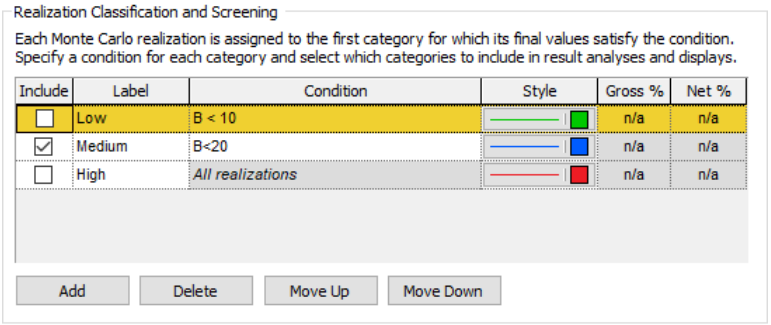
Read more: Exporting Final Value Results for Multiple Outputs and Multiple Realizations (page 799).

Using Result Classification and Screening in Multi-Variate Results

When carrying out probabilistic simulations, you may often run hundreds or thousands of realizations. In order to analyze the results, it is often quite useful to classify the realizations into *categories*. A category is simply defined by a condition relating one or more outputs in the model (e.g., those realizations in which the discount rate was above 3.5%; those realizations in which the profit exceeded $1,000,000; those realizations in which the peak concentration was between 1 mg/l and 10 mg/l).

Read more: Classifying and Screening Realizations (page 601).

Classification categories are defined at the bottom of the Monte Carlo Result Display Properties dialog:



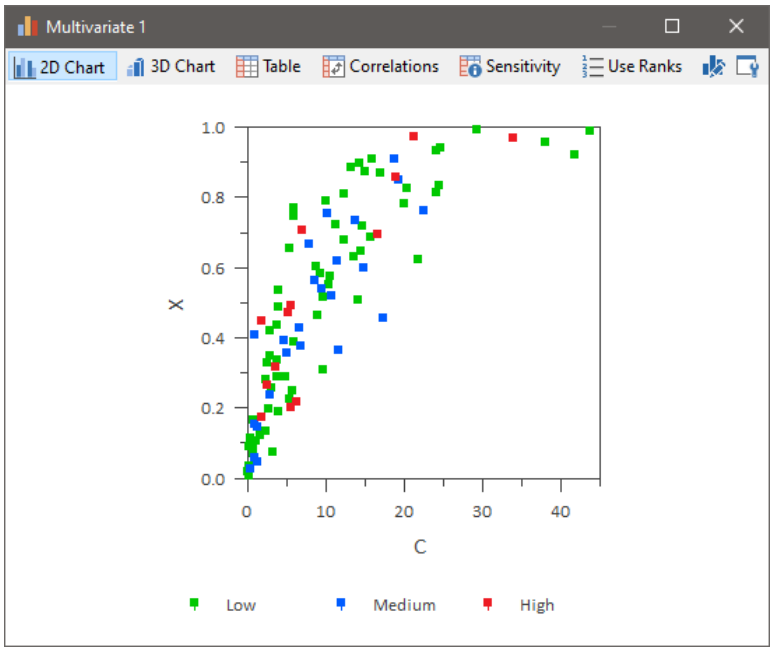
This dialog can be accessed from the Monte Carlo tab of the Simulation Settings dialog (via the **Result Options…** button), and is also accessible by pressing the **Options…** button available in the Result Properties dialog of a Multi-Variate Result element.

When viewing a Multi-Variate result, you can display a 2-D or 3-D scatter plot by selecting **2D Plot** or **3D Plot** button at the top of the display.

Read more: Viewing a 2D Scatter Plot (page 742); Viewing a 3D Scatter Plot (page 744).

In a scatter plot, each point represents a different realization. When viewing a scatter plot in a model in which categories have been defined, each category is displayed in a different color (and/or symbol).

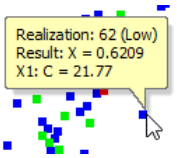
For the example categories shown above, the plot would look like this:



As can be seen, each category is presented as a different data set. Note that a legend is available for scatter plots (you may have to turn it on by right-clicking in the chart and selecting to show the legend from the context menu). The Labels specified in the Monte Carlo Result Display Properties dialog are used in the legend to label the category results.

The plot is based on the net number of realization falling into each category. In this particular example, the net number of realizations falling into each category is as follows: 63% of the realizations fall into the Low category, 24% fall into the Medium category, and 13% fall into the High category. This information is displayed in the the Monte Carlo Result Display Properties dialog after you run the simulation.

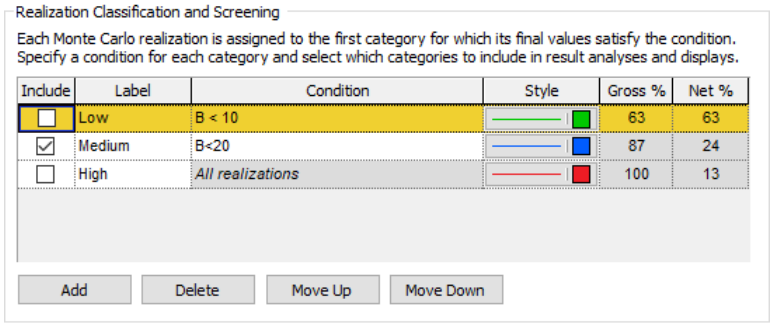
Note that if you place your cursor over any of the points, it will show a tool-tip with information regarding that particular data point:



Note that for each category, you can edit the **Style** via the Monte Carlo Result Display Properties dialog.

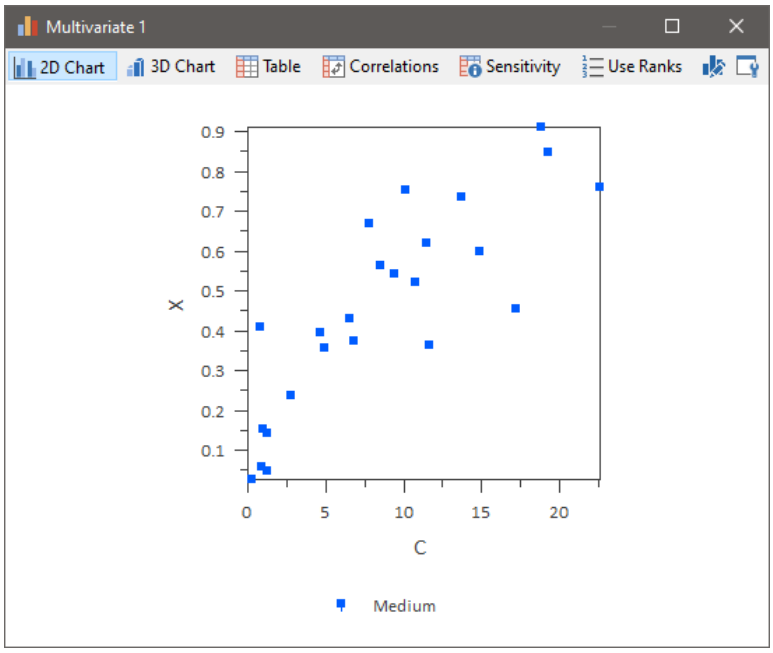
Read more: Controlling the Chart Style in Multi-Variate Results (page 753).

Within all Mult-Variate result displays, you can also choose to ***screen*** out one or more categories, so that the results that are shown (in charts and tables) only include those realizations in the categories which you have chosen to include. You can screen a particular category from the results by clearing the **Include** box at the bottom of the Monte Carlo Result Display Properties dialog:



Note: You can edit the **Include** box in Edit Mode, Result Mode Scenario Mode or Run Mode.

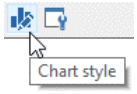
In the example above, the Low and High categories have been screened out, so when viewing a 2D Scatter Plot, only the Medium category is displayed:



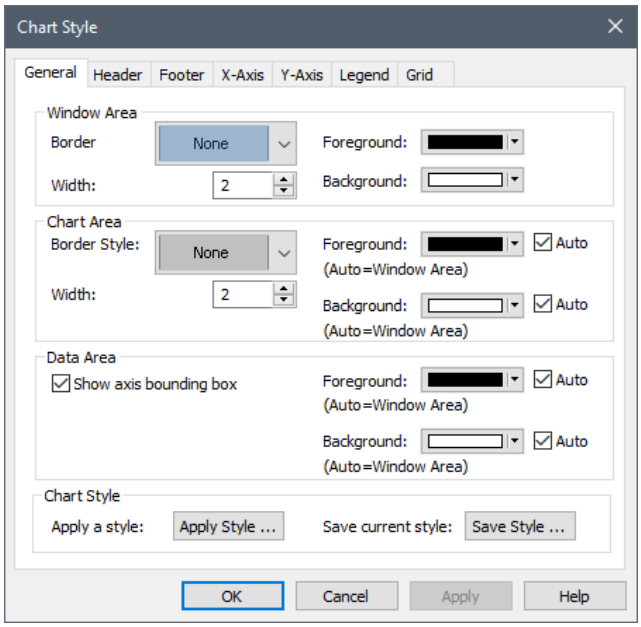
Note that if you screened categories in this way and viewed a Sensitivity Analysis, Correlation Matrix or Data Table, the analysis or display is based only on the unscreened realizations.

Controlling the Chart Style in Multi-Variate Results

GoldSim has powerful charting capabilities that allow you to customize the appearance of each chart. This includes adding headers and footers, and changing axis scales and labels for scatter plots. Most of these attributes can be edited by pressing the **Edit Chart Style** button at the top of the Multi-Variate display window:



Pressing this button (or right-clicking in a scatter plot and selecting **Edit Chart Style…**) provides access to the following dialog for editing the various chart properties:

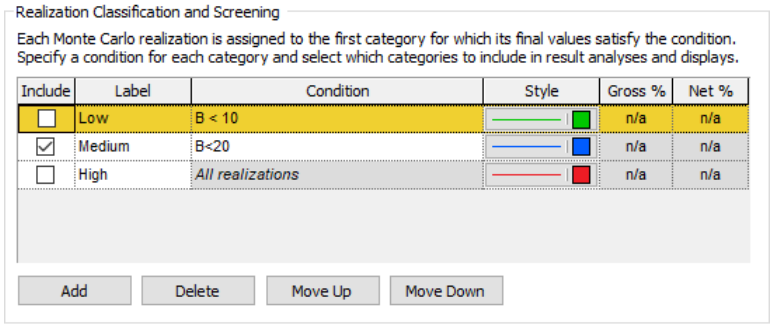


This dialog is common to all types of charts, and is discussed elsewhere.

Read more: Editing the Appearance of a Chart (page 768).

In the absence of Classification categories, the symbol used for a scatter plot is fixed and cannot be edited (a solid red square).

If you have defined realization categories, have run multiple realizations, then the symbol styles for the various categories can be specified in the Monte Carlo Result Display Properties dialog (most easily accessed by pressing the **Options…** button in the Result Properties dialog of a Distribution Result element). The bottom of the Monte Carlo Result Display Properties dialog looks like this:



Read more: Using Result Classification and Screening in Distribution Results (page 681).

The Style used for each category displayed in a scatter plot can be edited by clicking on the field (in the **Style** column) corresponding to each category.

Viewing Array Results

Many complex models utilize arrays (vectors and matrices).

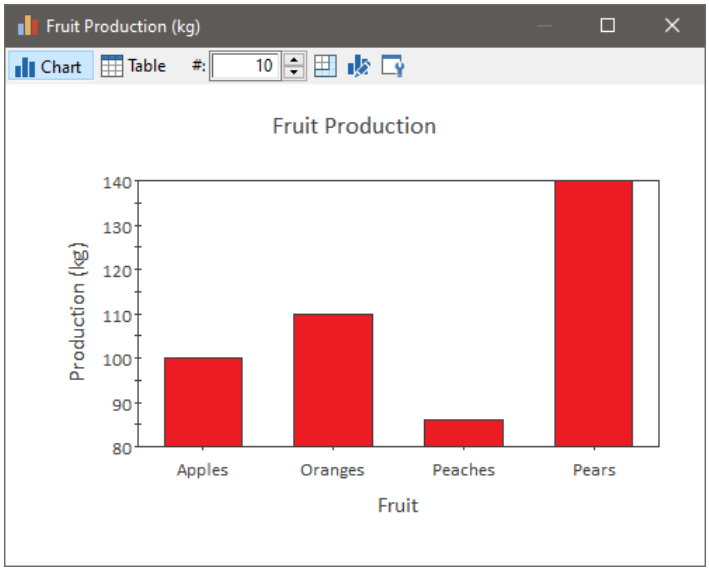
Read more: Using Vectors and Matrices (page 848).

Array results allow you to view "snapshots" of vectors and matrices at particular points in time in both graphical and tabular form. By default, Array

results display Final Values (i.e., values at the end of each realization). However, by defining Capture Times, you can display results at any specified time. If you have created Capture Times, an additional drop-list is added to the display window to allow you to select the set of data (i.e., the values at the specified Capture Time) that you would like to display.

Read more: Viewing Results at Capture Times (page 592).

If you have saved Final Values for an array output, you can display an Array result by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Array Result…** from the context menu. By default, an Array Chart will be displayed:



This example shows a vector chart. The vector has four items.

Note: When viewing an Array Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

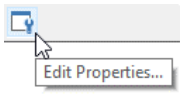
Note: Array results are not available in Scenario Mode. They can only be viewed in Result Mode.

Note: Final Value results are more flexible for viewing arrays and for the most part make this result display redundant (i.e., this is a legacy feature). It does have two minor features not available in Final Value elements (the ability to sum rows and columns and the ability to produce 3D charts), but for most applications Final Value displays are much more powerful (e.g., they are available in Scenario Mode and can produce a wider variety of chart types).

Read more: Viewing Final Value Results (page 694).

Viewing the Properties of an Array Result

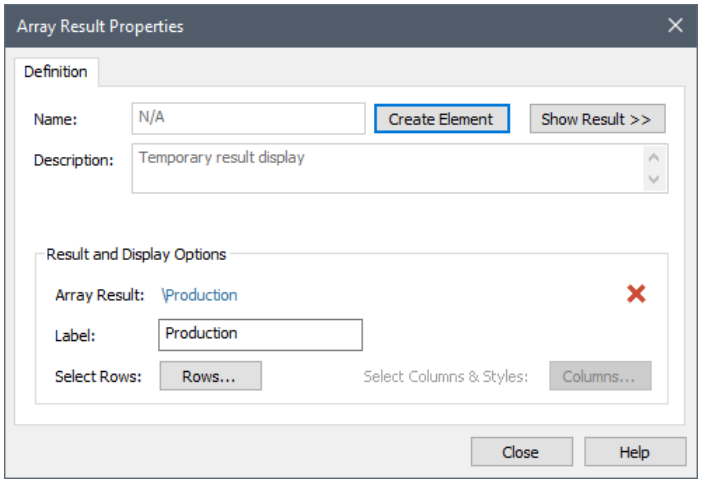
If you create a new Array Result element in Edit Mode or you click on the Result Properties button at the top of the display window when viewing an Array Result chart or table, the Properties dialog for the result will be displayed:



Note that when you press this button while viewing results, it does not close the result display window you were displaying. Both windows are displayed simultaneously (although you can subsequently close one or the other). When viewing results, any changes you make to the Result Properties are immediately represented in the result display.

The Result Properties dialog is always modal. That is, it cannot be minimized, and with the exception of viewing the result display (which can be displayed simultaneously and share the focus with the Properties dialog), it retains the focus while it is displayed. As a result, you must close the Result Properties dialog before you can edit any other part of your GoldSim model.

The Result Properties dialog for an interactive Array result looks like this:



At the top of the page is a button to **Create Element**. By pressing this button, a Result element is created. When you do so, the key change that will be noticeable is that the **Name** will now be editable. The **Create Element** button becomes an **Appearance** button (which is used to modify the appearance of the element itself).

Read more: Creating and Using Result Elements (page 593).

The **Show Result >>** button opens a result display window (while keeping the Properties dialog simultaneously open.

Read more: Viewing a Vector Chart (page 757); Viewing a Matrix Chart (page 760); Viewing an Array Table (page 762).

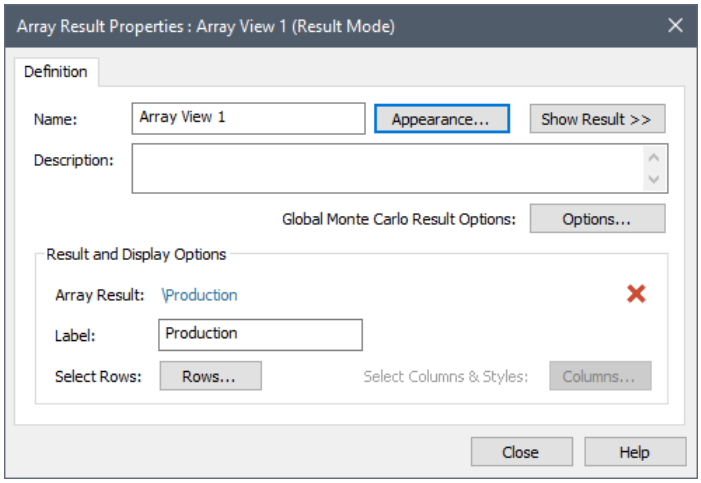
The output being displayed by the Array result is listed directly to the right of the **Array Result** text. If you click on the output, it will open a browser, allowing you to select a different array (you must select an array; GoldSim will not allow you to select a scalar output). If you click on the **Remove** button (the red script X just above the **Columns…** button), it will remove the selected output (and replace it with "<Click to select>". You would then need to click this to select another array.

The **Label** defaults to the name of the result being displayed. However, you can edit this (to make it more readable). It is displayed on the vertical axis of charts.

The **Rows…** and **Columns…** buttons provide access to a dialog for selecting which items to show in the display (and in the case of matrices, the **Columns…** button also provides access to a dialog for selecting the style of the bars shown in the chart). The **Columns…** button is only available for matrices.

Read more: Controlling the Chart Style in Array Results (page 766).

The Properties dialog for an Array Result element has several differences:



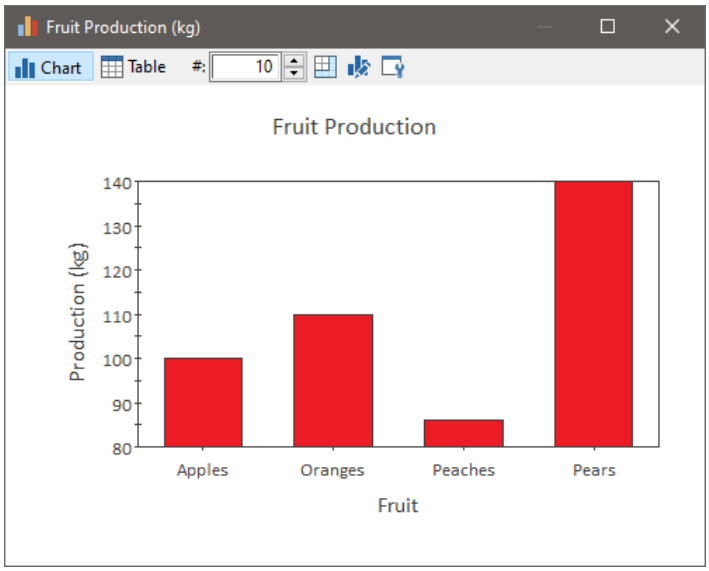
- The **Create Element** button is replaced by an **Appearance** button (which is used to modify the appearance of the element itself).
- The **Name** (and **Description**) are editable (since this is an element).
- An **Options…** button is available that provides access to the Monte Carlo Result Display Properties.

Read more: Controlling Monte Carlo Result Options (page 500).

Viewing a Vector Chart

If you have saved Final Values for a vector output, you can display the final values of the vector by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Array Result…** from the context menu.

By default, a Vector Chart will be displayed:



If you are viewing an Array Table, you can view a Vector Chart by pressing the **Chart** button at the top of the display.

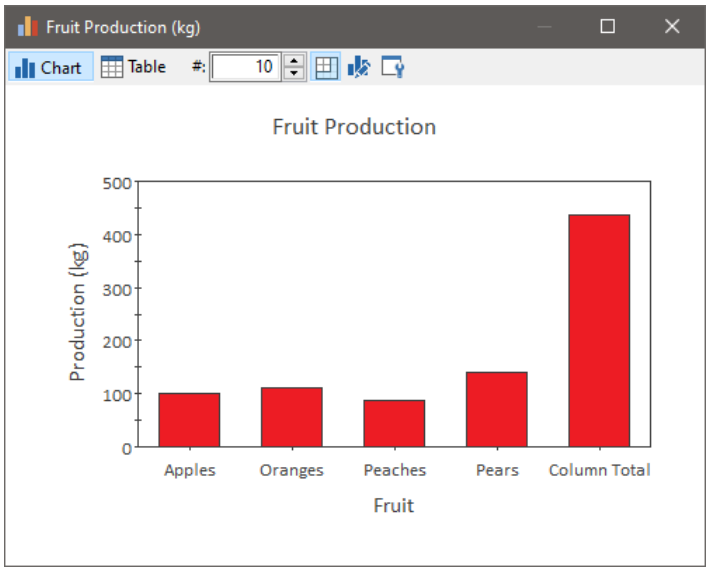
Note: When viewing an Array Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

By pressing the **Rows…** button from the Result Properties dialog for the Array result, you can select which items in the array are to be displayed (by default, all are displayed).

Read more: Viewing the Properties of an Array Result (page 756); Controlling the Chart Style in Array Results (page 766).

A row/column totals button is available at the top of the display window:

Pressing this button displays an additional bar with the total of al the row values:



Vector charts have several hot-keys which can be used to modify the plot:

Keys	Action
Ctrl+S	Switches between a bar chart and line chart.
Ctrl+W	Increases the width of the bars in a bar chart.
Ctrl-Shft+W	Decreases the width of the bars in a bar chart.

The following six hot-keys allow you to rotate and view the chart in three dimensions:

Key	Action
F6	Increases the depth (into the page) of the bars.
Shft+F6	Decreases the depth (into the page)of the bars.
F7	Increases the vertical inclination from which the chart is viewed.
Shft+F7	Decreases the vertical inclination from which the chart is viewed.
F8	Rotates the chart to the left.
Shft+F8	Rotates the chart to the right.

You can copy the chart to the clipboard by right-clicking in the chart, and selecting **Copy** from the context menu. Alternatively, you can press **Ctrl+C** while viewing the chart. To export a chart, right-click in the chart, and select **Export…** from the context menu.

Read more: Copying a Chart or Table (page 800); Exporting a Chart (page 801).

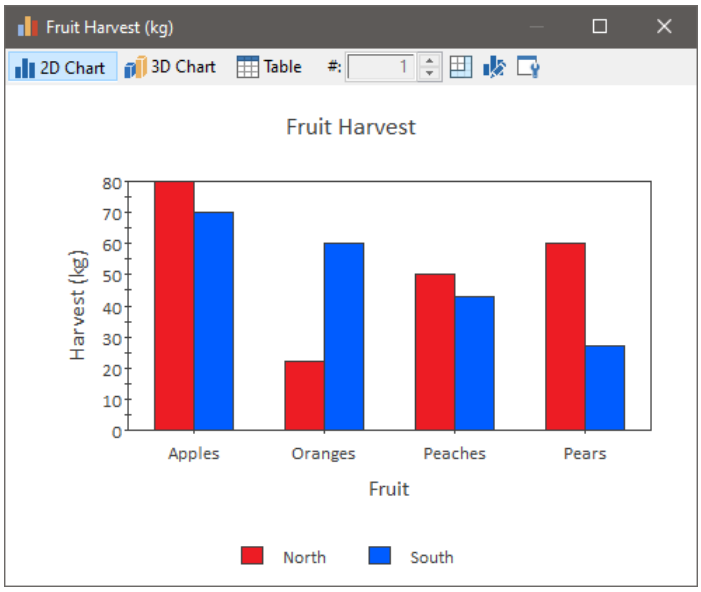
By default, Array results operate on Final Values. That is, the display uses the values at the end of each realization. However, by defining Capture Times, you can display values at any specified time. If you have created Capture Times, an additional drop-list is added to the display window to allow you to select the set of data (i.e., the values at the specified Capture Time) that you would like to display.

Read more: Viewing Results at Capture Times (page 592).

Viewing a Matrix Chart

If you have saved Final Values for a matrix output, you can display the final values of the matrix by right-clicking on the output (in a browser or the output interface), or the element (if the output is the element's primary output) and selecting **Array Result…** from the context menu.

By default, a Matrix Chart will be displayed:



The row items are plotted along the X axis, with multiple bars for each column item (which are identified in a legend, which you may have to turn on by right-clicking in the chart and selecting to show the legend from the context menu).

If you are viewing an Array Table, you can view an Array Chart by pressing the **2D Chart** button at the top of the display.

Note: When viewing an Array Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

Matrix charts have several hot-keys which can be used to modify the plot:

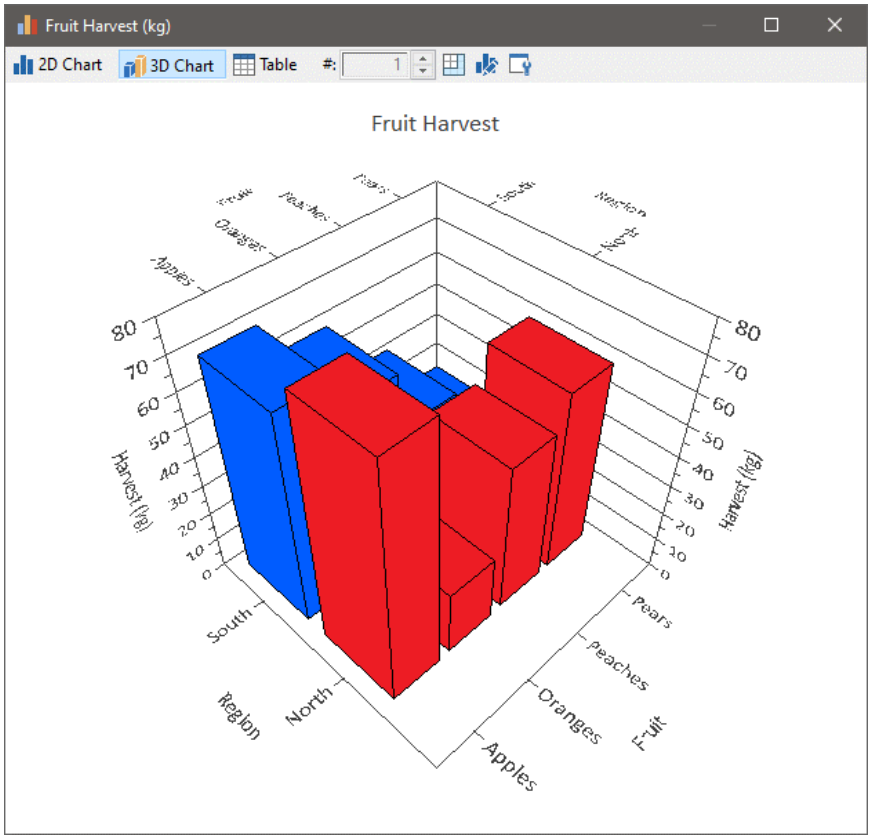
Keys	Action
Ctrl+S	Toggles between a bar chart and line chart.
Ctrl+W	increases the width of the bars in a bar chart.
Ctrl-Shft+W	decreases the width of the bars in a bar chart.

The following six hot-keys allow you to rotate and view the chart in three dimensions:

Keys	Action
F6	increases the depth of the bars.
Shft+F6	decreases the depth of the bars.
F7	increases the vertical inclination from which the chart is viewed.

Keys	Action
Shft+F7	decreases the vertical inclination from which the chart is viewed.
F8	rotates the chart to the left.
Shft+F8	rotates the chart to the right.

Pressing the **3D Chart** button displays the chart in three dimensions:



Note: In order for the labels to be legible for a 3D Chart, you will likely have to expand the window. The axes labels scale with the size of the window in 3D charts.

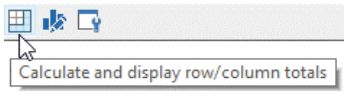
You can rotate the three dimensional image using by holding down the left mouse button and dragging within the chart. The following hot-keys can be used to manipulate the 3D Chart:

Keys	Actions
F6	increases the depth (into the page) of the bars.
Shft+F6	decreases the depth (into the page) of the bars.

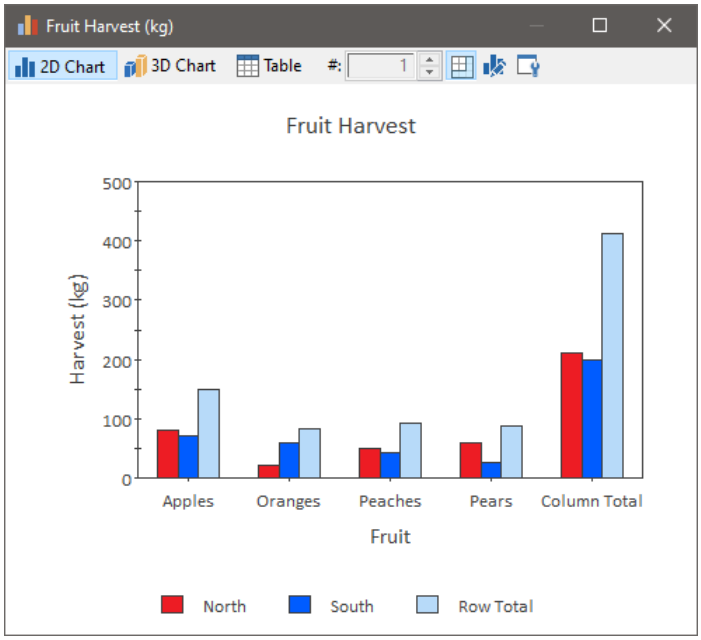
By pressing the **Rows…** and/or **Columns…** buttons from the Result Properties dialog for the array result, you can select which items in the array are to be displayed (by default, all are displayed). You can also change the colors for the column bars.

Read more: Viewing the Properties of an Array Result (page 756); Controlling the Chart Style in Array Results (page 766).

A row/column totals button is available at the top of the display window:



Pressing this button displays the row and column totals:



You can copy the chart to the clipboard by right-clicking in the chart, and selecting **Copy** from the context menu. Alternatively, you can press **Ctrl+C** while viewing the chart. To export a chart, right-click in the chart, and select **Export…** from the context menu.

Read more: Copying a Chart or Table (page 800); Exporting a Chart (page 801).

By default, Array results operate on Final Values. That is, the display uses the values at the end of each realization. However, by defining Capture Times, you can display values at any specified time. If you have created Capture Times, an additional drop-list is added to the display window to allow you to select the set of data (i.e., the values at the specified Capture Time) that you would like to display.

Read more: Viewing Results at Capture Times (page 592).

Plotting Condition Arrays

Condition outputs are either True or False and are typically used as state variables or flags in a simulation. You can create arrays of conditions, and, in some situations, you may want to plot these arrays. To facilitate this, when plotting an array of a condition, GoldSim plots True as 1 and False as 0.

Read more: Understanding Output Attributes (page 88).

Viewing an Array Table

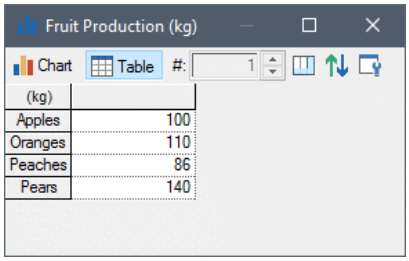
The default view for an Array result is a 2D Chart.

Read more: Viewing a Vector Chart (page 757); Viewing a Matrix Chart (page 760).

In some cases, however, you may want to view a table of values.If you are viewing a 2D Chart (or 3D Chart), you can view an Array Table by pressing the **Table** button at the top of the display.

Note: When viewing an Array Result element, the element "remembers"the last type of view that was displayed, and displays that view when you double-click on it.

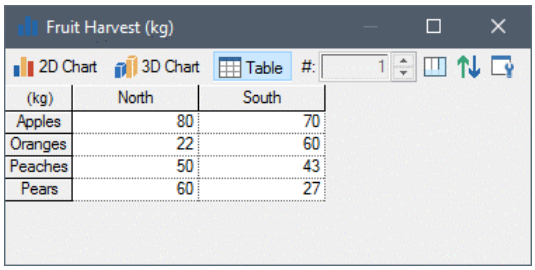
An Array Table for a vector looks like this:



(kg)	
Apples	100
Oranges	110
Peaches	86
Pears	140

The first column shows the item names for the vector. The units for the vector are in the first cell in the upper left-hand corner of the table.

An Array Table for a matrix looks like this:



(kg)	North	South
Apples	80	70
Oranges	22	60
Peaches	50	43
Pears	60	27

The units for the vector are in the first cell in the upper left-hand corner of the table. The first row shows the item names for the columns. The first column shows the item names for the rows.

You can increase or decrease the width of a column by dragging the line separating columns to the right or to the left, respectively.

Note: Conditions are displayed in tables as either 1/0, true/false, True/False, TRUE/FALSE, on/off, or High/Low. You select which of these pairs to use on the Results tab of the Options dialog (accessed via **Model |Options…** from the main menu). The default setting is true/false.

Note: You can control the number of significant figures displayed in tables from the Results tab of the Options dialog (accessed via Model |Options… from the main menu).

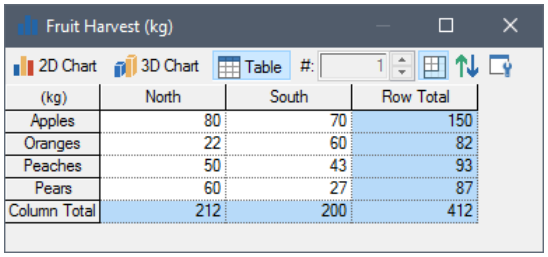
Read more: Controlling Significant Figures and Scientific Notation in Result Displays (page 591).

By pressing the **Rows…** and/or **Columns…** buttons from the Result Properties dialog for the Array result, you can select which items in the array are to be displayed in the table (by default, all are displayed).

Read more: Viewing the Properties of an Array Result (page 756).

A row/column totals button is available at the top of the display window:

Pressing this button displays the column and row (for matrices) totals in the table:



(kg)	North	South	Row Total
Apples	80	70	150
Oranges	22	60	82
Peaches	50	43	93
Pears	60	27	87
Column Total	212	200	412

You can copy the contents of an array table to the clipboard by pressing **Ctrl+C**. You must first select the cells you wish to copy. You can do so by placing your cursor in one cell and dragging to another location. You can select the entire table by pressing the cell in the upper left-hand corner of the table. Cells that are not adjacent can be selected using **Ctrl** key when selecting. Selected items will be highlighted in black. You can subsequently paste the table into another application (such as a spreadsheet).

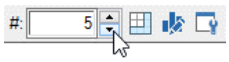
Read more: Selecting Items and Copying Values in Result Tables (page 590).

By default, Array results operate on Final Values. That is, the display uses the values at the end of each realization. However, by defining Capture Times, you can display values at any specified time. If you have created Capture Times, an additional drop-list is added to the display window to allow you to select the set of data (i.e., the values at the specified Capture Time) that you would like to display.

Read more: Viewing Results at Capture Times (page 592).

Viewing Multiple Realizations of Array Results

If you have run (and saved) multiple realizations, a realization control is added to the top of the display window for an Array result:.



By default, the final (unscreened) realization is shown. You can type in a specific realization (and press Enter), move upward or downward through the available realizations using the spin control, or use the **Ctrl-Up** and **Ctrl-Down** keys to view the previous or next available realization, respectively.

Note: You can only view those realizations which are available (i.e., those which have been saved and have not been screened out).

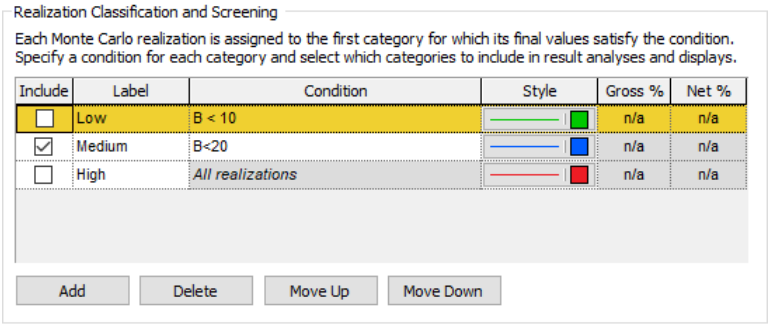
Read more: Using Result Screening in Array Results (page 765).

Using Result Screening in Array Results

When carrying out probabilistic simulations, you may often run hundreds or thousands of realizations. In order to analyze the results, it is often quite useful to screen out some of the realizations by classifying the realizations into *categories*. A category is simply defined by a condition relating one or more outputs in the model (e.g., those realizations in which the discount rate was above 3.5%; those realizations in which the profit exceeded $1,000,000; those realizations in which the peak concentration was between 1 mg/l and 10 mg/l).

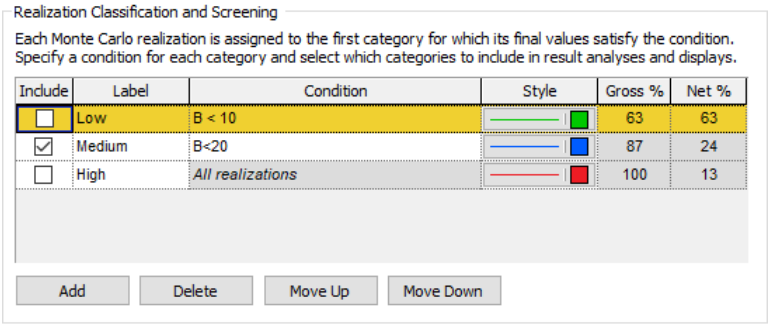
Read more: Classifying and Screening Realizations (page 601).

Classification categories are defined at the bottom of the Monte Carlo Result Display Properties dialog:



This dialog can be accessed from the Monte Carlo tab of the Simulation Settings dialog (via the **Result Options…** button), and is also accessible by pressing the **Options…** button available in the Result Properties dialog of an Array Result element.

You can screen a particular category from the results by clearing the **Include** box at the bottom of the Monte Carlo Result Display Properties dialog:



Only include those realizations in the categories which you have chosen to include can then be displayed in charts and tables.

Note: You can edit the **Include** box in Edit Mode, Result Mode Scenario Mode or Run Mode.

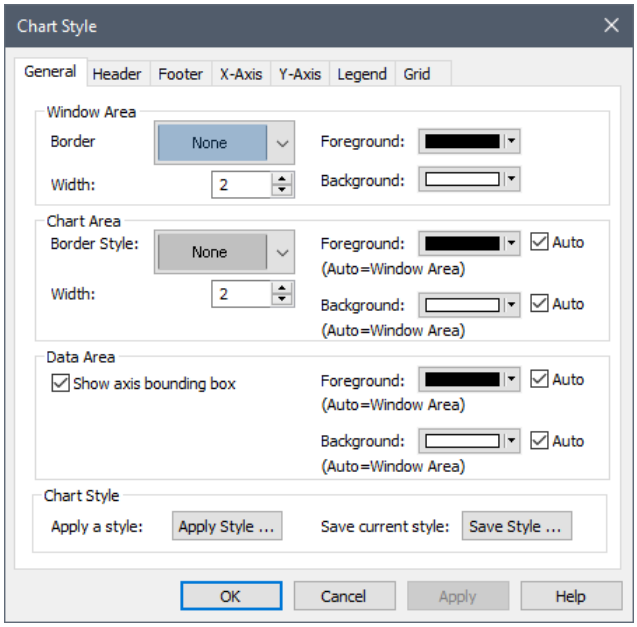
In the example above, the Low and High categories have been screened out, so when displaying results, only those realizations that fall into the Medium category would be available in the realizations spin control at the top of the display window:

Read more: Viewing Multiple Realizations of Array Results (page 764).

Controlling the Chart Style in Array Results

GoldSim has powerful charting capabilities that allow you to customize the appearance of each chart. This includes adding headers and footers, and changing axis scales and labels for scatter plots. Most of these attributes can be edited by pressing the **Edit Chart Style** button at the top of the Multi-Variate display window:

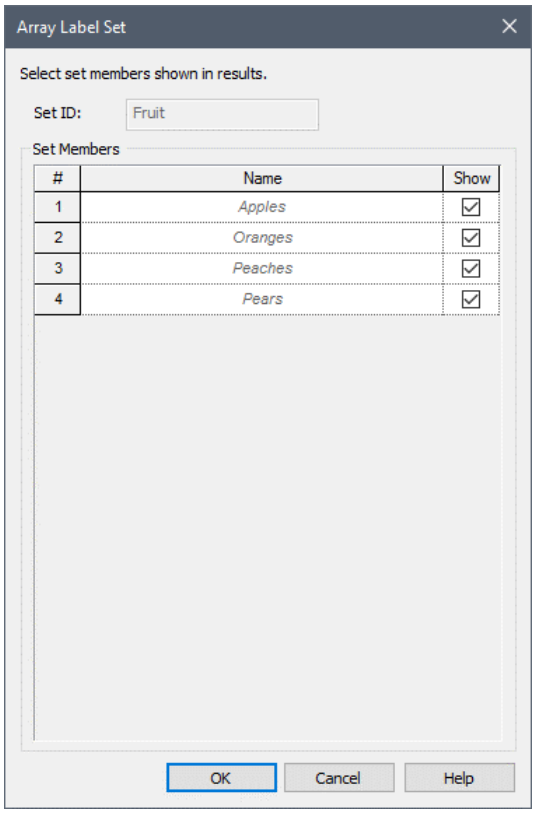
Pressing this button (or right-clicking in a chart and selecting **Edit Chart Style…**) provides access to the following dialog for editing the various chart properties:



This dialog is common to all types of charts, and is discussed elsewhere.

Read more: Editing the Appearance of a Chart (page 768).

For Vector Charts, the bar chart color is fixed and cannot be edited (solid red). You can, however, modify which items are actually included in the chart. Pressing the **Rows…** button from the Result Properties dialog for the Array result displays the following dialog:

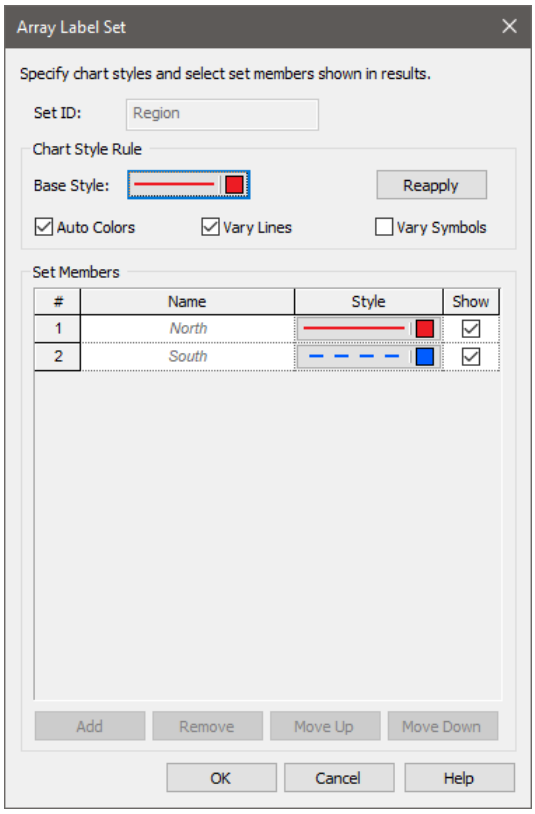


Read more: Viewing the Properties of an Array Result (page 756).

Note: This dialog can also be accessed from the main GoldSim menu (by selecting **Model | Array Labels…** and then selecting the appropriate Array Label Set). When you access the dialog in this manner, the Style for each item is also displayed, but changing these has no impact on Vector Charts, since the Style is fixed.

By default, the **Show** box is checked for all items. If you clear this box, the row item will not be displayed in charts (or tables).

For Matrix Charts, the bar chart color for each column can be specified by pressing the **Columns…** button from the Result Properties dialog for the Array result. The following dialog will be displayed:



Note: This dialog can also be accessed from the main GoldSim menu (by selecting **Model | Array Labels…** and then selecting the appropriate Array Label Set).

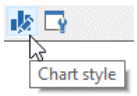
The **Style** column controls the style for the bars for the columns in the Matrix Chart. You can also modify which column items are actually included in the chart. By default, the **Show** box is checked for all items. If you clear this box, the column item will not be displayed in charts (or tables).

Editing the Appearance of a Chart

Whenever you first view a result in GoldSim, it takes on a set of characteristics (e.g., fonts, axis titles, header) defined by a default chart style for that particular type of chart. In some cases, these default chart styles will be sufficient.

In other cases, however, you will want to customize the appearance of the chart. GoldSim allows you to do so. In addition, after customizing a set of properties for a particular type of chart, you can save this set as a new style which you can then selectively apply to subsequent charts (or set as the default for all subsequent charts of that type).

Selecting the **Chart Style…** button in any chart (or right-clicking on any chart and selecting **Edit Chart Style** from the context menu) displays the Chart Style dialog for editing the appearance of the chart:



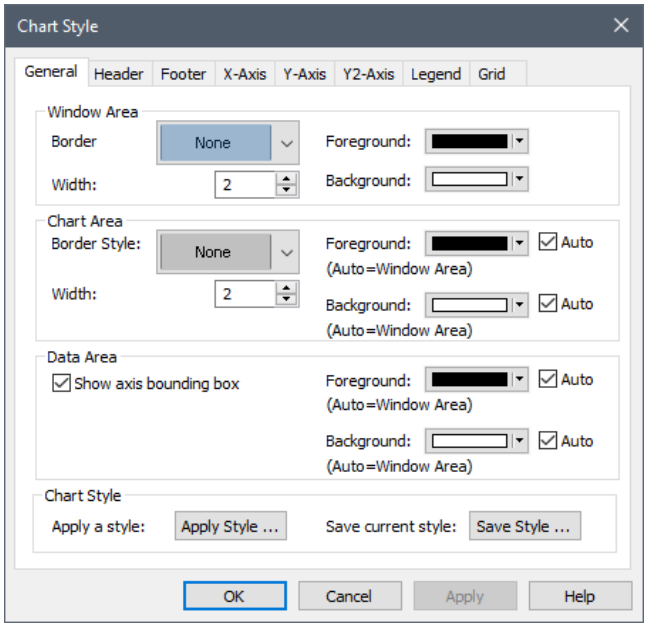
This dialog allows you to edit the appearance of the chart (e.g., by modifying headers, footers, axis labels and scales, legends, etc.). To make it easier to modify and customize your charts, the same tabbed dialog is used for all chart types in GoldSim; some of the tabs and/or options, however, are hidden for those charts for which they are not applicable.

Note: When this dialog is displayed, the Chart display stays active. If you modify some part of the chart's appearance using the dialog and press the Apply button, the change is applied to the Chart. This allows you to view changes without closing the dialog.

The dialog has a number of tabs, which are described in the following sections.

The Chart Style General Tab

The General tab is shown by default when you first open the Chart Style dialog.



The General tab serves two purposes:

- The upper portion of the tab allows you to specify the colors and border styles for the chart; and
- The lower portion of the tab allows you to apply a specific chart style (a common group of appearance properties than can be applied to the entire chart), and (if changes have been made) allows you to overwrite the current chart style or save the current set of properties as a new chart style.

Read more: Creating and Using Chart Styles (page 779).

The upper portion of the **General** tab of the dialog is described below.

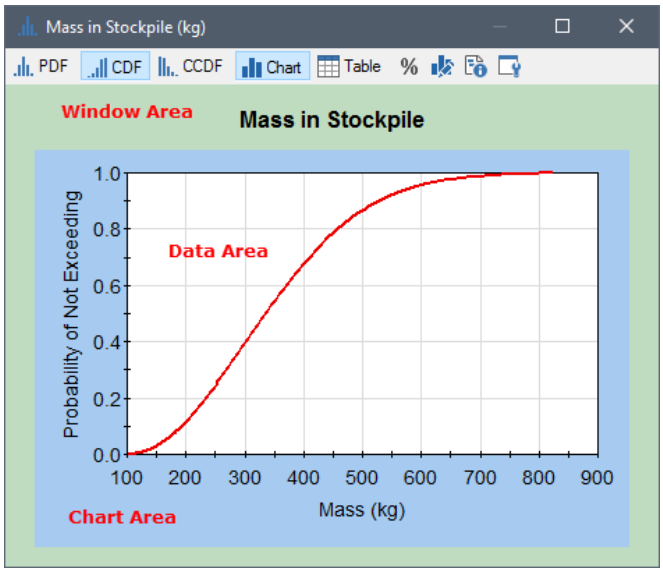
By default, the Chart Area defaults to the same colors as the Window Area and the Data Area defaults to the same colors as the Chart Area.

The Background Color controls the background.

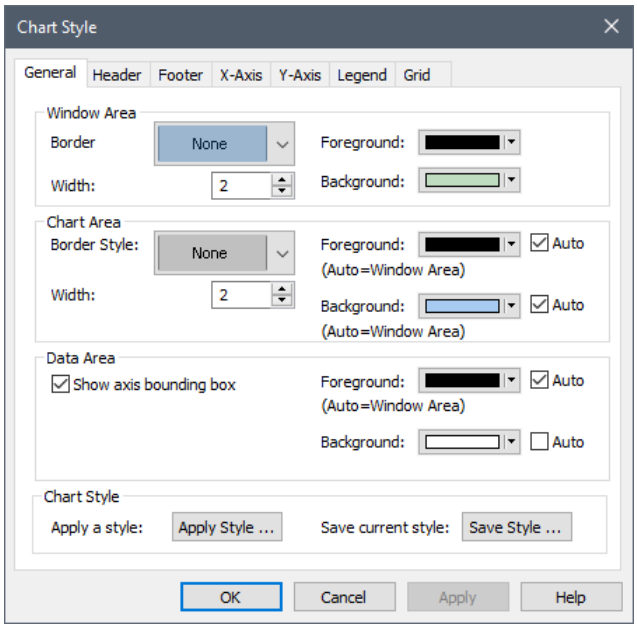
The Foreground Color controls the text or lines that appear in the chart. The Window Area Foreground Color controls the header, the footer and the legend. The Chart Area Foreground Color controls the axes, the axis labels and the grid.

Read more: Using and Managing the Color Palette (page 437).

Colors are defined in a hierarchical manner for a chart by Window Area, Chart Area, and Data Area. The Window Area encompasses the Chart Area, and the Chart Area encompasses the Data Area, as illustrated below:



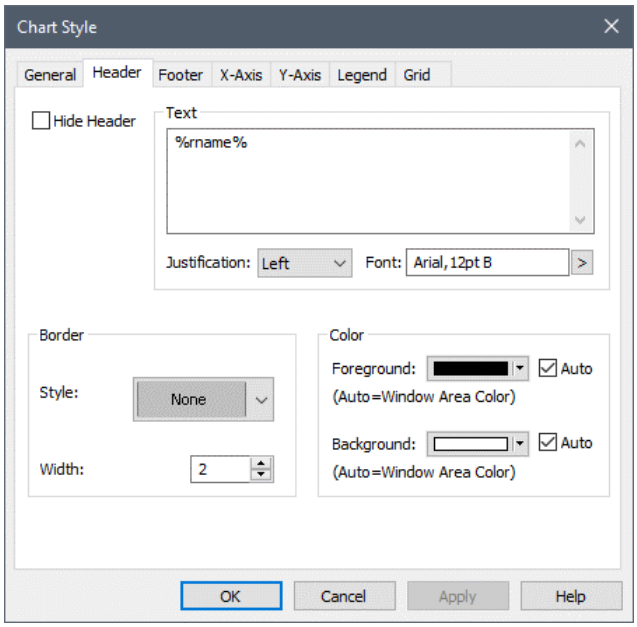
The Chart Style dialog for the example above (with three different background colors) would look like this:



You can place a border around the Window Area and/or the Chart Area of a specified style and width. You can also choose to display a bounding box around the Data Area by checking **Show axis bounding box**.

The Chart Style Header and Footer Tabs

The Header and Footer tabs are used to specify a header and footer for the chart, and are identical in appearance.



If **Hide Header** (or **Hide Footer**) is checked, the header or footer is hidden. You can also hide or show the header or footer via the chart context menu (under View) or via the header/footer context menu.

You enter **Text** for the header or footer, and determine the **Justification** (if it consists of multiple lines), and **Font**.

You can place a border around the header or footer, and specify its **Style** and **Width** (in terms of pixels). You can also specify the **Foreground** and **Background** color for the header or footer (or default the colors so they use that of the Window Area, as specified in the General tab).

Read more: Using and Managing the Color Palette (page 437).

Note: You can access the Header or Footer tab of the chart style dialog directly by selecting **Edit Header…** or **Edit Footer…** from the header/footer context menu.

Note: If you right-click within the **Text** edit field, a context menu providing a list of keywords will be provided. Keywords allow you to automatically insert text that is determined automatically by the context of the result (e.g., the keyword %Rname% inserts the Result element name). This allows you to use a single chart style for multiple results.

Read more: Using Keywords in Styles (page 783).

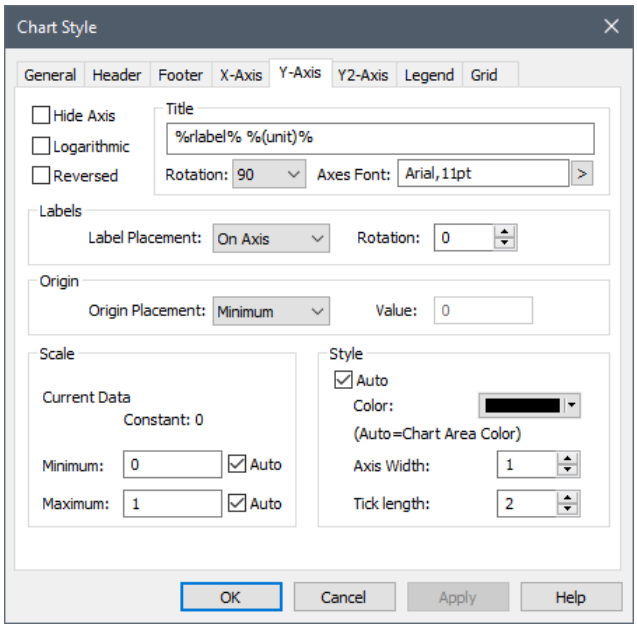
The Chart Style Axis Tabs

Depending on the type of chart and the number of outputs being plotted, up to three axis tabs may be present in the Chart Style dialog (there are always at least two):

Chart Type	X-axis	Y-axis	Y2-axis	Z-axis
Time History	X	X	X	

Chart Type	X-axis	Y-axis	Y2-axis	Z-axis
Distribution	X	X		
Scatter Plot	X	X		X
Array	X	X		X

The X, Y and Y2 axis tabs have the same appearance (with one minor exception noted below).



At the top of the dialog, GoldSim indicates what the particular axis represents, along with its units (if applicable).

The various fields in this tab are described below:

Title: This is the axis title. If you right-click within the **Title** edit field, a context menu providing a list of *keywords* will be provided. Keywords allow you to automatically insert text that is determined automatically by the context of the result (e.g., the keywords %rlabel% %(unit)% inserts the result label and the display units for the output associate with the axis). This allows you to use a single chart style for multiple results.

Read more: Using Keywords in Styles (page 783).

Title Rotation: This is only available for the Y and Y2 axes. There are three options: 90 (the default), in which the title is rotated and read from bottom to top; 270, in which the title is rotated and read from top to bottom; and None, in which the title is not rotated (i.e., is horizontal), and is placed at the top of the axis.

Axis Font: This provides access to a dialog for specifying the font for the axis. Note that this font is applied to all axes (i.e., all axes must use the same font).

Hide Axis: If this box is checked the entire axis (and all annotation) is hidden.

Logarithmic: If this box is checked, the axis is plotted logarithmically (rather than linearly). Note that if the data set you are plotting contains numbers which are less than or equal to zero, these points cannot be plotted

on a logarithmic axis. Therefore, if you make the axis logarithmic in such a situation, GoldSim will omit these points from the plot (i.e., they will appear as "holes" or "gaps" in the plot).

Note: Bar charts cannot be plotted on a logarithmic axis. For example, when plotting a distribution chart as a PDF, the X-axis cannot be logarithmic. If you check the **Logarithmic** box, it will be ignored. In addition, 2-D and 3-D scatter plots cannot be plotted using logarithmic axes. In these cases, the **Logarithmic** box is grayed out.

Reversed: If this box is checked, the axis numbering is reversed (e.g., going from high values to low values rather than from low values to high values).

Label Placement: This is only available for the X, Y and Y2 axes, and determines where the axis labels are placed relative to the other (orthogonal) axis. There are three options: On Axis (the default), in which the labels are placed alongside the axis, Minimum (in which they are placed at the minimum value of the other axis), or Maximum (in which they are placed at the maximum value of the other axis).

Label Rotation: This determines the angle that the axis numbers are rotated. The default is 0.

Origin Placement: This is only available for the X, Y and Y2 axes, and determines where the axis intersects the orthogonal axis (e.g., where the X-axis intersects Y-axis). There are three options: Minimum (the default), in which it intersects at the minimum value of the other axis; Maximum, in which it intersects at the maximum value of the other axis; or At Value, in which it intersects at the **Value** on the other axis indicated directly to the right.

Note: You cannot select label or origin placement for the Y axes for a time history chart with two vertical (Y and Y2) axes.

Scale Minimum: This is the minimum value (lower bound) on the axis. If **Auto** is checked, GoldSim will select the value for you (based on the range).

Scale Maximum: This is the maximum value (upper bound) on the axis. If **Auto** is checked, GoldSim will select the value for you (based on the range).

Note: If the axis being plotted is a date, the scale minimum and maximum will display date and time controls so you can specifically select a date/time range.

Color: This is the color of the axis and all of the annotation. If **Auto** is checked, the foreground color specified for the Chart Area (in the **General** tab) will be used.

Read more: Using and Managing the Color Palette (page 437).

Axis Width: This is the width of the axis lines, in pixels

Tick Length: This is the tick length, in pixels.

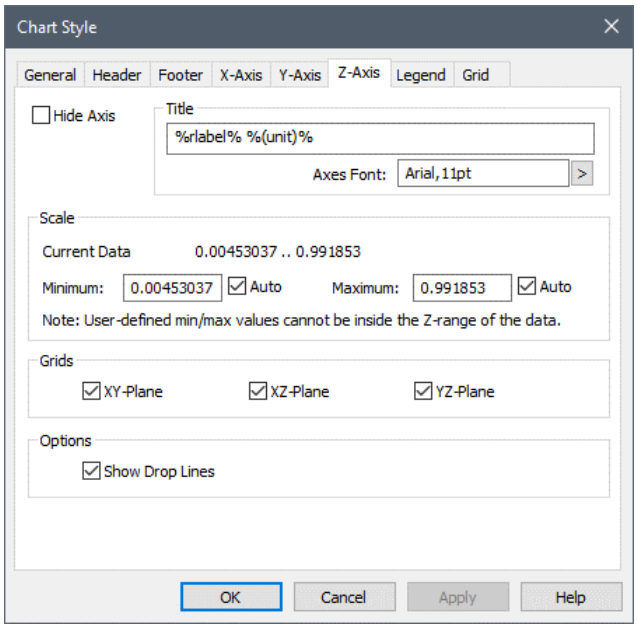
Note: One key attribute for charts is how values on axes are displayed. You cannot control the number of significant figures displayed (this is automatically determined). You can, however, control under what circumstances scientific notation is used via the **Results** tab of the Options dialog (accessed via **Model** |**Options…** from the main menu).

Read more: Controlling Significant Figures and Scientific Notation in Result Displays (page 591).

Note: When viewing a 3D scatter plot, some of the axis options are fixed by GoldSim and will automatically be grayed out in the X-Axis and Y-Axis tabs.

Specifying the Axis Appearance for 3D Charts

The Z-axis tab of the Chart Style dialog box is only available when viewing 3D scatter plots and 3D array plots and contains a subset of the options available on the other axes.



This is because the nature of a 3D plot is such that other than the title, the scale, the font and the font size, the appearance of the axis labels in a 3D plot are fixed by GoldSim and cannot be edited.

The various fields in this tab are described below:

Title: This is the axis title. If you right-click within the **Title** edit field, a context menu providing a list of *keywords* will be provided. Keywords allow you to automatically insert text that is determined automatically by the context of the **result** (e.g., the keywords %rlabel% %(unit)% inserts the result label and the display units for the output associate with the axis). This allows you to use a single chart style for multiple results.

Read more: Using Keywords in Styles (page 783).

Axis Font: This provides access to a dialog for specifying the font for the axis. Note that this font is applied to all axes (i.e., all axes must use the same font).

Hide Axis: If this box is checked the entire axis (and all annotation) is hidden.

Scale Minimum: This is the minimum value (lower bound) on the axis. If **Default** is checked, GoldSim will select the value for you (based on the range).

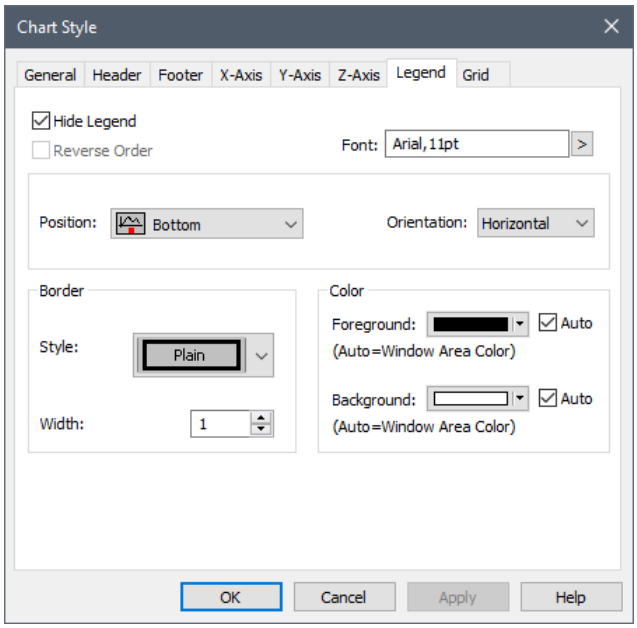
Scale Maximum: This is the maximum value (upper bound) on the axis. If **Default** is checked, GoldSim will select the value for you (based on the range).

Grids (XY-Plane, XZ-Plane, YZ-Plane): This determines if grids are shown for the specified planes. If checked (and applicable to the plot), the grids are shown.

Show Drop Lines: If this box is checked, GoldSim will draw a line from the data point to the XY-plane for scatter plots. It does not apply to array charts.

The Chart Style Legend Tab

The Legend tab of the Chart Style dialog is used to specify the legend for the chart, and is only available for those charts for which a legend is applicable.



If **Hide Legend** is checked, the legend is hidden. You can also hide or show the legend via the chart context menu (under View) or via the legend context menu.

You enter the **Title** for the legend, and determine its **Font**. If the **Reverse Order** box is checked, the items of the legend are listed in reverse order.

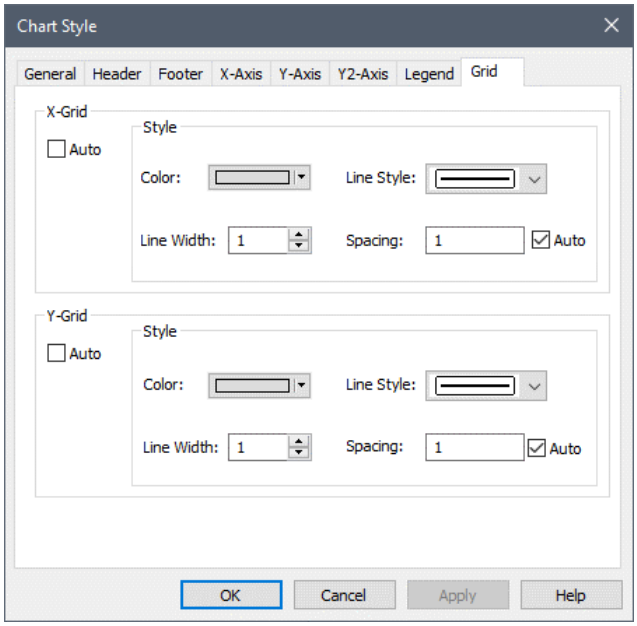
The **Position** field allows you to place the legend at various locations around the chart (Top, Bottom, Right, Left, etc.). The **Orientation** of the items in the legend can be specified as being vertical or horizontal.

You can place a border around the legend, and specify its **Style** and **Width** (in terms of pixels). You can also specify the **Foreground** and **Background** color for the legend (or default the colors by selecting **Auto** so they use that of the Window Area, as specified in the **General** tab).

Read more: Using and Managing the Color Palette (page 437).

The Chart Style Grid Tab

The Grid tab of the Chart Style dialog is used to specify the grid for the chart.



Note that the grid lines are specified for each axis (and are perpendicular to the axis).

You can specify the **Line Style** and **Line Width** (in terms of pixels). You can also specify the **Color** for the grid lines.

Read more: Using and Managing the Color Palette (page 437).

You specify the **Spacing** of the grid lines in terms of the actual units for the data assigned to the axis.

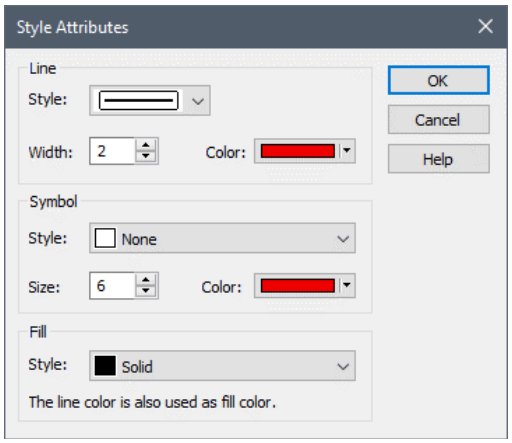
If **Auto** is checked, GoldSim automatically computes an appropriate spacing based on the data range, defaults the color so it uses the Chart Area foreground color (as specified in the **General** tab), and resets the **Line Style** and **Line Width** to default settings.

Editing Data Styles

Unlike the other attributes of a chart (e.g., axes labels, headers, legends), the manner in which the data itself is shown in the chart is not a property of the chart (and hence is not edited in the Chart Style dialog), but is determined by the type of result and the context in which it is being plotted (e.g., is the result an array, are scenarios being viewed, have classification categories been defined).

As such, Data Styles can be specified in multiple places within GoldSim and the style that is used for a particular chart is a function of the context for the display (discussed below).

In all cases, however, the Data Style dialog for a particular data set looks like this:



For each data set, you can select the **Line Style** (e.g., solid, dashed, etc.), the **Line Width** (in pixels) and the **Line Color**. You can also choose to plot a symbol at the data points (the default is no symbol is shown), and select a **Symbol Style** (e.g., square, solid circle, etc.), **Symbol Size** (in pixels), and **Symbol Color**. For bar charts, you can also choose the **Fill Style**. The selected line color is used as the fill color.

Read more: Using and Managing the Color Palette (page 437).

There are several different places from where this dialog can be accessed. It is easiest to summarize this by examining each type of result separately.

Time History Results

- In most situations, the Data Style is specified directly in the Result Properties dialog.

  Read more: Viewing the Properties of a Time History Result (page 605).

- If you are plotting an array, the Data Style for the different array items is defined in the Array Label Set dialog.

  Read more: Viewing Time Histories for Array Outputs (page 615).

- If you have run multiple realizations and you are displaying **Probabilities**, the Data Style for the display is specified at the top of the Monte Carlo Result Display Properties dialog (in the section labeled "History Statistics"). This dialog is accessed by pressing the **Options…** button in the Result Properties dialog of a Time History Result element.

  Read more: Viewing Probability Histories for Multiple Realizations (page 623).

- If you have run multiple realizations; 2) you have defined more than one category; and 3) you are displaying **All Realizations**, GoldSim will label the curves in the Time History Chart based on the categories you have defined. The Data Style for categories is defined at the bottom of the Monte Carlo Result Display Properties dialog (in the section labeled "Realization Classification and Screening"). This dialog is accessed by pressing the **Options…** button in the Result Properties dialog of a Time History Result element.

  Read more: Using Result Classification and Screening in Time History Results (page 638).

- When a model is in Scenario Mode, the Data Style for the different scenarios is controlled by the Scenario Manager dialog (accessed from the main menu (**Run | Scenario Manager…**) or by pressing **F7**).

  Read more: Viewing Scenario Results in Time History Result Elements (page 645).

Distribution Results

- In most situations, the Data Style is specified directly in the Result Properties dialog.

  Read more: Viewing the Properties of a Distribution Result (page 663).

- If you have run multiple realizations; 2) you have defined more than one category; and 3) the Distribution Result has only a single result defined, GoldSim will label the curves in the Distribution Chart based on the categories you have defined. The Data Style for categories is defined at the bottom of the Monte Carlo Result Display Properties dialog (in the section labeled "Realization Calssification and Screening"). This dialog is accessed by pressing the **Options…** button in the Result Properties dialog of a Time History Result element.

  Read more: Using Result Classification and Screening in Distribution Results (page 681).

- When a model is in Scenario Mode, the Data Style for the different scenarios is controlled by the Scenario Manager dialog (accessed from the main menu (**Run | Scenario Manager…**) or by pressing **F7**).

  Read more: Viewing Scenario Results in Distribution Result Elements (page 688).

Fianl Value Results

- Unlike all other result types, the colors of the bars, columns and pie slices in a Final Value chart are auto-selected and cannot be controlled by the user.

Multi-Variate Results

- In the absence of Classification categories, the symbol used for a scatter plot is fixed and cannot be edited (a solid red square).

- If you defined more than one category, GoldSim will label the points in the Scatter Plots based on the categories you have defined. The Data Style for categories is defined at the bottom of the Monte Carlo Result Display Properties dialog (in the section labeled "Realization Classification and Screening"). This dialog is accessed by pressing the **Options…** button in the Result Properties dialog of a Time History Result element.

  Read more: Using Result Classification and Screening in Multi-Variate Results (page 751).

Array Results

- The Data Style for the different array items is defined in the Array Label Set dialog.

  Read more: Controlling the Chart Style in Array Results (page 766).

Creating and Using Chart Styles

Often, after modifying the appearance of a chart, it is very useful to save the particular set of properties you have created (e.g., label fonts, header, footer) so that you can apply them to another chart. To facilitate this, GoldSim allows you to save the set of properties as a named ***chart style***. A chart style consists of all of the chart properties that you specify in the Chart Style dialog.

Read more: Editing the Appearance of a Chart (page 768).

The named chart style is saved as part of the model file, and can subsequently be applied to other results in your model. You can also export and import chart styles between models.

Note: Unlike the other attributes of a chart (e.g., axes labels, headers, legends), the manner in which the data itself is shown in the chart is not a property of the chart itself (and hence is *not* edited in the Chart Style dialog and is *not* saved in a chart style.)

Read more: Editing Data Styles (page 776).

Whenever you view a result, it will initially take on a set of characteristics defined by the *default chart style* for that particular type of chart (e.g., time history, distribution, etc.).

GoldSim provides five "built-in" chart styles:

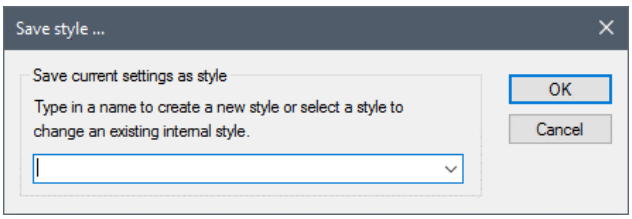
- Basic Time History Style
- Basic Distribution Result Style
- Basic Final Value Result Style
- Basic Multi-Variate Style
- Basic Array View Style

Initially, the five "built-in" styles are defined as the default chart styles for each type of plot. For any type of chart, you can specify one of your own custom chart styles as the default chart style for all subsequent results that are displayed.

Saving and Applying Chart Styles

After you have customized the appearance of a particular result, you can save a new chart style as follows:

1. From the **General** tab of the Chart Style dialog, press the **Save Style…** button.
2. To save a style, press the **Save Style…** button. The following dialog is displayed:

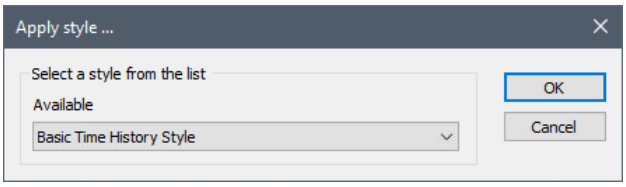


3. Type in a style name (to create a new style) or select an existing style from the drop list (to overwrite an existing style).
4. Press **OK** to save the style.

Note: You cannot overwrite the "built-in" styles provided by GoldSim. As a result, the drop list only contains user-defined styles.

You can apply a chart style to a result chart as follows:

1. From the **General** tab of the chart editing dialog, press the **Apply Style…** button.
2. The following dialog is displayed:



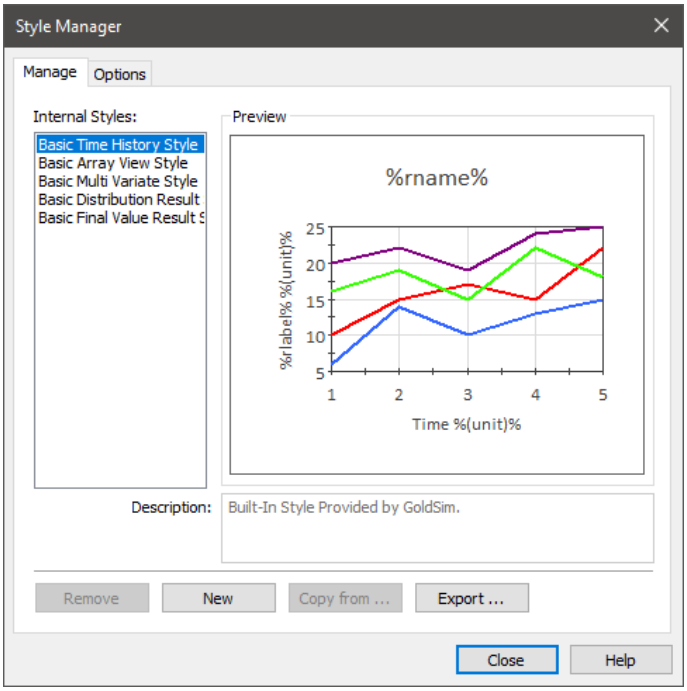
3. Select the style you wish to apply, and press **OK**.

Note: Styles store all the information required for all types of charts (with the exception of the Data Style). Hence, any style can be applied to any kind of chart. In practice, however, you will typically create and apply different styles for different types of charts in order to better customize their appearance.

Using the Style Manager

The GoldSim Style Manager is used to manage all of your styles. You can use the Style Manager to view where styles are being used, create new styles, import and export styles, and to define default styles.

The Style Manager is accessed from the main menu via **View|Style Manager…**:



The Style Manager consists of two tabs: **Manage** and **Options**. The **Manage** tab lists all of the styles in your model (including the "built-in" styles provided by

GoldSim). When you select a style, a preview (using a simple default data set), showing its primary attributes is shown in the Preview window. You can also enter a **Description** for any user-defined style (in order to remind yourself of the purpose or contents of the style).

You can delete a style by selecting it and pressing the **Remove** button. Note, however, that this button is grayed out if a "built-in" style is selected ("built-in" styles cannot be deleted).

If you right-click on one of the listed styles, a list of the Result elements which use that style is displayed.

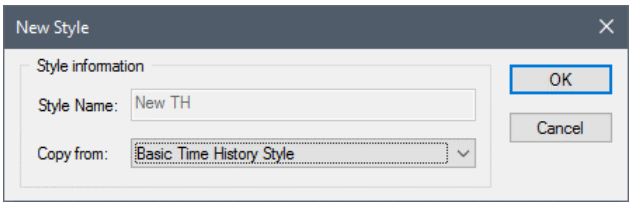
Read more: Creating and Using Result Elements (page 593).

Managing Styles in the Style Manager

You can use the Style Manager to copy the properties from one style to another, as well as import and export styles.

In some situations, you may have applied a style to a number of Result elements, and then want to edit that style so it is identical to some other style in your model. Rather than editing the style, you can simply copy all the properties of an existing style into another style as follows:

1. Press the **Copy from…** button from the **Edit Style** tab of the Style Manager. The following dialog is displayed:



2. Select an existing style from the **Copy from** drop-down list.
3. Press **OK**.

Chart styles are saved within the model file. Often, however, you may wish to use a style that you created in one model file within a second model file. To facilitate this, GoldSim allows you to save a style as an external ***style file***, and then create a new style (within a different model file) by importing the external style file.

You can export a style (i.e., create a style file) as follows:

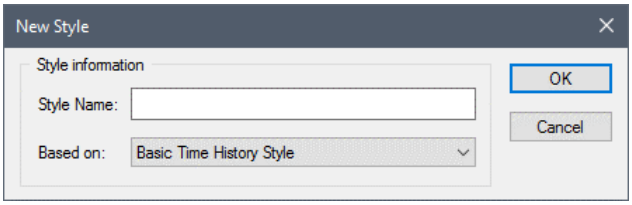
1. Press the **Export…** button from the **Manage** tab of the Style Manager. A Save As dialog will be displayed for saving the style to a file. The default filename is identical to that of the style. If you wish, you can modify it. Style files have the extension ".gcs".
2. Press the **Save** button to save the style file.

Note: The default location in which the style file will be saved is specified in the **Options** tab of the Style Manager. If desired, of course, you can also save the style file to a different folder.

You can import a style file into a model file as follows:

1. Make sure that the style file that you wish to import is in the default style file folder (specified in the **Options** tab of the Style Manager).

2. Press the **New…** button from the **Manage** tab of the Style Manager. The following dialog will be displayed:



3. If one of the built-in styles was selected when your pressed the **New** button, you can enter a **Style Name** for the style into which you wish to import the information contained in the style file (and a new style will be created). Otherwise, it will be imported into the selected style (overwriting it).
4. Expand the **Based on** drop list to display all of the available styles upon which you can base the new style.
5. In addition to including all of the styles, the list also includes all the style files located in the default style file directory. (Style files include the date they were created.)
6. Select the style file that you wish to import and press **OK**.

The new style will be added to the style list. You may want to edit the **Description** for the new file to indicate how it should be used.

Defining the Default Chart Styles

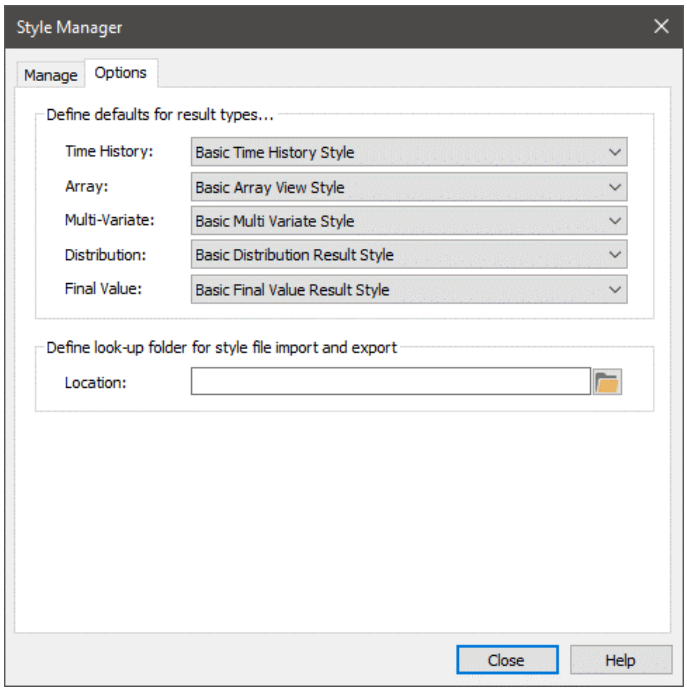
Whenever you view a result, it will initially take on a set of characteristics defined by the default chart style for that particular type of chart (e.g., time history, distribution, etc.).

GoldSim provides five "built-in" chart styles:

- Basic Time History Style
- Basic Distribution Result Style
- Final Value Result Style
- Basic Multi-Variate Style
- Basic Array View Style

Initially, these five "built-in" styles are defined as the default chart styles for each type of plot. For any type of chart, however, you can specify one of your own custom chart styles as the default chart style for all subsequent results that are displayed.

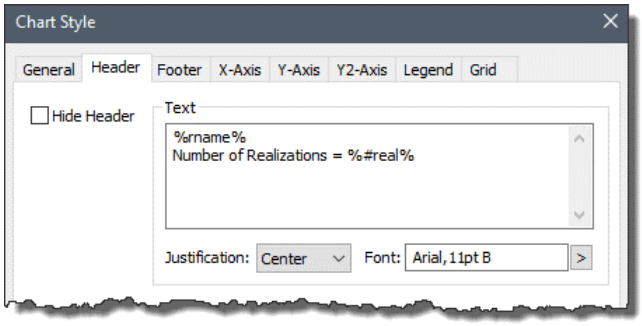
This is done from the **Options** tab of the Style Manager. The default styles for each of the five types of result charts are specified at the top of this tab of the dialog.



Note: Styles store all the information (except for Data Styles) required for all types of charts. Hence, any style can be applied to any kind of chart. In practice, however, you will typically create and apply different styles for different types of charts in order to better customize their appearance. Hence, it is likely that you will want to assign a different default chart style for each type of chart.

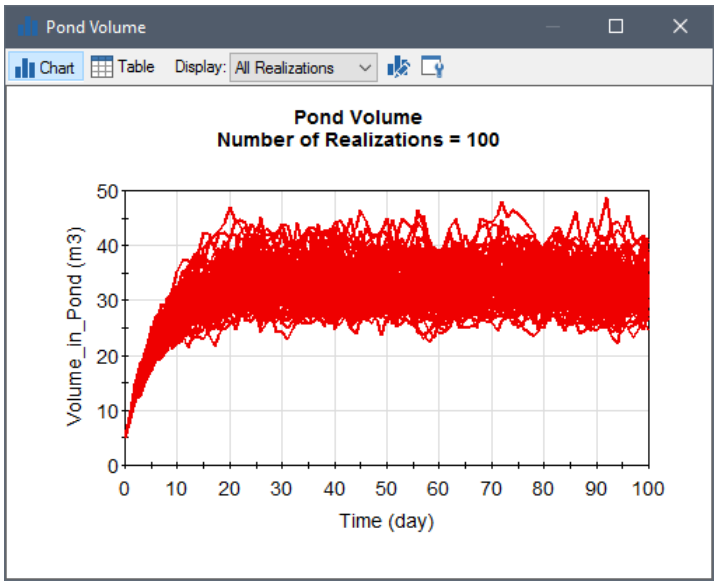
Using Keywords in Styles

In order to facilitate the use of a single chart style for multiple results, GoldSim allows you to use ***keywords*** (delimited by the % symbol) when you create and use chart styles. Keywords can be used in fields where titles or text is required (e.g., headers and footers, axis labels, legend titles). For example, the keyword %rname% inserts the name of the Result element being displayed, and the keyword %#real% inserts the number of realizations. We could insert these in a header, as shown below:



The keyword %rname% is actually the default header text for all results. It is hidden for interactive results (since there is no corresponding Result element).

This would appear in the chart as follows:



You can access the full list of keywords which are available by right-clicking in any Title or Text field in the chart style dialog.

A complete list of available keywords is provided below:

Keyword	Description
%rname%	Result element name[1]
%rdesc%	Result element description[1]
%rlabel%	Label of the first result mapped to the axis[2] (context sensitive)
%unit%	Display units for axis value[3] (context sensitive)
%(unit)%	Display units for axis value within parentheses[3] (context sensitive)
%[unit]%	Display units for axis value within brackets[3] (context sensitive)
%#real%	Number of realizations
%#creal%	Number of completed realizations[4]
%mctype%	Type of Monte Carlo simulation (Deterministic or Probabilistic)
%rundate%	Date simulation was started (displayed using Regional date format settings)
%runtime%	Time simulation was started (displayed using Regional time format settings)
%runduration%	Duration of simulation (simulation run time)
%curdate%	Current date (displayed using Regional date format settings)
%curtime%	Current time (displayed using Regional time format settings)
%period%	Period Label of reporting period being displayed (blank if result is not period-based)
%ctprec%	CT Module solution precision (Low, Medium, High). N/A shown if module not being used.
%author%	Model Author (as specified in the Information tab of the Simulation Settings dialog)
%an_desc%	Analysis Description (as specified in the Information tab of the Simulation Settings dialog)

Keyword	Description
%filename%	model filename (without extension)
%filename_ex%	model filename (with extension)
%copyright%	GoldSim copyright notice
%version%	GoldSim version number

[1] If an interactive result is being displayed, this is ignored.

[2] If the keyword is used in a location other than an axis title (e.g., a header or footer title), it simply appears as entered (e.g., %rlabel%) and is not replaced with a result label (as it would ambiguous as to which label to use).

[3] If the axis data is dimensionless, or if it represents a date/time, the keyword is ignored. If the keyword is used in a location other than an axis title (e.g., a header or footer title), it simply appears as entered (e.g., %unit%) and is not replaced with a unit (as it would ambiguous as to which unit to use).

[4] Displays total number of completed realizations, even if some are currently screened. In Scenario Mode, if all of the displayed scenarios do not have the same number of completed realizations, N/A is displayed.

Note that some of these keywords are used as defaults. For example, all result displays use %rname% in the Header, and the axis titles use both %rlabel% and %(unit)%.

Exporting Results

In some cases, rather than using the result plotting and post-processing capabilities provided by GoldSim, you may wish to plot, analyze, or store the results using a separate program, such as a spreadsheet, a database, or statistical analysis package.

To facilitate this, GoldSim provides three flexible methods for exporting results in the form of an MS-Excel file or a text file. The three methods are as follows:

Exporting Time Histories from a Time History Result Element. You can export outputs that are specified within a Time History Result to an MS-Excel spreadsheet file or a text file. This export can be set to occur automatically at the end of a simulation, or can be triggered manually while in Result or Scenario Mode. Spreadsheet export provides export of a single history per result (for single realization runs) or a specified statistic (for multi-realization runs). Text export provides export of all realizations for multi-realization runs.

Exporting Results Using a Spreadsheet Element. You can export specified GoldSim outputs to an MS-Excel spreadsheet file using a Spreadsheet element. Any GoldSim output can be exported in this way. By using the built-in capabilities of Spreadsheet elements (in particular, the ability to specify dynamic offsets), time histories and/or multiple realizations can be output. This export occurs automatically during the simulation.

Exporting Final Value Results for Multiple Outputs and Multiple Realizations. You can export the final values for each realization for specified GoldSim outputs to a text file. The export is carried out manually using a key combination when viewing a Raw Multi-Variate Data Table. This export is of particular value when you wish to carry out sensitivity and/or uncertainty analyses using a separate statistical analysis software package.

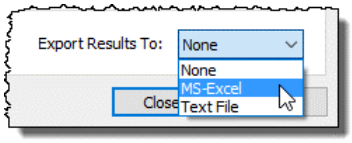
Exporting from a Time History Result Element to a Spreadsheet

These methods are described in detail in the sections below.

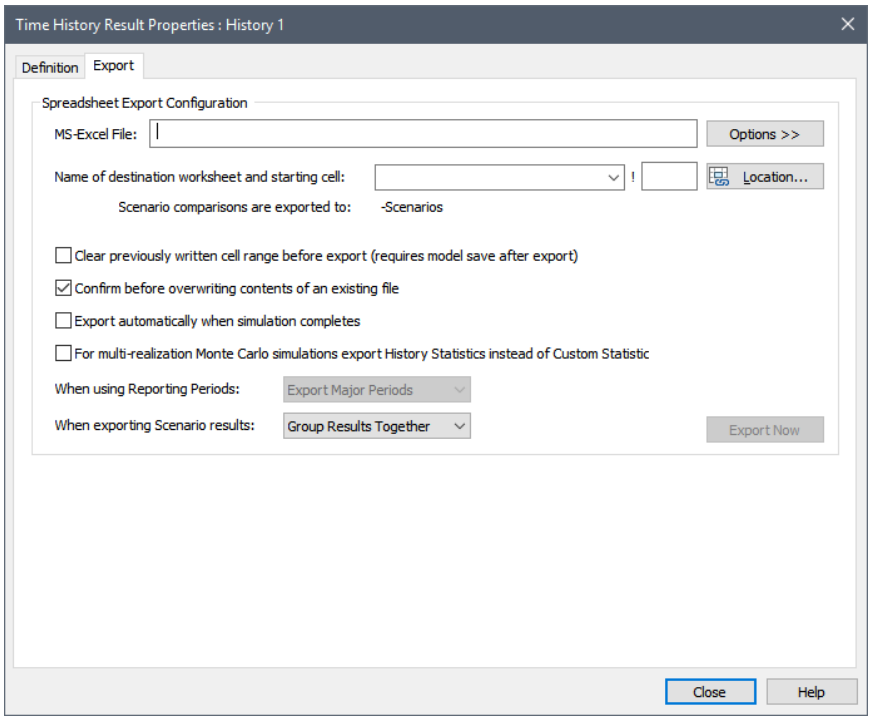
You can export outputs that are specified within a Time History Result to an MS-Excel spreadsheet file. This export can be set to occur automatically at the end of a simulation, or can be triggered manually while in Result or Scenario Mode. In addition, when running multiple scenarios, scenario comparisons can be written to the spreadsheet.

Read more: Exporting Scenario Results from a Time History Result Element to a Spreadsheet (page 791).

To enable this capability for a Time History Result element, select "MS-Excel" from the **Export Results To** drop-list at the bottom of the Time History Result element dialog:



By default, this is set to "None". When you select "MS-Excel", an **Export** tab is added to the dialog:



You must first specify the Excel filename to which you wish to export. You can enter the name of a Microsoft Excel spreadsheet file to which you wish to link by pressing the **Options >>** button. This will provide options for either selecting an existing file, or creating (and then selecting) a new file. You can also type in the name of a file directly. In this case, you must provide a full or relative path (relative to the model file).

The Excel file does not need to exist prior to the export. If you type in a file that does not exist, GoldSim will create it at the time of export. The filename that you enter can contain one or more of the following keywords which will be replaced with the appropriate text at the time of export:

Keyword	Description
%en%	The name of the Result element
%filename%	The name of the GoldSim file (without the extension)
%rundate%	Date simulation was started (displayed using Regional time format settings)
%runtime%	Time simulation was started (displayed using Regional time format settings).

If the file exists at the time of export, it will be overwritten by the new data. If **Confirm before overwriting contents of an existing file** is checked, GoldSim will confirm before doing so. Note, however, that for existing spreadsheet files, GoldSim only overwrites those cells to which it is specifically exporting results. It does not overwrite any other cells in the file. In some cases, this could lead to situations where only a portion of the data in a particular row or column is overwritten (e.g., if the number of timesteps is changed between simulations), and this has the potential to create confusion. To prevent this, you should check **Clear previously written cell range before export**. If this is checked, GoldSim clears out all the cells from the previous time it exported from this Result element before writing the new results.

Note: In order to be able to clear cells that were previously written to, GoldSim must "remember' the cells to which it has previously written by saving this information with the file *after* the export has taken place. As a result, if you carry out an export, and then close the file *without first saving it*, this information is lost (i.e., GoldSim does not "remember" the cells to which it has previously written). Hence, to take advantage of this feature, you should always save the model after you carry out an export.

In addition to specifying the Excel filename, you must also specify the **Name of destination worksheet and starting cell** (the sheet and starting cell) where the data is to be exported. If the Excel file already exists, you can use the **Location…** button, which opens the spreadsheet and provides a dialog allowing you to directly select the desired cell using your mouse. If the Excel file does not exist, you must manually enter the sheet name and starting cell.

Note: Scenario results are exported to a different sheet. In particular, the name of the sheet is "*Sheetname*-Scenarios", where *Sheetname* is the name that you specify in this dialog.

Read more: Exporting Scenario Results from a Time History Result Element to a Spreadsheet (page 791).

Data is always exported in columns (one column for the time, and one column for each result). If only a single realization is run, that realization is exported (for each result specified in the Result element).

If multiple realizations are run, by default the specified **Custom Statistic** for each result is exported. However, if you check **For multi-realization Monte Carlo simulations export History Statistics instead of Custom Statistic**, then

multiple statistics (those displayed in Probability History displays, and defined in the Monte Carlo Result Options dialog) will be exported.

Read more: Viewing Custom Statistics for Multiple Realizations (page 627); Viewing Probability Histories for Multiple Realizations (page 623).

Note: If you need to export all realizations of a multiple realization simulation, you can do so by choosing to export to a text file rather than a spreadsheet.

Read more: Exporting from a Time History Result Element to a Text File (page 794).

An example of what the exported data in a spreadsheet looks like is provided below:

	A	B	C
1	Date	Height	Flow_Rate
2		m	m3/day
3		Mean	50%
4	1/1/2013 0:00	10.01478	103.5608
5	1/2/2013 0:00	9.957983	102.2609
6	1/3/2013 0:00	9.876554	106.2593
7	1/4/2013 0:00	10.01512	96.57172
8	1/5/2013 0:00	10.03233	104.795
9	1/6/2013 0:00	9.852924	102.4378
10	1/7/2013 0:00	9.951	101.2296
11	1/8/2013 0:00	9.902326	101.7324
12	1/9/2013 0:00	10.10255	103.8019
13	1/10/2013 0:00	10.05865	99.36085
14	1/11/2013 0:00	10.005	98.30874

In this particular example, the Result element contained two results (Height and Flow_Rate). The model was run for multiple realizations, and the default choice of exporting the Custom Statistic was selected (which in this case was Mean for Height and the 50th percentile for Flow_Rate).

Note that GoldSim writes three header rows. The first identifies the result, the second the units, and the third the result type (in this example, the Mean the the 50th percentile). In addition, the first cell contains a comment with information regarding the run (e.g., version used, date/time of simulation and export, name of Result element, etc.).

Note: GoldSim exports the results as single-precision values. When exporting dates from a calendar time model, if the first cell of the time column is not formatted as a date, GoldSim will format the column as a localized date (based on Windows settings). None of other columns (i.e., the result values) will be formatted.

The time points that are exported to the spreadsheet are the same as those displayed in result charts and tables for the result element.

Read more: Specifying When Time History Results Will Be Saved (page 482).

If your Result element is configured to display Reporting Periods, and you have more than one Reporting Period defined, you must specify which period you

wish to export in the **When using Reporting Periods** drop-list. The type of Reporting Period results that are exported (e.g., Average, Cumulative, etc.) are as specified in the Properties dialog for the Result element.

Read more: Viewing Reporting-Period Based Results in Time History Result Elements (page 631).

If a result is an array, it is simply treated in the spreadsheet as separate items (i.e., an array of 10 items would produce 10 result columns).

Several other points regarding result export to spreadsheets should be noted:

- Conditions are exported as 0 (False) or 1 (True).
- Results that are dates (such as the output of a Milestone element) are exported as Julian days.
- If an output is an array, only those items of the array which have been selected to be viewed (via the Array Label Set dialog) are exported.

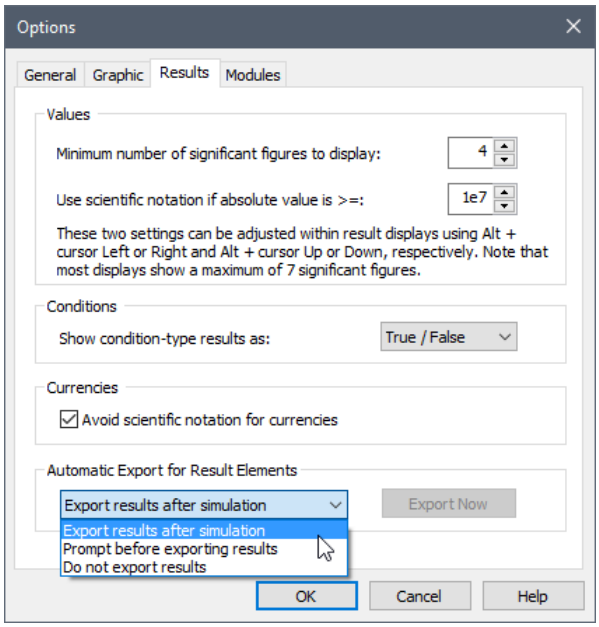
  Read more: Viewing Time Histories for Array Outputs (page 615).
- For simulations involving multiple realizations, only those realizations which have been specifically selected to be included (via the Monte Carlo Result Options dialog) are used to compute the Custom Statistic that is exported.

  Read more: Classifying and Screening Realizations (page 601).
- High resolution results are not exported. That is, if your Time History Result is configured to include unscheduled updates, these are not exported. Only scheduled updates are exported.

  Read more: Viewing Unscheduled Updates in Time History Result Elements (page 652).
- You cannot export time history results from a SubModel (i.e., if the **Time Display Setting** in the Result element is "SubModel Time").

The actual export of the results can be triggered in two ways: manually and automatically. This is determined by the **Export automatically when simulation completes** checkbox. If this box is cleared, GoldSim only exports the data if and when you press the **Export Now** button in the **Export** tab of the Result element dialog. If this box is checked, however, GoldSim automatically exports the results at the end of the simulation. When it exports the results in this way, any errors it encounters (e.g., running out of space in the spreadsheet) are written to the Run Log.

For elements which are set to export automatically, you can globally control their behavior from the **Results** tab of the Options dialog (accessed from the main menu via **Model|Options…**, and then selecting the **Results** tab):



The options in the drop-list affect all Time History Result elements which are set to export automatically when the simulation completes. If "Export results after simulation" is selected, any Result elements which are set to export results will export (silently) at the end of the simulation. If "Prompt before exporting results" is selected, at the end of the simulation, you will be prompted to determine whether or not to carry out an automatic export. If "Do not export results" is selected, no automatic export is carried out (i.e., this overrides the selection for each individual Result element).

Pressing the **Export Now** button manually exports results from all Time History Result elements.

Note: Within Dashboards, the Button control provides a command option that is equivalent to pressing the **Export Now** button from the **Result** tab of the Options dialog.

Button command options within a Dashboard are discussed in detail in the **Dashboard Authoring Module User's Guide**.

Several points should be noted regarding automatic export of spreadsheet results:

- Automatic export is ignored when carrying out a Sensitivity Analysis or an Optimization run.

  Read more: Running Sensitivity Analyses (page 560); Running an Optimization (page 548).

- Automatic export is ignored if the Result element is inside a SubModel.

  Read more: Using SubModels to Embed Models Within Models (page 1047).

- Automatic export is only carried out under special circumstances when running and comparing scenarios.

Read more: Exporting Scenario Results from a Time History Result Element to a Spreadsheet (page 791).

Finally, when exporting to spreadsheets, the following points regarding the use of Excel should be noted:

- GoldSim supports .xlsx, .xlsm, and .xls Excel files. However, if you have an older version of Excel (prior to Office 2007), you will need to install Microsoft's Office Compatibility Pack in order to read .xlsx and .xlsm files. Note that GoldSim does not officially support versions of Excel prior to Excel 2003.
- The .xls format is limited to 65,536 rows and 256 columns. Exporting in columns allows a maximum of 65,533 plot points to be exported (three rows are reserved for the header) and 255 output values (first column is reserved for time). If the data will not fit in the spreadsheet due to one of these limitations, a warning message will be written to the screen (if exporting manually) or the Run Log (if exporting automatically). Note, however, that Excel 2007 and later support an extended worksheet size (1,048,576 rows by 16,384 columns). If you wish to export data to an extended worksheet range into GoldSim, you must use Excel 2007 or newer, and the file format must be .xlsx or .xlsm.
- You should never try to open a spreadsheet that is linked to GoldSim while a simulation is running. In addition, prior to running a GoldSim model that is linked to a spreadsheet, all referenced spreadsheets should be closed. If you try to interact with a spreadsheet that is being used by GoldSim during a simulation, all interaction with the spreadsheet is blocked by GoldSim. However, under some circumstances this may not be possible and could lead to errors. Hence, as a general rule, you should not use Excel while a Goldsim model that references Excel is running.
- You should not specify Excel files with the same filename that are in different folders, drives or network locations. Excel is unable to open such files simultaneously, and this will cause GoldSim to fail.

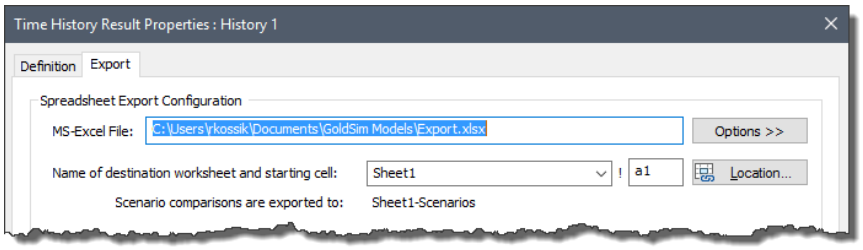
Exporting Scenario Results from a Time History Result Element to a Spreadsheet

When running multiple scenarios, time histories for different scenarios can be written to a spreadsheet.

Read more: Creating, Running and Comparing Scenarios (page 525).

Note, however, that export of scenario results to a spreadsheet must be carried out in a special way to prevent each export from simply overwriting previously exported scenarios.

In particular, when exporting scenarios, GoldSim exports all scenarios with results to a separate sheet from that defined in the dialog; it appends "-Scenarios" to the specified sheet name, and exports results to that sheet (creating it if it does not already exist). For example, if your specified sheet name was simply "Sheet1", scenario results would be exported to "Sheet1-Scenarios" (and this is indicated in the dialog):



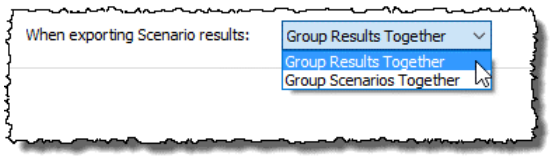
Scenario results are exported only under the following four conditions:

1. If the model is in Scenario Mode, pressing **Export Now** from the **Export** tab of the Result element exports results for all scenarios with results to the specified Scenarios sheet.
2. If the model is in Scenario Mode, pressing **Export Now** from the **Results** tab of the Model Options dialog exports results for all scenarios with results from *all* Time History Result elements to their specified Scenarios sheet.
3. Within Dashboards, the Button control provides a command option that is equivalent to pressing the **Export Now** button from the **Result** tab of the Options dialog. Hence, if the model is in Scenario Mode, this button command exports results for all scenarios with results from *all* Time History Result elements to their specified Scenarios sheet. Button command options within a Dashboard are discussed in detail in the **Dashboard Authoring Module User's Guide**.
4. If you press **Run All** in the Scenario Manager, any Result elements that are configured to automatically exports result will export results for *all scenarios* to their specified Scenarios sheet.

Several important points should be noted regarding scenario export:

- If you run a single scenario from the Scenario Manager or from the Scenario control on a Dashboard, no results are exported (even for Result elements that are configured to automatically export).
- If you run a model such that it ends in Result Mode (e.g., by pressing **F5** or the **Run** button in the Run Control toolbar), any Result elements that are configured to automatically export results will simply export results for the Active Scenario to the selected primary sheet (e.g., Sheet1). Similarly, if you press **Export Now** in Result Mode, the results for the Active Scenario will be exported to the primary sheet. In either case, any other results in the primary sheet will be overwritten. As a result, *you cannot export scenario comparisons in this way*.
- Since Player users cannot access the Scenario Manager, and single scenario runs are never automatically exported, if a Scenario control is present on a Dashboard when running the Player, automatic export will always be ignored. Results can only be exported manually. To export scenarios from the Player, the author should provide a Button control with an Export command (item #3 above). Note that the Result tab of the options dialog is accessible from the Player, so if the model is browsable, scenario export could also be carried out by pressing the Export Now button in that dialog (item #2). However, this would typically be a very awkward way for a Player user to trigger an export. The Scenario control within a Dashboard is discussed in detail in the **Dashboard Authoring Module User's Guide**.

When exporting scenario results to the Scenarios sheet GoldSim provides two options for how the results are exported on the **Export** tab of the Result element dialog:



If you select "Group Results Together", if multiple results are being exported, the columns will be grouped together by result:

	A	B	C	D	E	F	G
1		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2	Time	Flow	Flow	Flow	Cost	Cost	Cost
3	day	m3/day	m3/day	m3/day	$/day	$/day	$/day
4		#1	#1	#1	#1	#1	#1
5	0	14.09524155	26.0219841	40.11722565	1390.157349	3664.960205	3791.338379
6	1	14.53176975	26.82788277	41.35965347	2129.185059	5613.306641	5806.868164
7	2	13.41220188	24.76099014	38.17319107	2075.336914	5471.343262	5660.010254
8	3	12.42288685	22.93456268	35.35744858	2014.817627	5311.791992	5494.95752
9	4	11.57713223	21.37316704	32.95029831	1134.683472	2991.438232	3094.591553
10	5	12.16874218	22.46537018	34.63411331	2095.246338	5523.831055	5714.308105
11	6	11.62099266	21.45414162	33.07513428	1578.418457	4161.285156	4304.777832
12	7	16.18246269	29.87531662	46.05778122	1773.099243	4674.53418	4835.724609
13	8	11.67915154	21.56151009	33.24066162	1365.847046	3600.869385	3725.037598
14	9	13.03471088	24.06408119	37.09879303	1893.643677	4992.333008	5164.482422
15	10	11.18868828	20.65603828	31.84472466	1796.660522	4736.650391	4899.983398

In this particular example, the Result element contained two results (Flow and Cost) and three scenarios (Scenario1, Scenario2, and Scenario3) and was run for a single realization. Note that all the results for Flow are presented (for each scenario), followed by all the results for Cost.

If you select "Group Scenarios Together", if multiple results are being exported, the columns will be grouped together by scenario:

	A	B	C	D	E	F	G
1		Scenario 1	Scenario 1	Scenario 2	Scenario 2	Scenario 3	Scenario 3
2	Time	Flow	Cost	Flow	Cost	Flow	Cost
3	day	m3/day	$/day	m3/day	$/day	m3/day	$/day
4		#1	#1	#1	#1	#1	#1
5	0	14.09524155	1390.157349	26.0219841	3664.960205	40.11722565	3791.338379
6	1	14.53176975	2129.185059	26.82788277	5613.306641	41.35965347	5806.868164
7	2	13.41220188	2075.336914	24.76099014	5471.343262	38.17319107	5660.010254
8	3	12.42288685	2014.817627	22.93456268	5311.791992	35.35744858	5494.95752
9	4	11.57713223	1134.683472	21.37316704	2991.438232	32.95029831	3094.591553
10	5	12.16874218	2095.246338	22.46537018	5523.831055	34.63411331	5714.308105
11	6	11.62099266	1578.418457	21.45414162	4161.285156	33.07513428	4304.777832
12	7	16.18246269	1773.099243	29.87531662	4674.53418	46.05778122	4835.724609
13	8	11.67915154	1365.847046	21.56151009	3600.869385	33.24066162	3725.037598
14	9	13.03471088	1893.643677	24.06408119	4992.333008	37.09879303	5164.482422
15	10	11.18868828	1796.660522	20.65603828	4736.650391	31.84472466	4899.983398

Note that in this case all the results for the first scenario are presented (for each result), followed by all the results for the second scenario, and finally all the results for the third scenario.

Note that when exporting scenario results, GoldSim writes four header rows (rather than three). The first identifies the scenario, the second the result, the third the units, and the fourth the result type. In this example, in which only a

single realization was run, the result type is simply the realization number. If multiple realizations were run, the result type would be a statistic.

In addition, the first cell contains a comment with information regarding the run (e.g., version used, date/time of simulation and export, name of Result element, names of scenarios being exported, etc.).

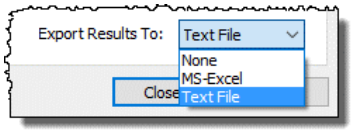
Exporting from a Time History Result Element to a Text File

You can export outputs that are specified within a Time History Result to a tab-delimited text file. This export can be set to occur automatically at the end of a simulation, or can be triggered manually while in Result Mode. Unlike spreadsheet exports, when running multiple realizations, instead of outputting only a single statistic for each result, in addition, all realizations can be exported to the text file.

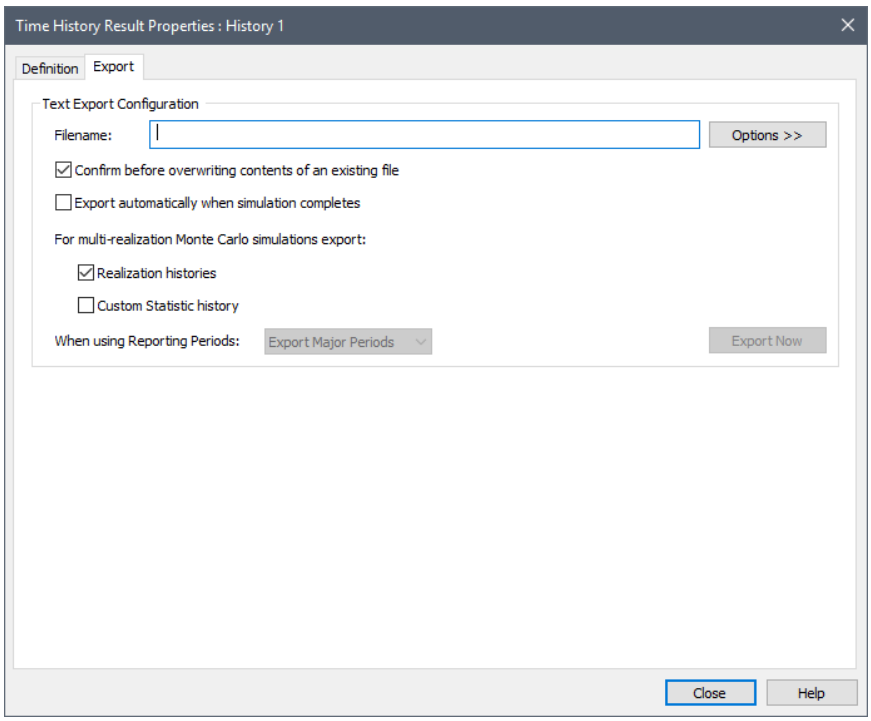
Note: You cannot export scenario results to a text file. If you need to export scenario results, you can do so by choosing to export to a spreadsheet rather than a text file.

Read more: Exporting Scenario Results from a Time History Result Element to a Spreadsheet (page 791).

To enable this capability for a Time History Result element, select "Text File" from the **Export Results To** drop-list at the bottom of the Time History Result element dialog:



By default, this is set to "None". When you select "Text File", an **Export** tab is added to the dialog:



You must first specify the text filename to which you wish to export. You can enter the name of an existing file to which you wish to link by pressing the **Options >>** button. This will provide options for either selecting an existing text file (with the extension .txt), or creating (and then selecting) a new file. You can also type in the name of a file directly. In this case, you must provide a full or relative path (relative to the model file).

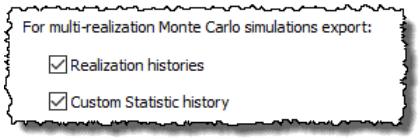
Note: The output file must have the extension ".txt".

The file does not need to exist prior to the export. If you type in a file that does not exist, GoldSim will create it at the time of export. The filename that you enter can contain one or more of the following keywords which will be replaced with the appropriate text at the time of export:

Keyword	Description
%en%	The name of the Result element
%filename%	The name of the GoldSim file (without the extension)
%rundate%	Date simulation was started (displayed using Regional time format settings)
%runtime%	Time simulation was started (displayed using Regional time format settings).

If the file exists at the time of export, it will be overwritten by the new data. If **Confirm before overwriting contents of an existing file** is checked, GoldSim will confirm before doing so.

You then must specify what you would like to export. If running a single realization, the options are not relevant. However, when running multiple realizations, you can export two kinds of information:



You can export the individual histories for each result and/or you can export the Custom Statistic for each result.

Note: If you wish to export multiple statistics, you can do so by simply adding multiple result items to the Result element that reference the same output but have different Custom Statistics. Alternatively, you could choose to export to a spreadsheet, which provides an option for export multiple statistics (i.e., those used for Probability Histories)

Read more: Exporting from a Time History Result Element to a Spreadsheet (page 786).

Data is always exported in a tab-delimited format, with header information written at the top of the file. If multiple realizations are run, all (unscreened) realizations are written to the file. Multiple results are exported in separate blocks (unless the results reference the same output, have the same label and the

same axis mapping, in which case they are exported in the same block so as to list all results referencing the same output together).

An example of what the exported data in a text file looks like is provided below:

```
!Goldsim Version: 11.0.0000
!Model File: C:\Users\rkossik\Desktop\test.gsm
!Simulation Time: 7/7/2013 11:11
!Export Time: 7/7/2013 11:11
!Result Name: Result1
!Result Path: \
!Result Description: (none)
!Time Points: 5
!Realizations: 5
!Weights:       1       1       1       1       1

!Result: Flow
!Unit: m3/day
(Date)  #1      #2      #3      #4      #5
"1/1/2013 0:00:00"      10.70646        11.28938        8.448304        9.233838        9.802564
"2/1/2013 0:00:00"      11.17828        10.51371        10.19991        9.988766        10.40429
"3/1/2013 0:00:00"      10.31708        9.398015        10.06617        11.69179        10.22887
"4/1/2013 0:00:00"      9.556067        8.286284        9.691882        11.48532        11.37942
"5/1/2013 0:00:00"      8.905486        11.67070        8.445362        10.52193        9.000431

!Result: Cost
!Unit: $/day
(Date)  #1      #2      #3      #4      #5
"1/1/2013 0:00:00"      1852.756        1198.883        1217.685        1481.143        1687.330
"2/1/2013 0:00:00"      1935.623        1548.398        1061.841        1280.337        1269.063
"3/1/2013 0:00:00"      1886.670        1384.743        1554.021        1775.878        1997.357
"4/1/2013 0:00:00"      1831.652        1768.296        1494.343        1293.594        1959.220
"5/1/2013 0:00:00"      1031.530        1268.548        1339.408        1547.809        1219.714
```

In this particular example, the Result element contained two results (Flow and Cost). The model was run for 5 realizations, and contains 5 timesteps. If you export both realizations and one or more statistics, for each result, the realizations are listed first, followed by columns for the statistics.

Note that the first 10 lines contain header information (each preceded by a "!"):

- Version number
- Filename
- Time simulation was run
- Time export took place
- Name of Result element
- Full path to Result element
- Description for Result element
- The number of time points
- The number of realizations
- The relative realization weights (only included if realization are exported)

The time points that are exported to the text file are the same as those displayed in result charts and tables for the result element.

Read more: Specifying When Time History Results Will Be Saved (page 482).

The relative realization weights are normally all 1. However, if you use importance sampling (e.g., for Stochastics or Timed Events) or directly specify weights in the Simulation Settings dialog, they will be different and it is critical to take this into account for any post-processing that you carry out on results.

Read more: Applying Importance Sampling to a Stochastic Element (page 187); Timed Event Elements (page 379); Probabilistic Simulation Options (page 498).

After the header information, the result data is written. For each result, there are two header rows (preceded by a "!") indentifying the result name and the units.

The realization numbers are then shown, followed by a row for each timepoint. Each row contains all the (unscreened) realizations.

Note: GoldSim exports the results as single-precision values.

If your Result element is configured to display Reporting Periods, and you have more than one Reporting Period defined, you must specify which period you wish to export in the **When using Reporting Periods** drop-list. The type of Reporting Period results that are exported (e.g., Average, Cumulative, etc.) are as specified in the Properties dialog for the Result element.

Read more: Viewing Reporting-Period Based Results in Time History Result Elements (page 631).

If a result is an array, it is simply treated in the text file as separate items (i.e., an array of 10 items would produce 10 result groupings).

Several other points regarding result export to text files should be noted:

- Conditions are exported as 0 (False) or 1 (True).
- All dates are exported wrapped in quotes.
- If an output is an array, only those items of the array which have been selected to be viewed (via the Array Label Set dialog) are exported.

  Read more: Viewing Time Histories for Array Outputs (page 615).

- For simulations involving multiple realizations, only those realizations which have been specifically selected to be included (via the Monte Carlo Result Options dialog) are exported.

  Read more: Classifying and Screening Realizations (page 601).

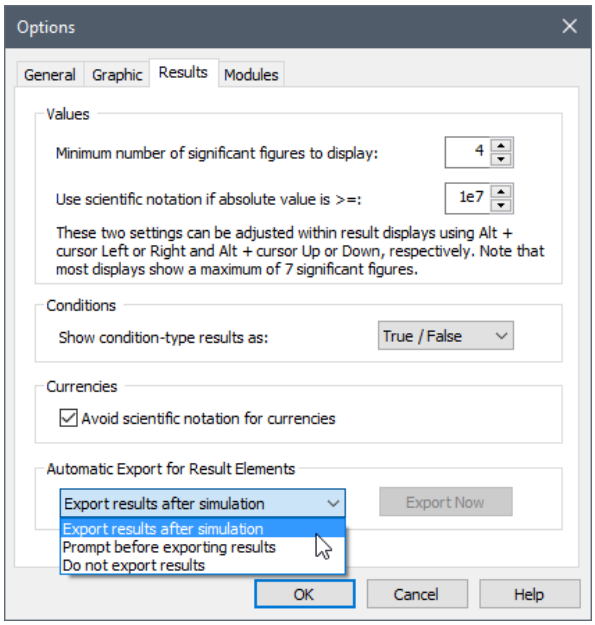
- High resolution results are not exported. That is, if your Time History Result is configured to include unscheduled updates, these are not exported. Only scheduled updates are exported.

  Read more: Viewing Unscheduled Updates in Time History Result Elements (page 652).

- You cannot export time history results from a SubModel (i.e., if the **Time Display Setting** in the Result element is "SubModel Time").

The actual export of the results can be triggered in two ways: manually and automatically. This is determined by the **Export automatically when simulation completes** checkbox. If this box is cleared, GoldSim only exports the data if and when you press the **Export Now** button in the **Export** tab of the Result element dialog. If this box is checked, however, GoldSim automatically exports the results at the end of the simulation.

For elements which are set to export automatically, you can globally control their behavior from the **Results** tab of the Options dialog (accessed from the main menu via **Model|Options…**, and then selecting the **Results** tab):



The options in the drop-list affect all Time History Result elements which are set to export automatically when the simulation completes. If "Export results after simulation" is selected, any Result elements which are set to export results will export (silently) at the end of the simulation. If "Prompt before exporting results" is selected, at the end of the simulation, you will be prompted to determine whether or not to carry out an automatic export. If "Do not export results" is selected, no automatic export is carried out (i.e., this overrides the selection for each individual Result element).

Pressing the **Export Now** button manually exports results from all Time History Result elements.

Note: Within Dashboards, the Button control provides a command option that is equivalent to pressing the **Export Now** button from the **Result** tab of the Options dialog.

Button command options within a Dashboard are discussed in detail in the **Dashboard Authoring Module User's Guide**.

Several points should be noted regarding automatic export of text file results:

- Automatic export is ignored when carrying out a Sensitivity Analysis or an Optimization run.

  Read more: Running Sensitivity Analyses (page 560); Running an Optimization (page 548).

- Automatic export is ignored if the Result element is inside a SubModel.

  Read more: Using SubModels to Embed Models Within Models (page 1047).

- Automatic export is ignored when running and comparing scenarios.

Exporting Results Using a Spreadsheet Element

An additional method that can be used to export results from GoldSim is to use a Spreadsheet element. A spreadsheet element can be used to export any output to a spreadsheet. By using the built-in capabilities of Spreadsheet elements (in

particular, the ability to specify dynamic offsets), time histories, scenarios, and/or multiple realizations can all be output.

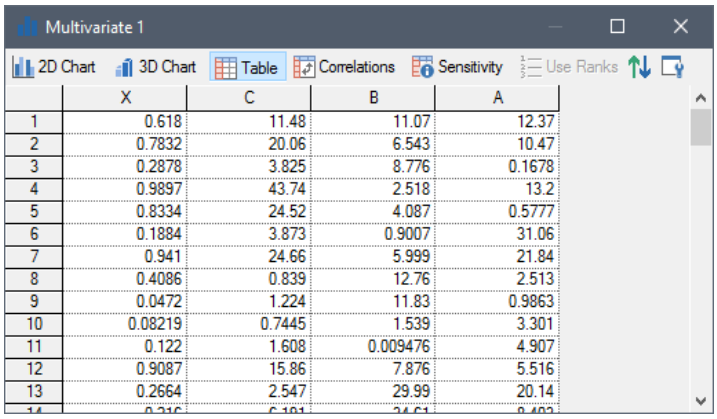
Note: When exporting results, you should not specify Excel files with the same filename that are in different folders, drives or network locations. Excel is unable to open such files simultaneously, and this will cause GoldSim to fail.

Read more: Spreadsheet Elements (page 982).

Exporting Final Value Results for Multiple Outputs and Multiple Realizations

In some cases, you may want to export the final values for selected outputs (e.g., all Stochastics) for every realization to an external file that you can subsequently read into a statistical analysis software package to facilitate post-processing (e.g., detailed uncertainty and/or sensitivity analysis).

You can do this by manually using a key combination when viewing a Raw Multi-Variate Data Table:



	X	C	B	A
1	0.618	11.48	11.07	12.37
2	0.7832	20.06	6.543	10.47
3	0.2878	3.825	8.776	0.1678
4	0.9897	43.74	2.518	13.2
5	0.8334	24.52	4.087	0.5777
6	0.1884	3.873	0.9007	31.06
7	0.941	24.66	5.999	21.84
8	0.4086	0.839	12.76	2.513
9	0.0472	1.224	11.83	0.9863
10	0.08219	0.7445	1.539	3.301
11	0.122	1.608	0.009476	4.907
12	0.9087	15.86	7.876	5.516
13	0.2664	2.547	29.99	20.14

Read more: Viewing a Raw Multi-Variate Data Table (page 749).

Note: The default view for a Multi-Variate result is a 2D Scatter Plot. If you are viewing a 2D Scatter Plot (or a different type of Multi-variate display), you can view a Multi-Variate Data Table by pressing the Table button at the top of the display.

Recall that the specific outputs that are displayed in the table are manually selected when you create a Multi-Variate result (with one option being to display all Stochastic elements).

Read more: Selecting Outputs for a Multi-Variate Result Display (page 738).

You can export the data displayed in the table by pressing **Ctrl+E** while viewing it. This will produce a tab-delimited text file (you will be prompted for a filename). The first line is a header line (Realization, followed by the result labels). Units are shown in parentheses after each result label. Each subsequent line consists of the realization number followed by the values. Data is exported using the current precisions setting (as displayed in the table).

Note: You can control the number of significant figures displayed in tables from the Results tab of the Options dialog (accessed via Model |Options… from the main menu).

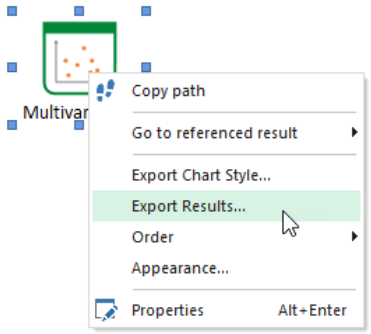
Read more: Controlling Significant Figures and Scientific Notation in Result Displays (page 591).

Ctrl+Shft+E adds the full path to the result labels in the header row.

GoldSim exports exactly what is displayed in the table, so that if you choose to use result classification and screening when displaying the table, this is also reflected in the exported file. Similarly, if you define Capture Times, the selected Capture Times will be reflected in the exported file.

Read more: Using Result Classification and Screening in Multi-Variate Results (page 751); Viewing Results at Capture Times (page 592).

In some cases, it may be cumbersome to open the Multi-Variate Result element and view the Raw Data table before exporting the data. GoldSim therefore provides an additional option to export the final values for all of the outputs specified in the Multi-Variate Result element. In particular, when the model is in Result Mode, you can simply right-click on the icon for the element in the graphics pane and select **Export Results…**:



Only the final values are exported (no Capture Times). However, if you choose to specify result classification and screening in the Result element, this is also reflected in the exported file.

The file that is exported in this case is comma-delimited (actually, comma + space) rather than tab-delimited. If the **Shft** key is pressed while selecting the menu option, the full path to the result labels are added in the header row.

Copying and Exporting Result Displays

Once you have created some result displays (in the form of charts or tables), you may want to copy and/or export the results. This is described below.

Copying a Chart or Table

GoldSim allows you to copy a chart or table to the clipboard. You can then subsequently paste it into another application (e.g., a word processor). Note that charts are pasted as enhanced metafiles, so that the picture can be edited after it is pasted into another application (if you have software that allows you to edit an enhanced metafile).

To copy a chart display window, right-click in the chart, and select **Copy** from the context menu. Alternatively, you can press **Ctrl+C** while viewing the chart.

Read more: Using Context Menus in Charts (page 588).

Table data can be copied using **Ctrl+C**. Note, however, that before copying a table, you must select the items of the table that you wish to copy. If your cursor is simply placed in a cell of the table, only that cell will be copied to the clipboard. You can select multiple cells in the table by placing your cursor in one cell and dragging to another location in the table. Selected items will be indicated in black. Double-clicking on the item in the upper left-hand corner of the table selects the entire table.

Read more: Selecting Items and Copying Values in Result Tables (page 590).

Once you have copied multiple items from a table, you can readily paste them into a spreadsheet. The table retains its rows and columns in the clipboard, and therefore will be correctly pasted into separate rows and columns in the spreadsheet.

Note: If you press the Copy button (or **Ctrl+C**) from the Summary View of a Distribution result, the preview pane chart is copied to the clipboard.

Exporting a Chart

You can export a chart to a file of a specified format. You can then subsequently open and edit the file in a separate application (e.g., a graphics package).

To export a chart, right-click in the chart, and select **Export…** from the context menu.

Read more: Using Context Menus in Charts (page 588).

You will be prompted for the graphics format. The following choices are available:

- Windows Bitmap (BMP)
- Enhanced Windows Metafile (EMF)
- JPEG Image (JPEG)
- Portable Network Graphics (PNG)
- Graphics Interchange Format (GIF)

Sensitivity Analysis References

Iman, R.L. et al., 1985. *A FORTRAN Program and User's Guide for the Calculation of Partial Correlation and Standardized Regression Coefficients*, NUREG/CR-4122, SAND85-0044.

Saltelli, A. and S. Tarantola, 2002, *On the Relative Importance of Input Factors in Mathematical Models: Safety Assessment for Nuclear Waste Disposal*, J. Am. Stat. Ass., Vol. 97, No. 459.

Chapter 9: Documenting and Presenting Your Model

> A mathematical theory is not to be considered complete until you have made it so clear that you can explain it to the first man whom you meet on the street.
>
> David Hilbert

Chapter Overview

A model which cannot be easily explained is a model that will not be used or believed. As a result, GoldSim was specifically designed to allow you to effectively document, explain and present your model. You can add graphics, explanatory text, notes and hyperlinks to your model, and organize it in a hierarchical manner such that it can be presented at an appropriate level of detail to multiple target audiences. This chapter describes how to use these important features.

In this Chapter

The following topics are discussed in this chapter:

- Step One: Organize Your Model!
- Adding Graphics and Text
- Modifying the Appearance of Elements
- Creating, Editing and Viewing Notes
- Adding Hyperlinks to the Graphics Pane
- Manipulating Graphical Objects
- Creating Printed Documentation
- Creating a GoldSim Player File

Step One: Organize Your Model!

The most important way to ensure that your model is easy to explain and present is to spend some time to organize your model.

The sections below provide some guidance and ideas for ensuring that your model is well organized.

Defining the Audiences for Your Model

When you begin to design your model, you should always have in mind the audiences to whom you will be presenting or explaining the model. Most models will have at least two audiences:

- a high-level audience (managers and decision-makers who are primarily interested in the "big picture" or "bottom line"); and
- a low-level audience (analysts who are also interested in the technical details and assumptions of the model).

Often, there will be multiple low-level audiences, which are interested in different technical aspects of the model. There may also be a "mid-level" audience, which is interested in more than the "big picture", but does not want to get lost in the details.

For a model to be successful (i.e., useful), you must be able to present and explain your model effectively to all of these audiences.

GoldSim provides the tools for you to create a single model that can be explained and presented to multiple audiences. The primary way in which you accomplish this is by organizing your model into a logical, top-down hierarchy.

Using Containers to Organize Your Model

Perhaps the most important requirement of a well-documented and easily understood model is that it be well-organized.

Containers provide the mechanism in GoldSim by which you can create well-organized models. In most cases, you do this by placing model elements in a “top-down” containment hierarchy in which the level of detail increases as you "push down" into the hierarchy.

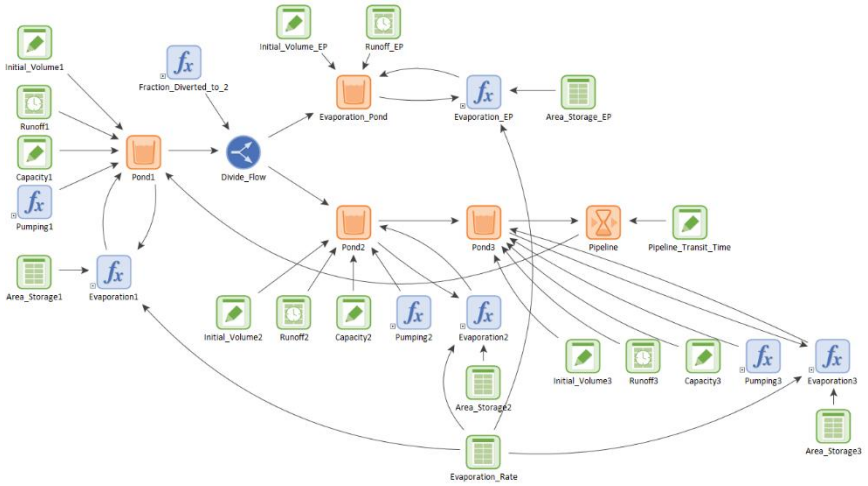
In a well organized model, you can imagine that each Container has a specific "message" and a corresponding audience at which it is targeted.

For example, a model's highest level Container might have the following message: "This is the problem I am trying to solve, and here is the overall structure of the model I have built to solve it". Such a Container would be intended for all audiences.

Another Container's message in the model might be "Here are the detailed assumptions regarding process X". This Container's audience would be the analysts or technical personnel interested in that particular aspect of the model.

You "hide" these details in a Container, because they are of no interest to higher level audiences (e.g., managers). Those who are interested, however, can be shown the contents of the Container.

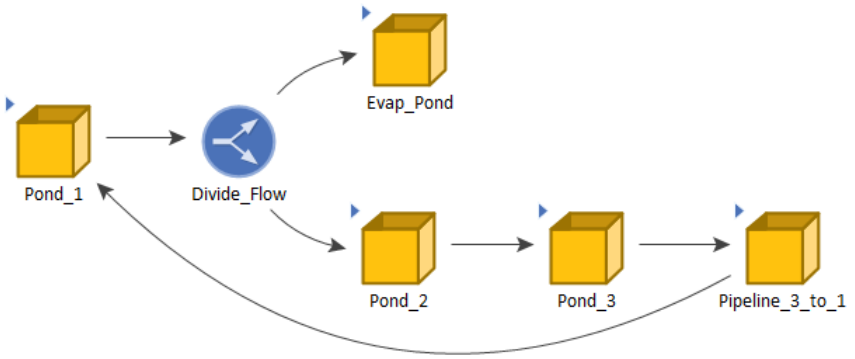
Note, however, that there is no one “right” way to organize a model. To illustrate this, consider the model below:



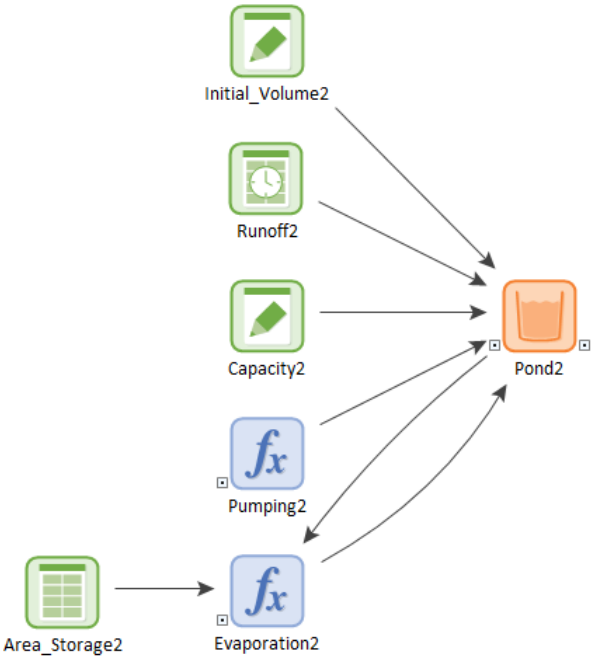
This is a simple water management model. The primary components are four ponds (Pond1, Pond2, Pond3 and Evaporation_Pond) and a Pipeline though which water flows and is stored. Conceptually, the model is actually quite simple (as we will see below). What makes the model so complex-looking at first glance is that all of the inputs for each of the five primary components are all in the same Container with those components. It makes the graphics pane very difficult to understand.

There are two different (but equally effective) ways we could use Containers to organize this model in a much more effective manner.

In the first, we create a separate Container for each of the primary components. The main Container would then look something like this:



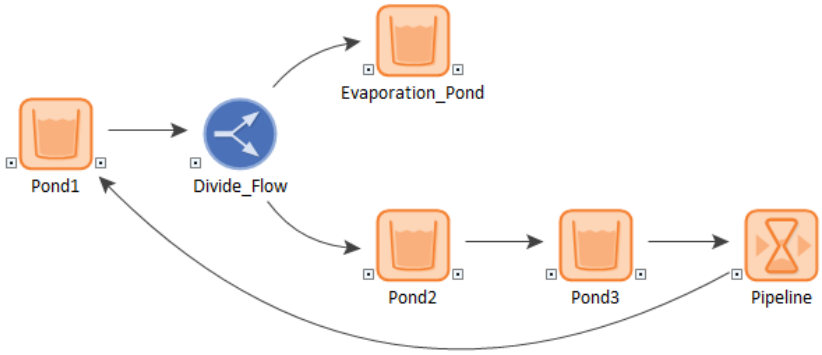
The inside of one of the component Containers (e.g., for Pond_2) would look like this:



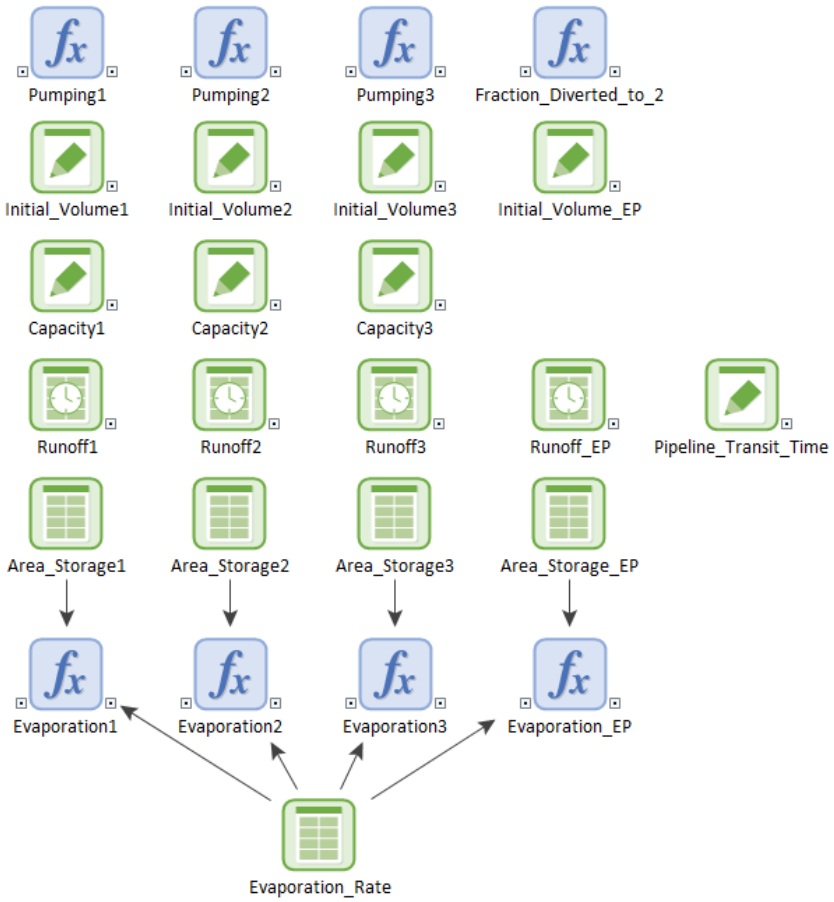
Clearly, this model is much easier to understand than the first one!

Although this approach can work quite well for some models, for others, it may not. In particular, if there are multiple logical connections between the various primary components (e.g., Reservoirs) via intermediate auxiliary calculations, the actual movement of material (e.g., the influences representing the flow of water) can be masked by a "spider web" of influences between the Containers.

Fortunately, there is also a very different way to organize such a model. Instead of creating a separate Container for each of the primary components (and its auxiliary calculations and inputs), we could instead just create two Containers. The primary components would be in one Container and all of the auxiliary calculations and inputs would be in another. The Container for the primary components would then look something like this:



The Container with all of the auxiliary calculations and inputs would look something like this:



Clearly, this model is also much easier to understand than the original one. It also has the advantage of highlighting the "flows" of material or information (in this example, the flow of water) between the primary components.

The point here is that Containers can be used to organize your models in different ways and you should think carefully about how you organize your models. Different parts of the model may be organized in different ways, and there is never one "best" way to organize a model. Your goal, however, should be to create a model structure that makes your model easy to explain and present to multiple audiences.

Note: You can always add Containers and move elements between them after your model has been built. In fact, it is quite common to reorganize a model multiple times as it is being built.

Read more: Understanding Containers (page 96); Moving Elements Between Containers (page 103).

Other Suggestions for Organizing Your Model

In addition to structuring your model in a top-down manner, the following suggestions can also help you to create well-organized and easy to understand models:

- Name the elements of your model carefully. If possible, avoid using abbreviations that will not be easily recognized by others.

- Use the Description field for all of your elements. Because the Description is displayed in tool-tips, it can be an effective and highly visible documentation tool.
- Don't hide the details of your model within long input expressions. It is better to add a few additional elements such that the relationships in the model can be shown graphically and are transparent.
- Filter influences in your model if they detract from the presentation. It is often particularly useful to filter influences at the highest model level (to make the diagrams easier to view).

  Read more: Filtering Influences (page 448).
- Modify the color of influences to highlight key relationships.

  Read more: Editing the Appearance of Influences (page 445).
- In some cases, it may be worthwhile to place similar items in a single Container (even if they are referenced throughout the model). For example, you may want to place all constant inputs in one Container named "Constants" or "Key_Assumptions". If it is important that some of these elements also appear in the Container in which they are referenced (in order to add clarity), you could place a *clone* of the element in that Container.

  Read more: Cloning Elements (page 1026).
- It is often useful to create a "Results" Container in the model Root (or perhaps one containment level down) with Result elements for all of the model's key outputs. This allows you to quickly access and display the model's results.

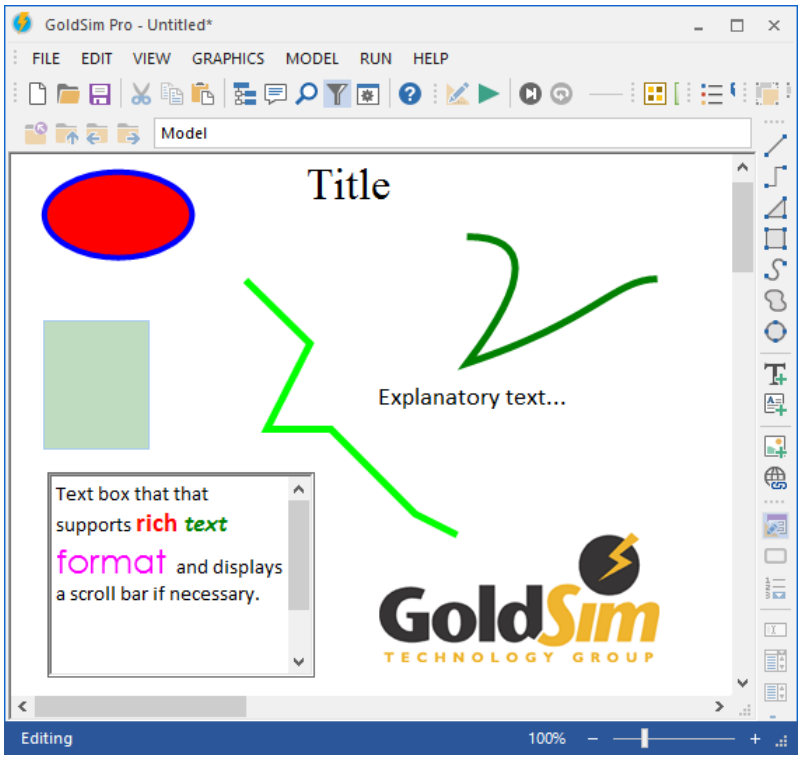
  Read more: Creating and Using Result Elements (page 593).
- You can use the Hyperlink object to provide navigation aids for your model. The Hyperlink object can be used to provide links "jumps" to specified Containers, Dashboards or elements from any location.

  Read more: Adding Hyperlinks to the Graphics Pane (page 826).

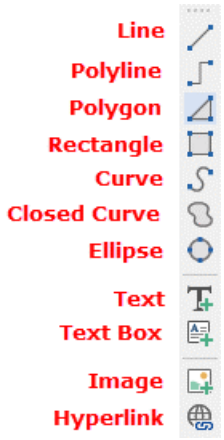
Adding Graphics and Text

Adding graphics (an image or a simple schematic) and explanatory text to the graphics pane is one of the most powerful and straightforward ways to document and explain a model.

The Drawing Tools toolbar in GoldSim provides access to a number of buttons for adding images, graphics and text to your model:



The Drawing Tools toolbar is present by default to the right of the graphics pane (although it can be moved to another location):



The same functions can also be accessed under **Graphics|Insert** in the main menu.

Adding and editing graphic objects, text and images is discussed in the sections below.

Adding Graphic Objects

Graphic objects (i.e., lines, polylines, polygons, rectangles, curves, closed curves and ellipses) can be added to the graphics pane by using the Drawing Tools toolbar (originally docked to the right of the graphics pane), or by selecting **Graphics|Insert** from the main menu.

+

Drawing cursor

All of the graphic object buttons (or menu options) operate in the same way: when you select a button or a menu option, the cursor changes its appearance (to a drawing cursor). Clicking in the graphics pane with the cursor allows you to insert the object at that point.

You can delete a graphic object by selecting it and pressing the **Delete** button, or by right-clicking on it and selecting **Delete** from the context menu.

Adding a Line

To add a Line to the graphics pane:

1. Select **Line** from the Drawing Toolbar or the main menu under **Graphics|Insert**.
2. Place the cursor at the location in the graphics pane where you want the line to start.
3. Left-click and drag the line to the location where you want it to end.

You can move a line by selecting it and dragging it around the graphics pane. You can move one end of the line by selecting the line and dragging one of the end points (vertices).

You can rotate a line by selecting the line and choosing **Graphics|Rotate** from the main menu.

Read more: Rotating Objects (page 835); Changing the Appearance of Graphic Objects (page 812).

Adding a Polyline

A Polyline is a segmented line. To add a Polyline to the graphics pane:

1. Select **Polyline** from the Drawing Toolbar or the main menu under **Graphics|Insert**.
2. Place the cursor at the location in the graphics pane where you want the polyline to start, and click.
3. Move the cursor to the next vertex of the polyline and click.
4. After adding as many vertices as desired, move the cursor to the location where you want the polyline to end and double-click.

You can move a polyline by selecting it and dragging it around the graphics pane. You can move a vertex of the polyline by selecting the line and dragging one of the vertices.

You can rotate a polyline by selecting the object and choosing **Graphics|Rotate** from the main menu

Read more: Rotating Objects (page 835); Changing the Appearance of Graphic Objects (page 812).

Adding a Polygon

To add a Polygon to the graphics pane:

1. Select **Polygon** from the Drawing Toolbar or the main menu under **Graphics|Insert**.
2. Place the cursor at the location in the graphics pane where you want one of the corners of the polygon to be and click.
3. Move the cursor to the next vertex of the polygon and click.
4. After adding as many vertices as desired, move the cursor to the location where you want the last vertex of the polygon to be and double-click.

You can move a polygon by selecting it and dragging it around the graphics pane. You can "stretch" a polygon by selecting the object and dragging one of the "handles" (there are eight handles - one on each corner and one on each side). Pressing the **Shft** key while resizing the object keeps the same aspect ratio; pressing the **Ctrl** key while resizing keeps the center of the object at the same location.

You can also move individual vertices by right-clicking on the object and selecting **Edit Vertices** from the menu. This will highlight individual vertices that can then be dragged and repositioned.

You can rotate a polygon by selecting the object and choosing **Graphics|Rotate** from the main menu.

Read more: Rotating Objects (page 835); Changing the Appearance of Graphic Objects (page 812).

Adding a Rectangle

To add a Rectangle to the graphics pane:

1. Select **Rectangle** from the Drawing Toolbar or the main menu under **Graphics|Insert**.
2. Place the cursor at the location in the graphics pane where you want one of the corners of the rectangle to be.
3. Left-click and drag the line to the location of the opposite corner of the rectangle.

You can move a rectangle by selecting it and dragging it around the graphics pane.

You can "stretch" a rectangle by selecting the object and dragging one of the "handles" (there are eight handles - one on each corner and one on each side). Pressing the **Shft** key while resizing the object keeps the same aspect ratio; pressing the **Ctrl** key while resizing keeps the center of the object at the same location.

You can rotate a rectangle by selecting the object and choosing **Graphics|Rotate** from the main menu.

Read more: Rotating Objects (page 835); Changing the Appearance of Graphic Objects (page 812).

Adding a Curve or a Closed Curve

To add a Curve or a Closed Curve to the graphics pane:

1. Select **Curve** or **Closed Curve** from the Drawing Toolbar or the main menu under **Graphics|Insert**.
2. Place the cursor at the location in the graphics pane where you want the curve to start, and click.
3. Move the cursor to the next "handle" of the curve and click.
4. After adding as many handles as desired, move the cursor to the location where you want the curve to end and double-click.

If you are drawing a closed curve, GoldSim will automatically draw a line from the end point to the starting point of the curve (in order to close the curve).

You can move a curve by selecting it and dragging it around the graphics pane. You can stretch the curve by selecting one of the "handles" and dragging it. For a closed curve, you can also move individual vertices by right-clicking on the object and selecting **Edit Vertices** from the menu. This will highlight individual vertices that can then be dragged and repositioned.

You can rotate a curve by selecting the object and choosing **Graphics|Rotate** from the main menu.

Read more: Rotating Objects (page 835); Changing the Appearance of Graphic Objects (page 812).

Adding an Ellipse

To add an Ellipse to the graphics pane:

1. Select **Ellipse** from the Drawing Toolbar or the main menu under **Graphics|Insert**.
2. Place the cursor at the location in the graphics pane where you want one of the corners of a rectangle surrounding the ellipse to be.
3. Left-click and drag the line to the location of the opposite corner of the rectangle.

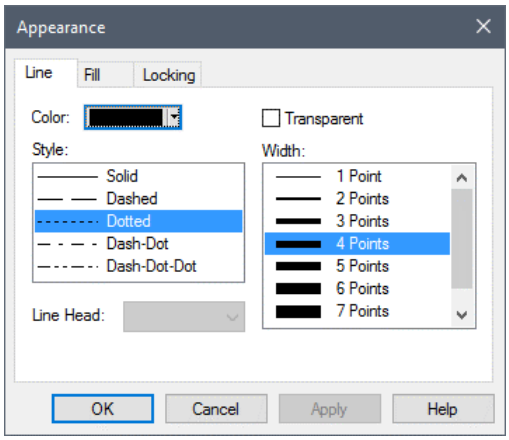
You can move an ellipse by selecting it and dragging it around the graphics pane. You can "stretch" an ellipse by selecting the object and dragging one of the "handles" (there are eight handles - one on each corner and one on each side). Pressing the **Shft** key while resizing the object keeps the same aspect ratio; pressing the **Ctrl** key while resizing keeps the center of the object at the same location.

You can rotate an ellipse by selecting the object and choosing **Graphics|Rotate** from the main menu.

Read more: Rotating Objects (page 835); Changing the Appearance of Graphic Objects (page 812).

Changing the Appearance of Graphic Objects

To edit the properties of a graphic object, double-click on it or right-click on it (to access its context menu), and select **Appearance…**. A dialog like this will be displayed:

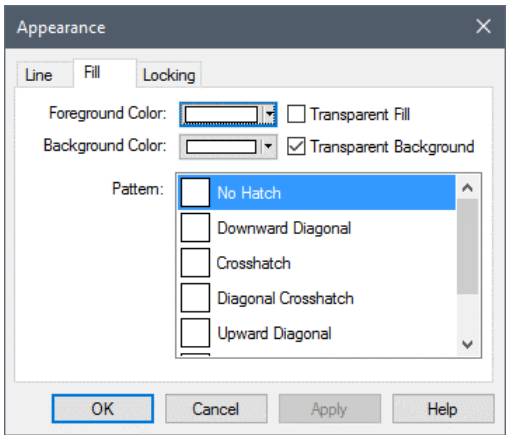


The Fill tab is not present when editing lines, polylines and curves.

The **Line** tab allows you to edit the appearance of the line itself (for lines, polylines and curves) or the outline for the object (for polygons, rectangles, closed curves, and ellipses). You can select the **Color**, the **Style** and the **Width** (and for Lines and Polylines, the **Line Head**). You can also make the line Transparent (which would only make sense for polygons, rectangles, closed curves, and ellipses).

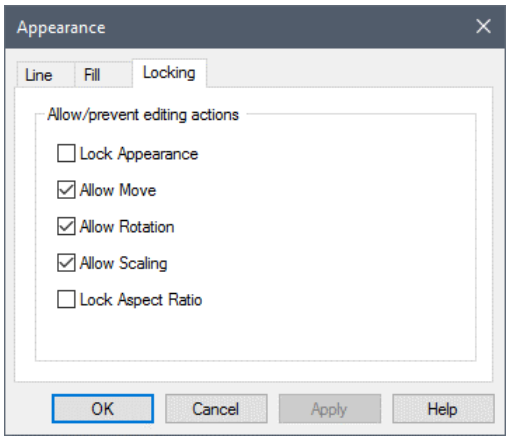
Read more: Using and Managing the Color Palette (page 437).

The **Fill** tab (which is not available for lines, polylines and curves) allows you to change the appearance of the fill for the object.



The fill consists of a background and a foreground. The **Foreground Color** is superimposed on top of a **Background Color** according to a selected **Pattern**. By default, the background is transparent.

The **Locking** tab determines what you can do with the object:



If the **Allow Move** and **Allow Rotation** boxes are checked (the default), you can move and rotate the object.

If **Allow Scaling** is checked (the default), you can resize the object. For objects that can be scaled, if **Lock Aspect Ratio** is checked, the object keeps its aspect ratio when it is resized.

If **Lock Appearance** is checked, all of these options are disabled (you cannot move, rotate or scale the object).

Adding and Editing Text

Text can be added to the graphics pane by using the Drawing Tools toolbar (originally docked to the right of the graphics pane), or by selecting **Graphics|Insert|Text** from the main menu.

text cursor

When you select the **Text** button or menu option, the cursor changes to the text cursor. Clicking in the graphics pane with the cursor allows you to insert the text object at that point.

Note: GoldSim provides two ways to add text to the graphics pane: a Text object and a Text Box. Text objects are movable objects that can utilize a single font. Text Boxes are scrollable boxes of text that can simultaneously utilize multiple fonts and can be "pinned" to a specific location in the graphics pane.

Read more: Adding and Editing Text Boxes (page 817).

To add a Text object to the graphics pane:

1. Select **Text** from the Drawing Toolbar or the main menu under **Graphics|Insert**.
2. Place the cursor at the location in the graphics pane where you want the text to be inserted and click.

"<Add your text here.>" is inserted into the graphics pane.

The default font which is used can be selected from the **Graphic** tab of the Options dialog (accessed via **Model|Options** in the main menu).

You can move a text object by selecting it and dragging it around the graphics pane. You can rotate a text object by selecting it and choosing **Graphics|Rotate** from the main menu.

Note: You can resize a text object by selecting it and dragging the "handles". However, when you should always ensure that the text object is sized to allow for some space around (above, below, left, right) the text itself. Otherwise, the text could potentially be cut off at certain resolutions and/or text scaling.

You can delete a text object in the graphics pane by selecting it and pressing the **Delete** button, or by right-clicking on it and selecting **Delete** from the context menu.

Read more: Rotating Objects (page 835).

Editing Text Objects

Double-clicking on a text object in the graphics pane selects the text (it will be highlighted in blue). If you start typing while the entire text is highlighted in blue, the text will be overwritten. Once the text is selected, clicking anywhere within the text places the cursor at that location.

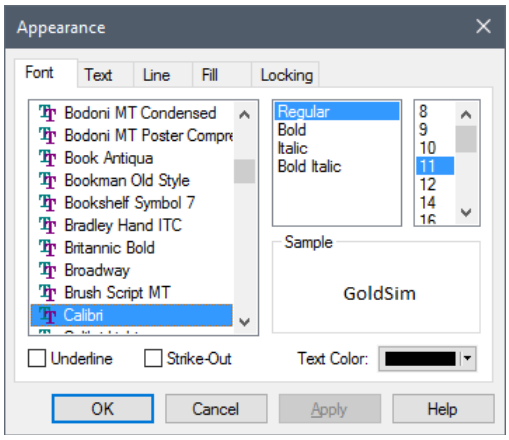
You can also use the **Home**, **End**, **Backspace** and arrow keys to move the cursor in the selected text.

A single click on a text object selects the object, but does not select the text itself. Eight "handles" will be visible, defining the limits of the *textbox* (one at each corner, and one on each side).

By default, word-wrap is on, so the text will wrap around given a specified width. As you type, the textbox will automatically expand downward.

Changing the Appearance of Text Objects

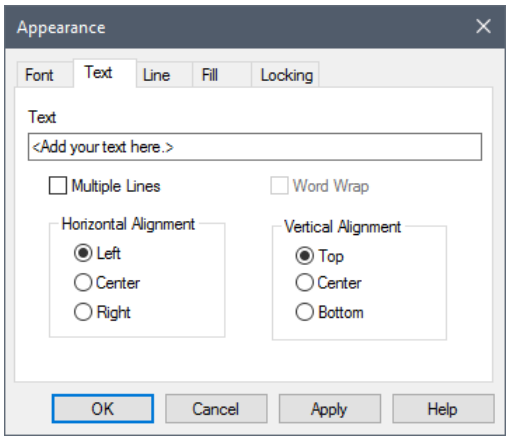
To edit the properties of a text object (e.g., font, fill), right-click on it (to access its context menu), and select **Appearance…**. The following dialog will be displayed:



The **Font** tab controls the font of the text, as well as the color.

Read more: Using and Managing the Color Palette (page 437).

The **Text** tab allows you to edit the text and adjust its alignment**:**

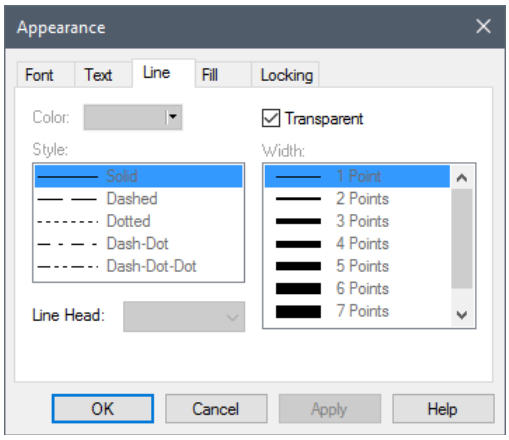


You can edit the **Text** directly in this tab. If **Multiple Lines** is checked (the default), the text object can continue onto multiple lines (either by pressing Enter while editing it or by turning on Word-wrap). The **Word Wrap** checkbox activates word wrap.

Warning: Word Wrap is ignored if **Multiple Lines** is turned off (cleared). That is, your text will only wrap if you allow for multiple lines.

You can center the text horizontally in the textbox by choosing a **Horizontal Alignment** option. You can center the text vertically in the textbox by choosing a **Vertical Alignment** option.

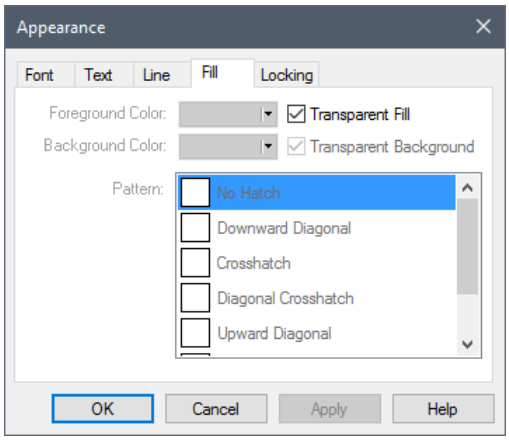
The **Line** tab allows you to edit the appearance of the outline for the textbox:



By default, there is no outline (it is **Transparent**).

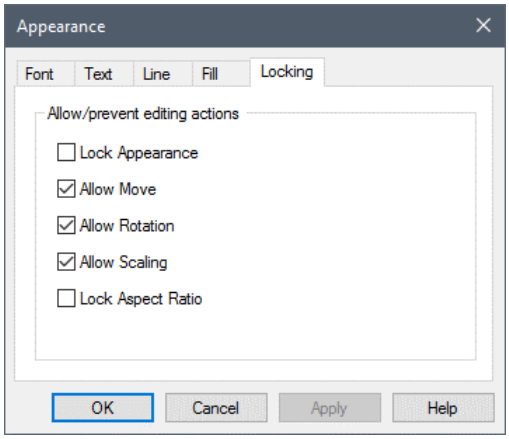
You can change the outline's **Color**, **Style** and **Width**.

The **Fill** tab allows you to change the appearance of the fill for the textbox.



The fill consists of a background and a foreground. The **Foreground Color** is superimposed on top of a **Background Color** according to a selected **Pattern**.

The **Locking** tab determines what you can do with the object:



If **Allow Move** and **Allow Rotation** boxes are checked (the default), you can move and rotate the text. If **Allow Scaling** is checked (the default), you can resize the textbox.

If **Lock Aspect Ratio** is checked, the textbox keeps its aspect ratio when it is resized. If **Lock Appearance** is checked, all of these options are disabled (you cannot move, rotate or scale the text).

Adding and Editing Text Boxes

Text boxes can be added to the graphics pane by using the Drawing Tools toolbar (originally docked to the right of the graphics pane), or by selecting **Graphics|Insert|Text Box** from the main menu.

Text box cursor

When you select the **Text Box** button or menu option, the cursor changes to the text box cursor. Clicking in the graphics pane with the cursor allows you to insert the text object at that point.

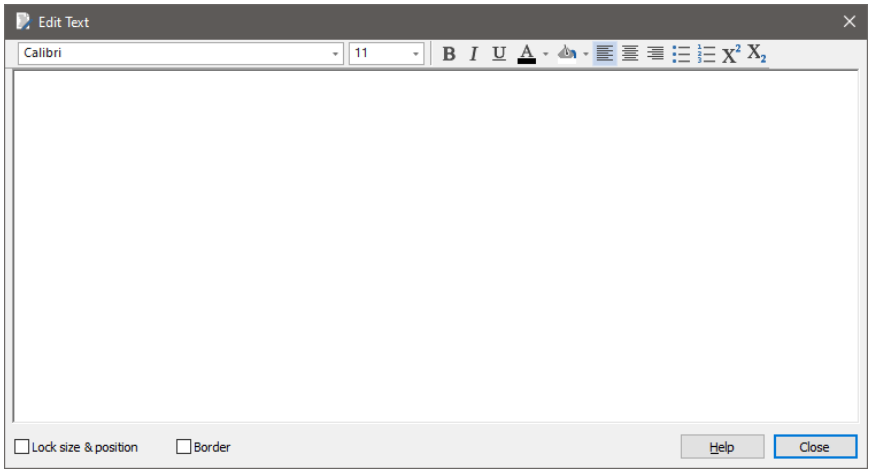
Note: GoldSim provides two ways to add text to the graphics pane: a text object and a text box. Text objects are movable objects that can utilize a single font. Text boxes are scrollable boxes of text that can simultaneously utilize multiple fonts and can be "pinned" to a specific location in the graphics pane.

Read more: Adding and Editing Text (page 813).

To add a text box to the graphics pane:

1. Select **Text Box** from the Drawing Toolbar or the main menu under **Graphics|Insert**.
2. Place the cursor at the location in the graphics pane where you want the text box to be inserted, left-click, drag the cursor to specify the size of the box, and release the mouse button.

At this point the text box will be inserted into the graphics pane and the dialog for editing the text box will be displayed:



After adding text, pressing the **Close** button closes the dialog.

You can double-click on the dialog to edit it again. You can move a text box by selecting it and dragging it around the graphics pane. You can resize the text box by grabbing and dragging one of the handles of the box. You can delete a text box in the graphics pane by selecting it and pressing the **Delete** button, or by right-clicking on it and selecting **Delete** from the context menu.

Note: All of these operations (editing, moving, resizing, deleting) can only occur if the size and position are not locked (i.e., the **Lock size & position** checkbox is cleared).

Controlling the Behavior of Text Boxes

You can control the format of the text in a text box by using the buttons and controls at the top of the dialog. These buttons and controls are self-explanatory (and all have tool-tips), and allow you to control the font, size, color, and justification of the text. Note that the text can have multiple fonts, formats and colors. You can also control these options by right-clicking on the text and selecting options from a context menu.

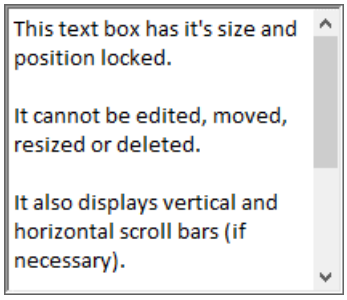
Read more: Using and Managing the Color Palette (page 437).

Note: The default font used within the text box can be selected from the **Graphic** tab of the Options dialog (accessed via **Model|Options** in the main menu).

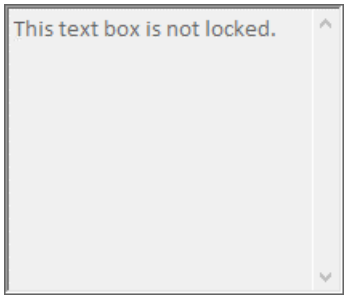
Two checkboxes at the bottom of the dialog control its behavior:

If the **Border** checkbox is checked, a border is placed around the textbox.

The **Lock size & position** checkbox switches the text box between display mode and edit mode. If this box is checked, a vertical slider appears in the text box (if necessary), and you cannot move, resize, edit or delete the text box:



If the **Lock size & position** checkbox is cleared, the text box can be edited by double-clicking on it, can be moved by selecting and dragging, can be resized by dragging the handles, and can be deleted by selecting and pressing the **Delete** key. A text box which is not locked appears in the graphics pane like this:



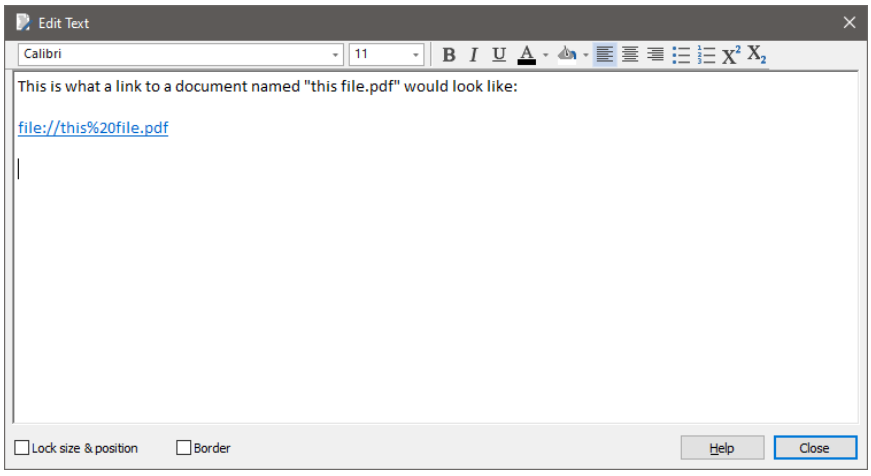
You can unlock a text box in the graphics pane by right-clicking on it and clearing the **Lock size & position** menu item. Likewise, you can lock a text box in the graphics pane by right-clicking on it and checking the **Lock size & position** menu item.

Inserting Hyperlinks into Text Boxes

You can insert hyperlinks from a text box to other documents:

- To insert a link to a URL which starts with "www", you need only type in the address (e.g., www.goldsim.com).
- To insert a link to a URL which does not start with "www", you must specify the transfer protocol (e.g., http://website.com/).
- To insert a link to an ftp site, you need only type in the address (e.g., ftp.asite.com).
- To insert a link that launches an email, you must type “mailto:” before the email address (e.g., mailto:name@company,com).
- To insert a link to some other document (e.g., a Word document or a PowerPoint presentation), you must type "file:///" before the document name and one of the following:
  - The full path (e.g., file://C:\Projects\Docs\report.doc).
  - A relative path (e.g., file://..\Docs\report.doc), in which case GoldSim searches relative to the current directory (the directory from which the model file was loaded). If the model file was in C:\Projects\Models, GoldSim would look for the document in C:\Projects\Docs.
  - No path (e.g., file://report.doc), in which case GoldSim looks only in the current directory (the directory from which the model file was loaded).

When you are entering a hyperlink, GoldSim recognizes it as a link as soon as it sees a space (it will become underlined and the text will become blue). As a result, when you are entering the text, *there cannot be any spaces in the link*. If the filename includes a space, you can represent this by using the characters %20 to represent the space. For example, if the filename you wanted to link to was “this file.pdf”, the link in the Note pane would need to look like this:



When you click on a hyperlink in a text box, GoldSim will immediately open the application associated with the link (e.g., Internet Explorer, Word).

Adding Images

In addition to adding text and graphics, you can also add images (as bitmaps and other graphic formats) to the graphics pane.

To add an image to the graphics pane:

1. Select Image from the Drawing Toolbar or the main menu under **Graphics|Insert**. A dialog is displayed for selecting the image file to be inserted.
2. Select a file and file type to insert and press **OK**.
3. Place the cursor at the location in the graphics pane where you want the center of the image to be inserted and click.

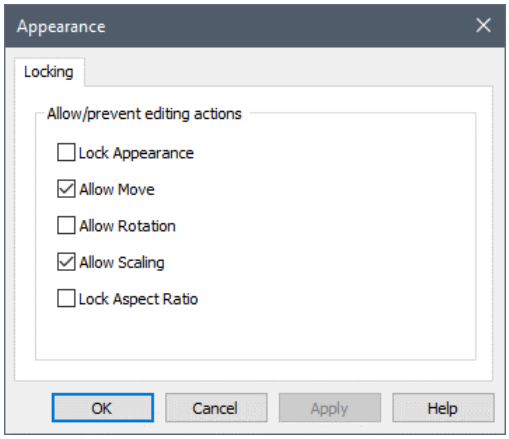
The image will be inserted into the graphics pane. You can move an image by selecting it and dragging it around the graphics pane.

You can "stretch" (resize) an image by selecting it and dragging one of the "handles" (there are eight handles - one on each corner and one on each side). Pressing the **Shft** key while resizing the image keeps the same aspect ratio; pressing the **Ctrl** key while resizing keeps the center of the object at the same location.

Changing the Appearance of an Image

GoldSim provides some capabilities for you to edit the properties and appearance of an image that you have inserted into the graphics pane.

To edit the properties of an image in the graphics pane, right-click on it (to access its context menu), and select **Appearance…**. The following dialog will be displayed:



If the **Allow Move** box is checked (the default), you can move the image.

If **Allow Scaling** is checked (the default), you can resize the image. If **Lock Aspect Ratio** is checked, the image keeps its aspect ratio when it is resized (scaled). If **Lock Appearance** is checked, both of these options are disabled (you cannot move or scale the image).

Note: If your image is an enhanced metafile, the dialog also contains a Line and a Fill tab. The Line tab allows you control the appearance of the outline of the image. The Fill tab allows you to control the appearance of the background of the image.

Modifying the Appearance of Elements

All of the GoldSim elements have default symbols (graphical images by which the element is represented in the graphics pane).

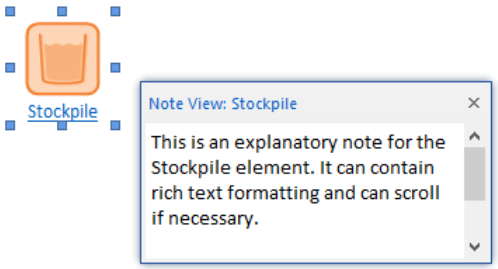
Read more: GoldSim Element Types (page 68).

One of the most powerful ways to document and visually augment your model is to replace the default symbols with customized symbols. This is particularly useful for Containers. For example, you may want to replace the image of a particular Container with a schematic or diagram of the subsystem that it represents.

Read more: Editing the Appearance of Elements (page 452).

Creating, Editing and Viewing Notes

In order to internally document your model, GoldSim allows you to attach a Note to each element:



An element with an attached note has its ID underlined (and by default the text is blue).

The topics below describe how to create, edit and display notes.

Opening the Note Pane

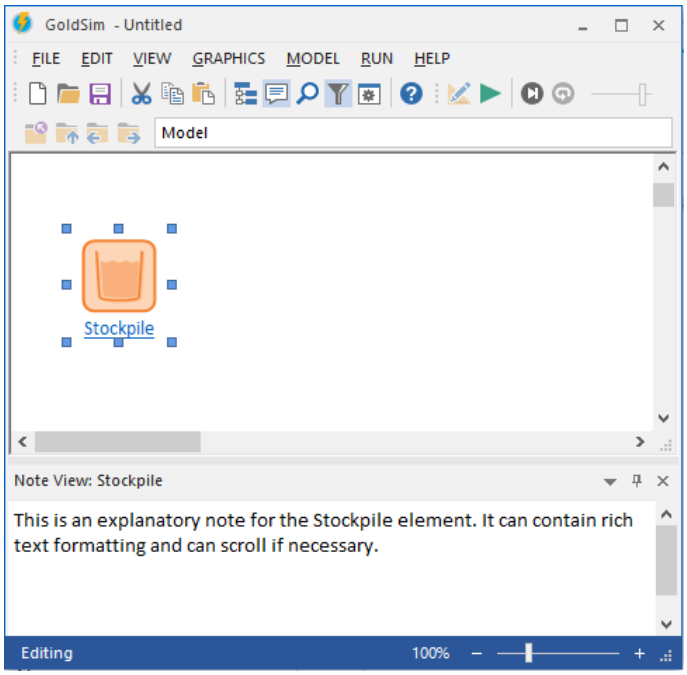
***Note Pane** button*

To display, create and edit notes, you must activate the ***Note pane***. By default, the Note Pane is turned off (hidden). The Note pane can be toggled on and off in order to edit and view notes for your elements.

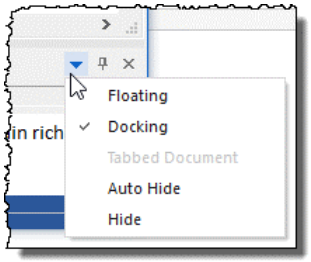
You do this by pressing the Note Pane button in the Standard toolbar, by selecting **View|Note** from the main menu, by pressing **Ctrl-Shft-N**, or selecting **Note View** from the toolbar context menu (accessed by right-clicking anywhere outside of the graphics pane and browsers).

You can also open the Note Pane for an element by clicking on the element ID for an element with an attached Note (indicated by an underline).

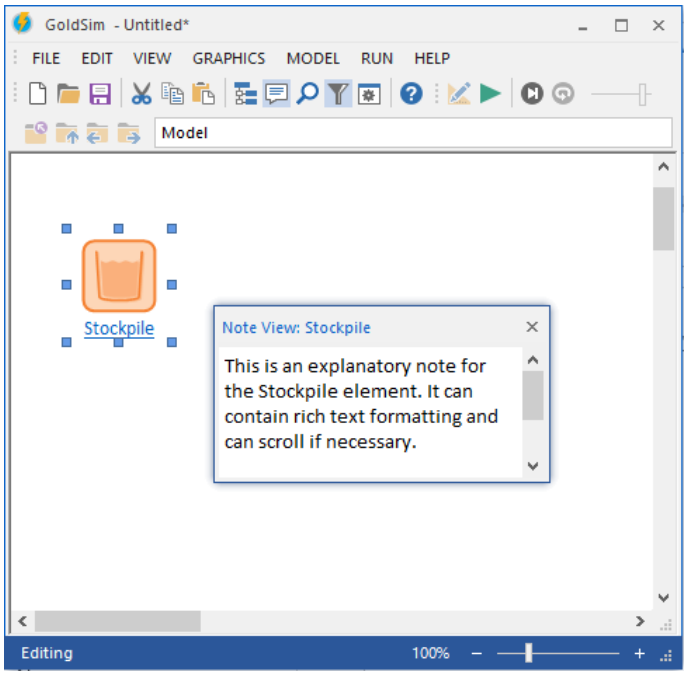
By default, the Note Pane is initially docked on bottom of the screen:



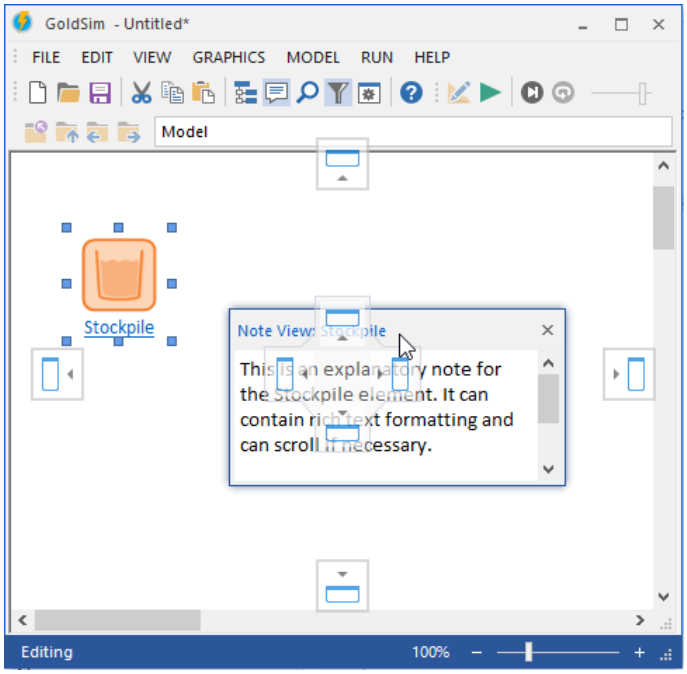
The Note Pane can be in four different states (Floating, Docking, Auto Hide and Hide), which can be selected from the drop-list at the top of the Note Pane:



You can make the Note Pane become a floating window by selecting **Floating** from the drop-list (or double-clicking on the Note Pane title bar):



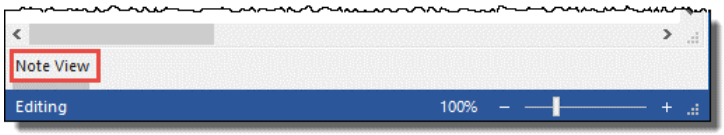
You can dock a floating Note Pane (to any side of the screen) by starting to drag it. When you do so, multiple docking points appear on the screen:



Dragging to the docking point docks the Note Pane at that location.
You can hide the Note Pane completely by selecting **Hide** from the drop-list.
You can also hide the browser by pressing **Ctrl-Shft-N** or by pressing the **Note Pane** button in the Standard toolbar:

The final option is to **Auto Hide** the Note Pane. If you select this option (which is not available if the Note is floating), the Note Pane is hidden until you move

the cursor over the section marked "Note View" on the side of the screen where the Note Pane is docked:



When you do so, the Note Pane opens (and stays open until you click the cursor moves outside of the Note Pane).

Whenever you select an element, the Note for that particular element is displayed in the Note Pane. The element whose Note is being displayed is indicated in the Note Pane. If nothing is selected in the graphics pane, the Note for the entire Container is displayed.

Creating and Displaying Notes

To add a note to an element, do the following:

1. Select the element (by clicking on it).
2. Open the Note Pane by pressing the Note Pane button in the Standard toolbar or by selecting **View|Note** from the main menu.
3. Click in the Note Pane and start typing.

The default font for a new note is specified in the **Graphic** tab of the Options dialog (accessed via **Model|Options** in the main menu).

A Format Toolbar is available that provides tools for formatting your Note. By default, the Format Toolbar is turned off. You can show and/or hide the Format Toolbar by right-clicking in the Note Pane and selecting **Show Format Bar** from the menu.

Note: The basic settings for the Note pane (its location, size and whether or not the Format Toolbar is visible) is saved to the Windows Registry, and are therefore applied to all GoldSim files on your machine. Formatting for specific Notes (e.g., font, color), however, is saved only with the file.

You can only enter a Note if an element is selected (or nothing is selected). If nothing is selected, the Note is attached to the Container being viewed. If a graphical object is selected, you will not be able to type in the Note pane (since Notes can only be associated with elements).

In addition to typing in the Note pane, you can paste text from another Note or another application (such as a word processor).

Note: Notes in GoldSim support multibyte characters sets (for supporting character sets, such as Japanese and Chinese, which cannot be represented in a single byte).

Once a Note has been created for an element, the element's ID will be underlined in the Graphics Pane and a single click on the element ID in the Graphics Pane will open the Note pane and display the Note for that element:

By default, the ID of an element with a Note associated with it is underlined *and* shown in blue (so that it looks like a hyperlink). You can modify this so that the ID is shown in the defined text color (black by default) via an option on the

General tab of the Options dialog (accessed by selecting **Model|Options** from the main GoldSim menu).

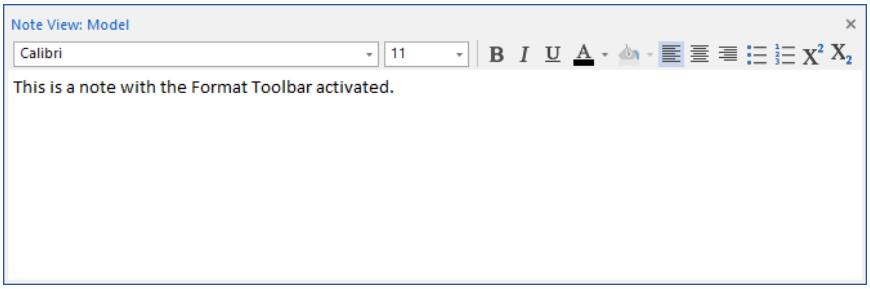
To delete a note attached to an element, simply delete all of the text in the note.

Editing and Formatting Notes

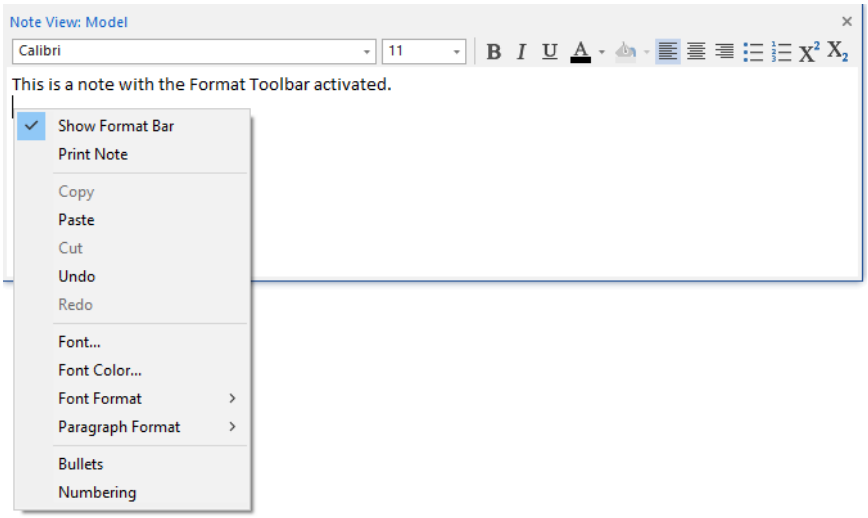
The Note Pane acts like a simple text editor. That is, you can specify alignment, fonts, font format, text color, indents, and create simple numbered and bulleted lists.

You can access formatting tools for your note in two ways:

- You can show and/or hide the Format Toolbar by right-clicking in the Note Pane and selecting **Show Format Bar** from the context menu:



- You can view a context menu with all formatting options by right-clicking anywhere within the Note pane:



The various formatting options in the toolbar and menu include font and color, are are self-explanatory.

Read more: Using and Managing the Color Palette (page 437).

Note also that you can use this menu to Print the note.

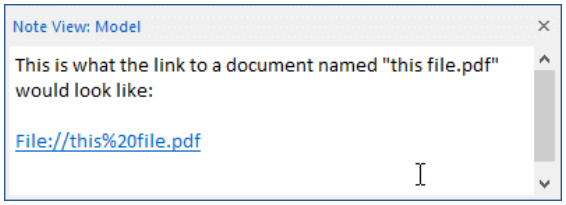
Inserting Hyperlinks into Notes

One of the most powerful features of Notes is that you can insert hyperlinks to other documents:

- To insert a link to a URL which starts with "www", you need only type in the address (e.g., www.goldsim.com).
- To insert a link to a URL which does not start with "www", you must specify the transfer protocol (e.g., http://website.com/).
- To insert a link to an ftp site, you need only type in the address (e.g., ftp.asite.com).

- To insert a link that launches an email, you must type “mailto:” before the email address (e.g., mailto:name@company,com).
- To insert a link to some other document (e.g., a Word document or a PowerPoint presentation), you must type "file:///" before the document name and one of the following:
  - The full path (e.g., file://C:\Projects\Docs\report.doc).
  - A relative path (e.g., file://..\Docs\report.doc), in which case GoldSim searches relative to the current directory (the directory from which the model file was loaded). If the model file was in C:\Projects\Models, GoldSim would look for the document in C:\Projects\Docs.
  - No path (e.g., file://report.doc), in which case GoldSim looks only in the current directory (the directory from which the model file was loaded).

When you are entering a hyperlink, GoldSim recognizes it as a link as soon as it sees a space (it will become underlined and the text will become blue). As a result, when you are entering the text, *there cannot be any spaces in the link.* If the filename includes a space, you can represent this by using the characters %20 to represent the space. For example, if the filename you wanted to link to was “this file.pdf”, the link in the Note pane would need to look like this:



When you click on a hyperlink in a note, GoldSim will immediately open the application associated with the link (e.g., Internet Explorer, Word).

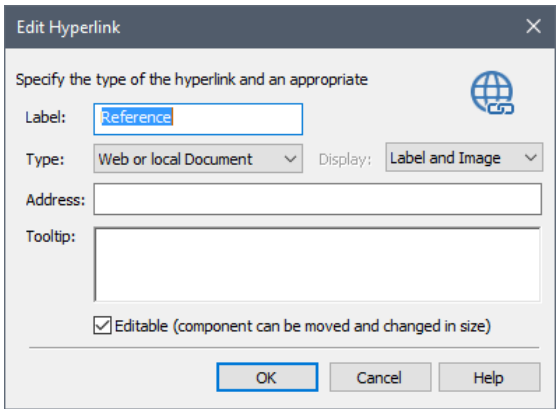
Adding Hyperlinks to the Graphics Pane

You can also add Hyperlink objects to the graphics pane. When you double-click on a hyperlink in the graphics pane, it can open another application (e.g., a website, a PowerPoint presentation, an email program, a Word document, a graphics image), or jump to a specific location in your model (which can be useful for navigation of complex models).

To insert a hyperlink, press the **Hyperlink** button on the Drawing Tools toolbar:

Alternatively, you can select **Graphics|Insert|Hyperlink…** from the main menu.

The following dialog will be displayed:

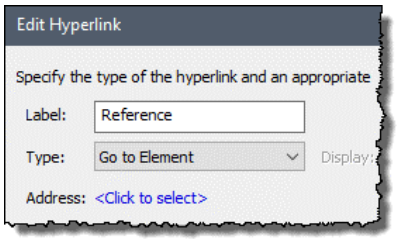


The **Label** appears below the Hyperlink object in the graphics pane. Note that unlike element IDs, the label can have spaces (but it cannot be completely empty).

The **Type** field contains the type of hyperlink you wish to make in the **Address** field. GoldSim provides the following options:

- **Web or local document**: Opens a website or a document (e.g., a Word or PowerPoint document);
- **Email to…**: Opens your default email program and inserts the specified email address in the "To" field. ;
- **FTP**: Opens an FTP site;
- **Execute Command**: Opens a specific program;
- **Go to Element**: Jumps to a specific element and selects it. This is useful for navigating a model.
- **Open Container**: Jumps to a specific Container. This is useful for navigating a model.
- **Open Dashboard**: Jumps to a specific Dashboard. This is useful for navigating a model.

In the latter three cases, after selecting the option, you must specify the element, Container or Dashboard that you wish to link to:



You can also enter a **Tooltip**. This is displayed when you place your cursor over the Hyperlink object in the graphics pane.

If the **Editable** check box is checked (the default), you will be able to move the Hyperlink object around the graphics pane (and resize it). If this checkbox is cleared, the object will be "pinned" to the location where you placed it. You can make the object editable by right-clicking on it in the graphics pane and checking the **Editable** menu item. Likewise, you can lock (make uneditable) an editable hyperlink by right-clicking on it in the graphics pane and clearing the **Editable** menu item.

After entering the Hyperlink's properties in the dialog and pressing **OK**, you will be presented with a "placement cursor". When you click with the cursor, the Hyperlink object is inserted at that location. The Hyperlink object looks like this:

You can access the dialog for editing the Hyperlink's properties by selecting **Properties…** from the context menu for the object.

When you double-click on a Hyperlink object, GoldSim will immediately open the application associated with the link (e.g., Internet Explorer, Word).

You can move a Hyperlink object by selecting it and dragging it around the graphics pane. You can resize a hyperlink by selecting the object and dragging one of the "handles" (there are eight handles - one on each corner and one on each side). Note, however, that these operations are only available if you have checked the Hyperlink as being Editable.

Specifying Addresses for the Various Hyperlink Types

The details regarding how the various Hyperlink types are specified are provided below:

Web or local document: To insert a link to a URL which starts with www, you need only type in the address (e.g., www.goldsim.com). To insert a link to a URL which does not start with www, you must specify the transfer protocol (e.g., http://website.com).

To insert a link to some other document (e.g., a Word document or a PowerPoint presentation), you can provide the full path (e.g., C:\Docs\Projects\report.doc), or if the document is in the same directory as the model file, you can provide just the file name. That is, if you only provide a file name, GoldSim will look for the document in the active directory (the directory containing the current model file). You can also use the Browse… button to find a particular file to which you wish to create a hyperlink.

One common type of document that you may wish to open is a Microsoft Excel file (*.xls, *.xlsx or *.xlsm). When opening a spreadsheet file, in some cases you may want to immediately jump to a specified location (sheet and cell range) when opening the file. GoldSim provides specialized syntax to support this. The syntax is as follows:

Filename#sheetname!cellrange (e.g., Book1.xlsx#Sheet1!a1:c3)

The following points should be noted:

- The entire text can be wrapped in quotes. This should be done if the filename or sheet name contain any spaces.
- For an Excel file, GoldSim will recognize extension .xls, .xlsx, or .xlsm.
- The filename can be specified as a relative or absolute path. Absolute filenames must start with the drive letter or be a UNC path (starting with "\\"). Relative paths can contain "." and ".." as well as folder names (e.g., ".\..\DataFolder\file.xlsx"). Relative filenames with no path are assumed to refer to the folder in which the model file is located.

- # is the delimiter between the filename and the sheet name. It is optional (you do not need to provide a sheet name).The sheet name is not case-sensitive.
- ! is the delimiter between the sheet name and the cell range. It is optional (you do not need to provide a cell range). The cell range can refer to a single cell (e.g., A2) or a range (e.g., A1:A3).

Email to…: When you click on an email link, it opens your default email program with the specified address in the "To" field. You should enter an email address (e.g., support@goldsim.com).

FTP: To insert a link to an ftp site, simply type in the address (e.g., ftp.asite.com).

Execute Command: This allows you to run a specific application. This can be useful, for example, if you wish to open a document with an application which is *not* the default application with which the file extension is associated:

C:\graphics\paint.exe c:\images\bitmap.doc

Note that when using this type of Hyperlink, if the filename has spaces in it, it must be enclosed in quotation marks:

C:\graphics\paint.exe "c:\images\my bitmap.doc"

Go to Element. This causes GoldSim to immediately jump to (but not open) the specified element. You can also specify a full path when using the element command. When you do so, the path name must start with a backslash:

\Container1\Container2\XYZ

Open Container. This causes GoldSim to immediately display the contents of the specified Container. GoldSim searches upward through the containment hierarchy from the current location and jumps to the first Container with the specified name. If you need to be more explicit (i.e., you have multiple Containers with the same name), you can also specify a full path when using the Container command. When you do so, the path name must start with a backslash:

\Container1\Container2\Container3

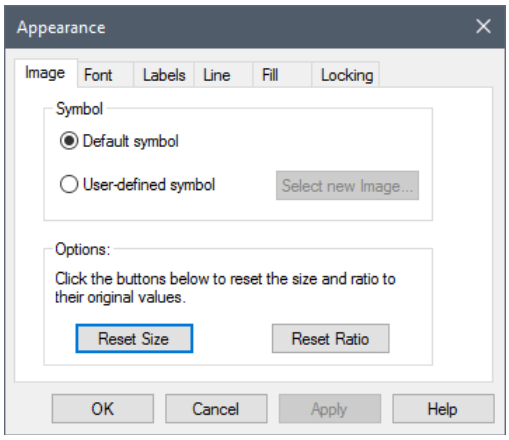
Open Dashboard. This causes GoldSim to immediately jump to the specified Dashboard. You can also specify a full path when using the Dashboard command. When you do so, the path name must start with a backslash:

\Container1\Container2\InputScreen

Note: Dashboards are discussed in detail in the GoldSim Dashboard Authoring Module User's Guide.

Changing the Appearance of a Hyperlink Object

You can edit the appearance of a hyperlink by right-clicking on the object and selecting **Appearance…** from the context menu. The following dialog will be displayed:

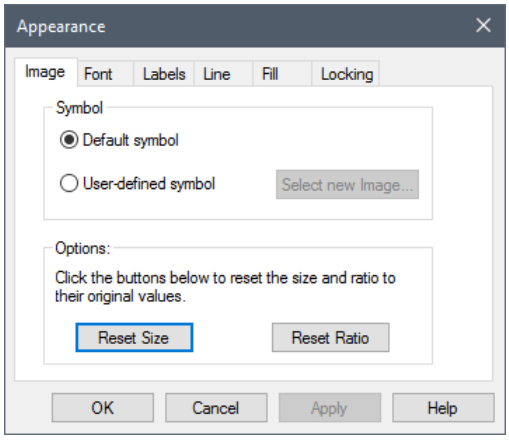


Note: You can only change the appearance of a Hyperlink object if it is specified as being Editable. Editing can be enabled and disabled by right-clicking on the object and setting or clearing the **Editable** menu item.

The dialog is tabbed. The various tabs are discussed in the sections below.

Changing the Hyperlink Object's Symbol

The **Image** tab of the Hyperlink Appearance dialog allows you to change the image used for the Hyperlink object in the graphics pane.



If you select the **User-defined symbol** radio button within this tab, you will be prompted for the name of a file to be used for the symbol. The file must be an enhanced Windows metafile (.emf)

Note: GoldSim utilizes enhanced metafiles for symbols because they are vector graphics (and therefore scale without losing image quality). Most advanced graphics programs can create enhanced metafiles (or convert other formats to an enhanced metafile). Note, however, that unless you create the original image as an enhanced metafile, it will not be a true vector graphic and will lose image quality when scaling.

You can use GoldSim's graphic capabilities to convert other graphics formats to an enhanced metafile as follows:

1. Insert a graphic image (e.g., a bitmap) into the graphics pane;

2. Select the image and click **Graphics | Export…** from the main menu (or press **Ctrl+E**);
3. Specify that you wish to save the file as an enhanced metafile.

Read more: Adding Images (page 820).

Once the symbol is defined using a user-defined symbol, you can change the symbol by pressing **Select new Image…**, or you can switch back to the default image provided by GoldSim by selecting the **Default symbol** button.

You can access the dialog for selecting a new image directly (without using the Appearance dialog) by selecting **Change Symbol…** from the context menu for the element.

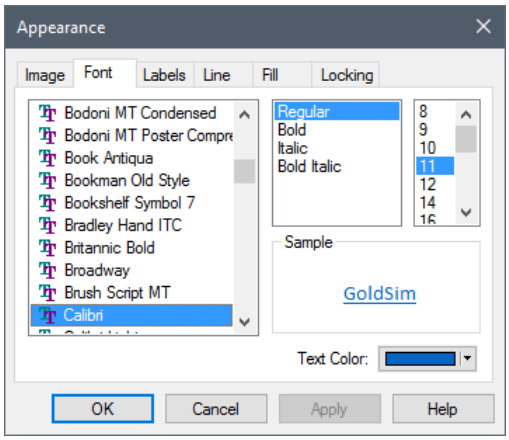
Two additional buttons are also on the **Image** tab:

Reset Size: This resets the size of a scaled image back to its original size.

Reset Ratio: This resets the aspect ratio of a scaled image back to its original ratio (by changing the symbol's height).

Changing the Hyperlink Object's Label

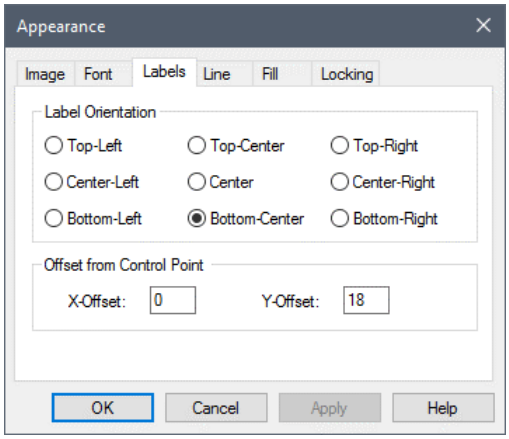
Two tabs within the Hyperlink Appearance dialog control the appearance of the object's label. The **Font** tab controls the label's font.



The options in this dialog include font and color.

Read more: Using and Managing the Color Palette (page 437).

The **Labels** tab controls the position of the label relative to the symbol.

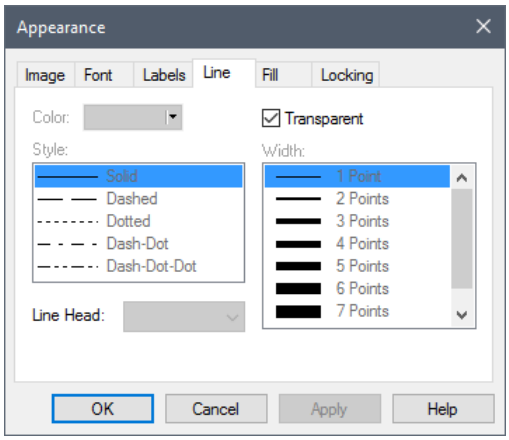


You can choose one of nine positions for the label. Note that if one of these nine positions is not sufficient, you can also manually move the label by selecting an

X-Offset and/or a **Y-Offset** (these can be negative numbers). In addition, if **Allow Label Move** is checked in the **Locking** tab, you can select and manually move the label.

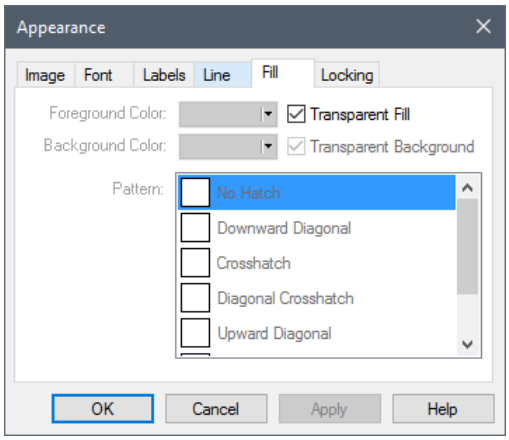
Changing the Hyperlink Object's Background and Outline

Two tabs within the Hyperlink Appearance dialog control the appearance of the object's background and outline. The **Line** tab allows you to draw a line (a box) around the symbol and label.



By default, the line is transparent. If you clear this box, you can change the line's color, style and width. Note, however, that the style can only be applied to 0 point lines.

The **Fill** tab allows you to change the appearance of the fill for the symbol and label.

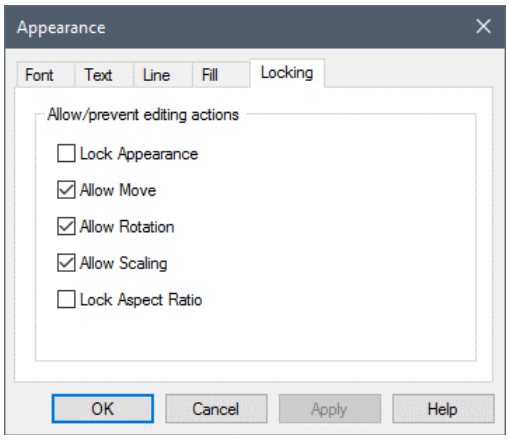


The fill consists of a background and a foreground. The **Foreground Color** is superimposed on top of a **Background Color** according to a selected **Pattern**. By default, both are transparent.

Read more: Using and Managing the Color Palette (page 437).

Locking the Appearance of the Hyperlink Object

The **Locking** tab determines what you can do with the object:



If **Allow Move** and **Allow Rotation** boxes are checked (the default), you can move and rotate the text. If **Allow Scaling** is checked (the default), you can resize the textbox. If the Allow Label Move box is checked you can select and move the object's label (separately from the object itself). If the box is cleared (the default), the label can only be moved with the object itself.

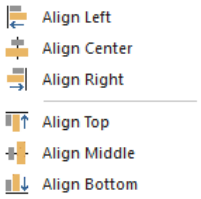
If **Lock Aspect Ratio** is checked, the textbox keeps its aspect ratio when it is resized. If **Lock Appearance** is checked, all of these options are disabled (you cannot move, rotate or scale the object).

Manipulating Graphical Objects

GoldSim provides a number of utilities for aligning, ordering, spacing, sizing, grouping, rotating, pasting and moving graphical objects (including element symbols) in the graphics pane.

Aligning and Ordering Objects

If you have selected multiple objects and/or elements in the graphics pane, you can choose **Graphics|Align** from the main menu to access a submenu.



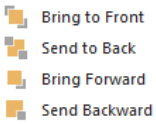
The options in this menu (which are self-explanatory) can be used to align the selected objects.

When you add an object to the graphics pane, it is assigned a particular order. The order determines how objects are "stacked" (i.e., whether an object is in front or behind another object) when they overlap. Higher order objects are always placed in front of lower order objects:

With regard to order, GoldSim groups objects into three classes: 1) elements; 2) influences; and 3) everything else (graphical objects like images and text). Elements always have a higher order than influences and influences always have a higher order than graphical objects. Hence, influences will always appear behind elements, and images and text will always appear behind influences.

Within a given class of objects (i.e., elements, influences or graphical objects), the latest object added to the graphics pane always has the highest order. Hence, if you add three circles, the first one added will have the lowest order and the last one added will have the highest order.

Once an object is placed in the graphics pane, you can manually change its order (within its class of objects) by selecting the object and choosing Order from the context menu to display a submenu.



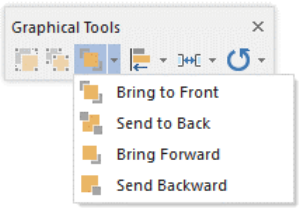
Bring to Front brings the object all the way to the front (gives it the highest order).

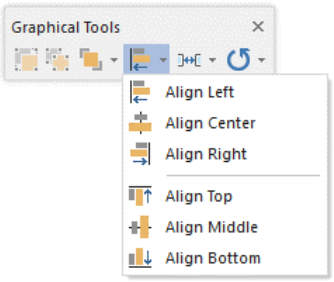
Send to Back sends the object all the way to the back (gives it the lowest order).

Bring Forward increases the object's order by one.

Send Backward decreases the object's order by one.

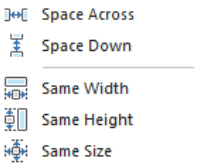
The order and align options are also available in the Graphical Tools toolbar:



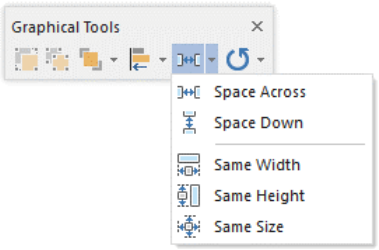


Spacing and Sizing Objects

If multiple objects are selected, you can also choose to space them evenly (horizontally or vertically), or set their widths, heights or sizes to be identical. These options are provided under **Graphics|Layout** in the main menu:



The layout options are also available from the Graphical Tools toolbar:



Precisely Moving Objects

Although you can move objects around the graphics pane by simply dragging them from one location to another, in some cases you may want to move them in a more precise manner. To facilitate this, GoldSim allows you to move objects vertically and horizontally using the arrow keys.

There are two modes of movement using the arrow keys:

- Using the arrow keys alone moves the object a short distance in a horizontal or vertical direction.
- Holding the **Shift** key down while using the arrows increases the distance moved by a factor of five.

Note also that when moving objects in the graphics pane, you can force their upper left hand corner to snap to a grid.

Read more: The Graphics Pane Grid and Background (page 442).

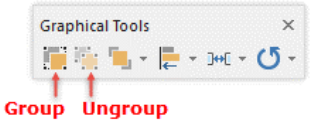
Grouping Objects

If you have selected multiple objects in the graphics pane, you can choose **Grouping|Group** from the context menu of one of the objects or **Graphics|Group|Group** from the main menu to group the objects. When objects are grouped, they behave as a single object. Hence, when you select one object, all objects in the group are selected. When you edit the graphical property (e.g., font, background color) of one object, the corresponding property of all objects in the group is modified.

Note: Elements cannot be a member of a group. Only graphical objects, text, images and hyperlinks can be members of a group.

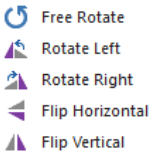
To Ungroup the set of objects, select the Group, and choose **Grouping|Ungroup** from the context menu of one of the objects or **Graphics|Group|Ungroup** from the main menu.

The Group and Ungroup options are also available in the Graphical Tools toolbar:



Rotating Objects

You can rotate a graphic object or text object in the graphics pane by selecting the object and choosing **Graphics|Rotate** from the main menu to access a submenu.



Free Rotate activates a Rotate Cursor (when placed over the object). Dragging the cursor within the object rotates it about its center point.

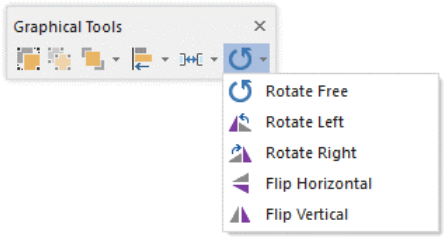
Rotate Left rotates the object 90 degrees counter clockwise.

Rotate Right rotates the object 90 degrees clockwise.

Flip Horizontal flips the object horizontally (around a vertical center axis).

Flip Vertical flips the object vertically (around a horizontal center axis).

The Rotate options are also available in the Graphical Tools toolbar:



Note: If an element is selected, the rotate option will be unavailable (grayed out). That is, you cannot rotate an element.

Copying, Pasting, Moving and Deleting Graphical Objects

You can copy and paste objects within the graphics pane using **Ctrl+C** and **Ctrl+V**, respectively.

You can delete an object by selecting it and pressing the **Delete** key.

You can also use the context menu for the object to **Cut**, **Copy**, **Paste** or **Delete**.

You can paste graphical objects and text from one GoldSim model to another and/or from other applications into GoldSim. For example, you could paste a bitmap from a graphics program directly into the GoldSim graphics pane, or you could paste text from a word processing application or text editor directly into the graphics pane.

When you paste text from another application into the GoldSim graphics pane, any tabs that are present in the pasted text will be replaced with 4 spaces.

You can also move graphical objects from one container to another in the same manner that you can move elements.

Read more: Moving Elements Between Containers (page 103).

Using the Graphical Undo and Redo Functions

GoldSim provides an automated "undo" and "redo" capability for actions involving the manipulation of graphics. These are accessible from the main menu (**Edit|Undo** and **Edit|Redo**). Alternatively, you can use **Ctrl+Z** and **Ctrl+Y** for Undo and Redo, respectively.

The Undo function only operates on actions involving the manipulation of graphic objects, such as adding, moving or modifying graphics and text. It cannot Undo actions that affect the model itself (such as editing inputs to an element).

The "stack" of actions that can be undone is terminated as soon as you carry out an action which cannot be undone. For example, if you add a text object, then add a rectangle, and then edit its graphical properties, you can step backward and undo these actions. If you subsequently added a new element, however, the "stack" of graphical actions would be deleted (and could not be undone using the Undo function).

The Redo function is only available after you Undo an action. That is, its function is to reverse an Undo.

Creating Printed Documentation

GoldSim provides two mechanisms to create printed documentation of your model:

- You can print the graphics pane;

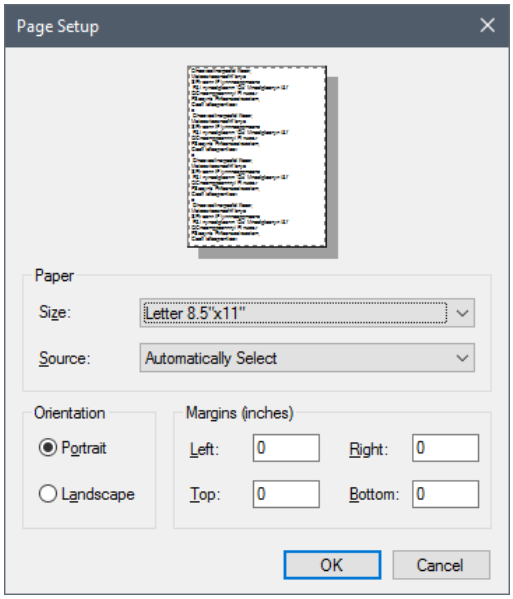
- You can export the graphics pane (or one or more selected objects) to a graphics file; and
- You can create a simple XML file that can be viewed in a text editor, browser or XML editor that echoes out all of the elements in a GoldSim model.

Printing the Graphics Pane

If you scroll far enough horizontally or vertically you will eventually reach the "edge" of the graphics pane. That is, the graphics pane represents a document of fixed size. This means that an element on the screen scales to a specific size on paper, and the entire graphics pane maps to a printed document with specific dimensions.

Read more: Adjusting the Size of the Graphics Pane (page 444).

In order to print the document, you must specify the manner in which the document is to be represented on paper. In particular, you must specify the paper size and orientation, along with the margins. You do this from a dialog accessed **File|Page Setup…** on the main menu:



When you make a change to the Page Setup (and press OK), GoldSim will ask if you want to apply these settings to all Containers, or just the current Container.

You can view the Page Bounds within the graphics pane by selecting **Properties…** from the context menu for the graphics pane (and then checking **Show Printer Page Boundaries** in the Graphics tab that is displayed.

You can preview the printed document by selecting **File|Print Preview** from the main menu. You can print the graphics pane directly from the Print Preview window or by selecting **File|Print** from the main menu.

Exporting the Graphics Pane

You can export the graphics pane and save it to a graphics format.

The simplest way to do this is to use **Alt+PrtSc** to cut the entire window to the clipboard (as a bitmap).

You can also use GoldSim's Export utility to save just the graphics pane (or selected items in the graphics pane) to a particular graphics format.

To do so:

1. Select an object (or objects) in the graphics pane, and select **Graphics | Export…** from the main menu (or press **Ctrl+E**). A dialog for specifying a file type and a location for the file is displayed.
2. Select a file type and a location, and then press **Save**.

If no object is selected in the graphics pane when you choose **Graphics | Export…** from the main menu (or press **Ctrl+E**), the entire graphics pane will be exported.

Creating an XML Model Inventory File

You can create a simple XML file that can be viewed in a text editor, browser or XML editor that echoes out all of the elements in a GoldSim model. This file contains the name, type, description and path for each element, and specifically illustrates the model hierarchy. With one exception, however, the file does not include the definition (e.g., input values, units) for any elements (it does include this information for all Data elements in the model).

You can create this file by selecting **File | Save Inventory…** from the main menu.

XML stands for eXtensible Markup Language. It was designed as a software and hardware independent tool to store and transport data such that it is both human- and machine-readable. Like HTML, XML uses tags. However, unlike HTML, XML does not have predefined tags. Rather, the author defines custom tags (as well as the document structure).

The general concept behind XML is to create a tree structure which starts at a root object and branches to child object. Such a structure, of course, is ideal for displaying the hierarchical design of a GoldSim model.

Objects that contain other tags as "contents" (such as Containers in GoldSim) are identified and formed by using opening and closing tags. The closing tag is identical to the opening tab with a forward slash (e..g, <Global>, </Global>).

The tags used by GoldSim are as follows:

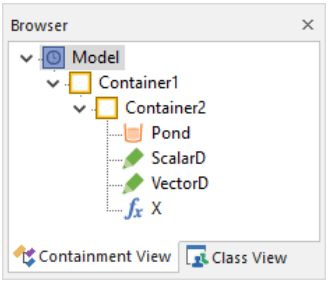
Tag	Description
<GSM>	Opening and closing tags for entire file.
<Global>	Demarcates global information regarding file. <File>, <Author>, <Created> and <Modified> tags are always inside <Global> opening and closing tags.
<File>	GoldSim filename and path.
<Author>	Model Author.
<Created>	Date and time GoldSim file was created.
<Modified>	Date and time GoldSim file was last modified.
<Model>	Demarcates information defining the model itself. <Container>, <Elements>, and <Element> tags are always inside <Model> opening and closing tags.
<Container>	A GoldSim Container. This tag also includes a number of properties (e.g., the Container name).
<Elements>	Demarcates a list of elements inside a GoldSim Container.

Tag	Description
<Element>	A GoldSim element. This tag also includes a number of properties (e.g., the element name).

As pointed out above, with one exception, the file does not include the definition (e.g., input values, units) for any elements. It does, however, include this information for Data elements. To facilitate this, several additional tags are only used to describe Data elements (these are nested inside the <Element> tag):

Tag	Description
<Input>	An input field. This tag also includes a number of properties (e.g., the input name, the type – Value or Condition, and the units).
<Equation>	The expression entered into the input field.
<Row>	For arrays, the row of the array. This tag also includes a property (id) identifying the row item ID
<Column>	For 2-D arrays (matrices), the column of the array. This tag also includes a property (id) identifying the column item ID

The best way to illustrate this is to examine a very simple model file. Consider the following simple model (as illustrated in the browser):



In this model, Container1 contains Container2, which contains a Reservoir named Pond, an Expression named X, a scalar Data element named ScalarD, and a vector Data element named VectorD (this element uses an Array Label Set named “Region” that has three items: East, North and South).

XML files can be viewed in any text editor. The “raw” XML Model Inventory file for the model above as viewed as text looks like this:

```
<GSM>
    <!-- Model Inventory generated by GoldSim 12.2.0095 -->
    <Global>
        <File>C:\Users\rkossik\Desktop\data.gsm</File>
        <Author>Rick Kossik</Author>
        <Created>4/29/2020 11:18:31 AM</Created>
        <Modified>4/30/2020 1:32:58 PM</Modified>
    </Global>
    <Model>
        <Container type="Container" typeID="0" id="Model" desc="The base container for the project" path="\">
            <Elements>
                <Container type="Container" typeID="0" id="Container1" desc="" path="\">
                    <Elements>
                        <Container type="Container" typeID="0" id="Container2" desc="" path="\Container1\">
                            <Elements>
                                <Element type="Expression" typeID="3" id="X" desc="" path="\Container1\Container2\" />
                                <Element type="Reservoir" typeID="12" id="Pond" desc="" path="\Container1\Container2\" />
                                <Element type="Data" typeID="1" id="ScalarD" desc="" path="\Container1\Container2\">
                                    <Input id="Definition" type="Value" order="Scalar" orderID="0" unit="m3">
                                        <Equation>100 m3</Equation>
                                    </Input>
                                </Element>
                                <Element type="Data" typeID="1" id="VectorD" desc="" path="\Container1\Container2\">
                                    <Input id="Definition" type="Value" order="Vector" orderID="1" rowSet="Region" unit="kg">
                                        <Row id="East">
                                            <Equation>10 kg</Equation>
                                        </Row>
                                        <Row id="North">
                                            <Equation>12 kg</Equation>
                                        </Row>
                                        <Row id="South">
                                            <Equation>8 kg</Equation>
                                        </Row>
                                    </Input>
                                </Element>
                            </Elements>
                        </Container>
                    </Elements>
                </Container>
            </Elements>
        </Container>
    </Model>
</GSM>
```

The XML Model Inventory file can be viewed in most browsers, and by default will look similar to this (this is viewed using Chrome):

Note that when viewing an XML file in a browser, you can expand and collapse branches of the tree. In Chrome, this is done using the arrowheads at each branch (in Internet Explorer, the branches are opened and closed using + and – signs). In the example above, all of the branches are expanded.

As can be seen, the file structure is quite simple. The following should be noted:

- The <Elements> </Elements> tags surround all of the elements inside a particular Container.
- Every element is described using a tag that has the following format:
    - <Element type="*element type*" typeID="*element type number*" id="*element name*" desc="*element description*" path="*element path*"/>.
    - If the element is the Container, a <Container> tag is used (with the same format as the <Element> tag).
    - In addition to the type of element being specified by name, it is also specified by a define typeID. The typeID is an integer; typeIDs for all elements are listed below:

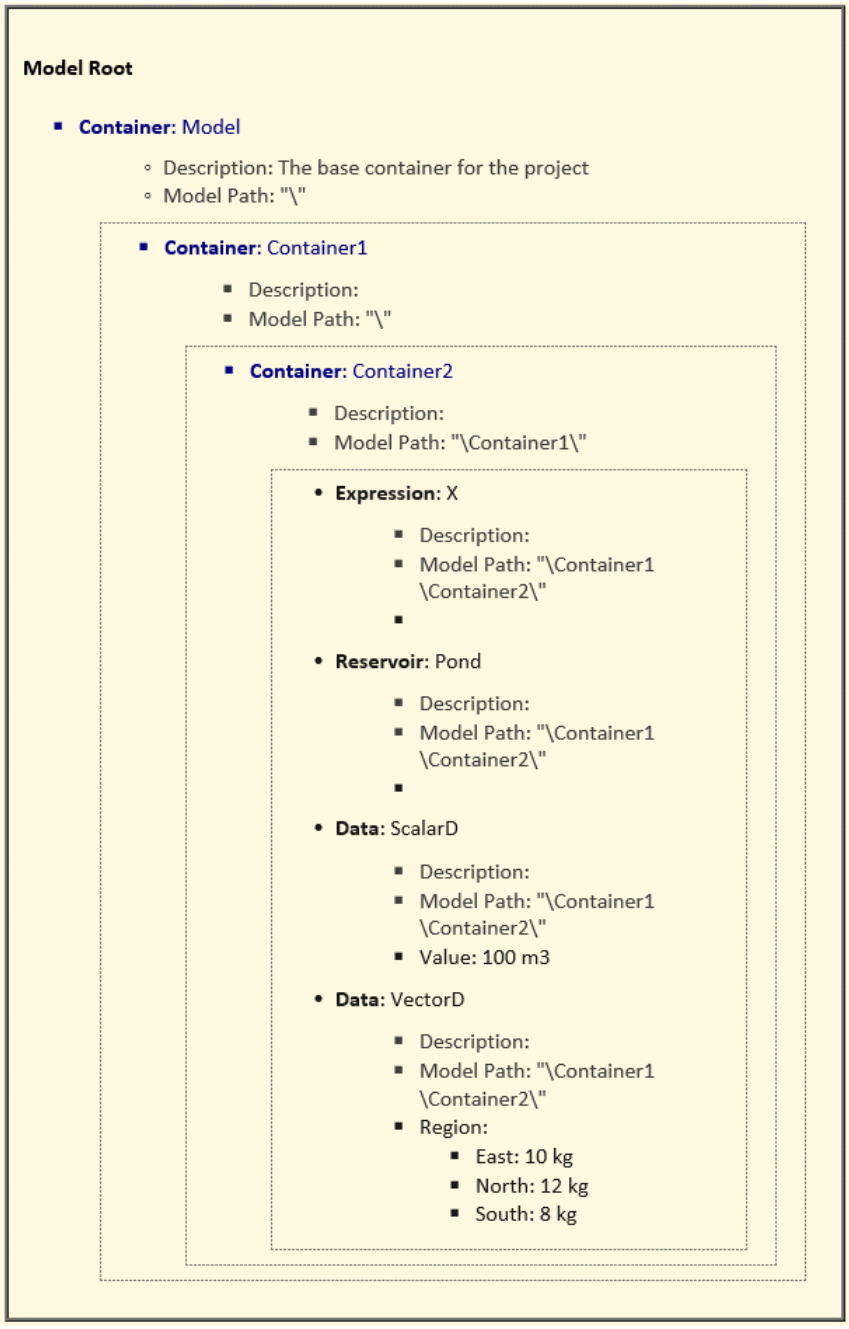
TypeID	Element	TypeID	Element	TypeID	Element
0	Container	25	File	200	Pipe Pathway
1	Data	26	Dashboard	201	Cell Pathway
2	Integrator	27	Milestone	202	Species
3	Expression	28	Status	203	Receptor
7	Stochastic	29	Not	204	Source
8	Event Delay	30	Material Delay	205	Reference Fluid
9	Decision	31	Information Delay	206	Fluid
11	Selector	32	Discrete Change Delay	207	Solid
12	Reservoir	33	Triggered Event	208	External Pathway
13	Time History Result	36	Convolution	209	Network Pathway
14	External	37	Lookup Table	210	Fracture Set
15	Timed Event	38	Previous Value	211	CellNet Generator
16	Discrete Change	39	Random Choice	212	Aquifer Pathway
17	Array Result	40	SubModel	340	Function (RL)
18	Mult-Variate Result	41	History Generator	341	Action (RL)
19	Distribution Result	42	Splitter	380	Insurance
20	Spreadsheet	43	Allocator	381	Fund
21	And	44	Interrupt	382	Cash Flow
22	Or	45	Time Series	383	Investment
23	Sum	46	Script	384	Option

TypeID	Element	TypeID	Element	TypeID	Element
24	Extrema	48	Pool		

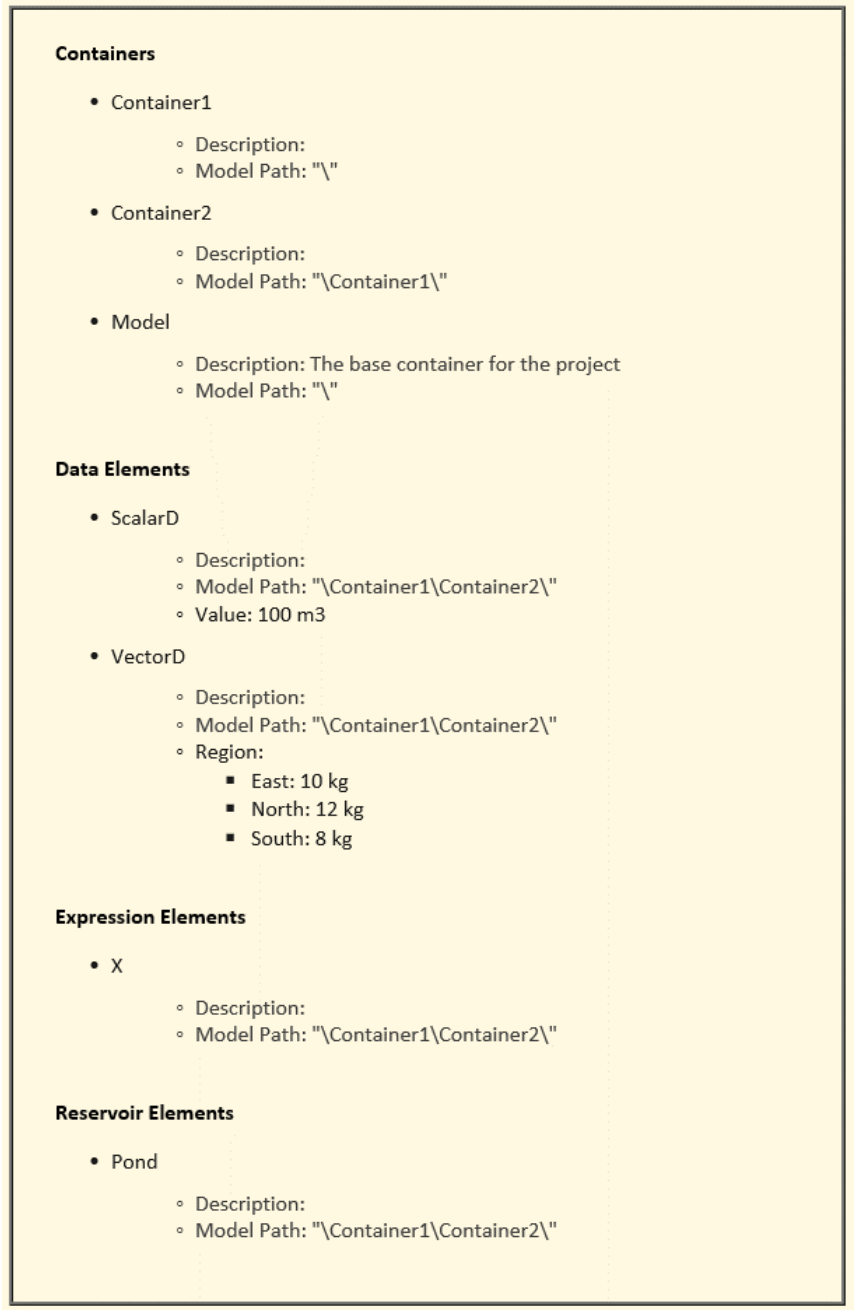
Data elements provide more details than the other elements. In particular, every Data element has an <Input> tag that is nested inside the <Element> tag that has the following format:

- <Input id="Definition" type="*input type"* order=*"order"* orderID="*ordernum*" unit=*"units*"> in which:
    - *input type* is either Value or Condition
    - *order* is either Scalar, Vector or Matrix
    - *ordernum* is either 0, 1 or 2 (0 for scalar, 1 for vector and 2 for matrix)
    - *unit* is the actual display units
    - Vector Data elements have one additional property (rowSet) and Matrix Data elements have two additional properties (rowSet and columnSet). The rowSet property is the name of the Array Label Set for the rows. The columnSet property is the name of the Array Label Set for the columns
- Every scalar Data element has an <Equation> tag nested inside the <Input> tag containing the expression entered into the input field.
- Every vector Data element has multiple <Row id="*RowLabel*" > tags (one for each row item, where *RowLabel* is the label for that row) that are nested inside the <Input> tag. Every <Row> tag has an <Equation> tag nested inside it containing the expression entered into the input field for that row.
- Every matrix Data element has multiple <Column id="*ColumnLabel*" > tags (one for each column item, where *ColumnLabel* is the label for that column) that are nested inside the <Input> tag. Every <Column> tag has mulitple <Row> tags nested inside it (containing the row items for that column). Every <Row> tag has an <Equation> tag nested inside it containing the expression entered into the input field for that row in that column.

XML files can be formatted by editing the file and specifying a stylesheet (when the XML file is created by Goldsim, no stylesheet is specified). This allows the files to appear much more readable. For example, this is how the XML file for the model above appears if a stylesheet is used that formats the XML file emphasizing the containment hierarchy:



Alternatively, this is how the XML file for the model above appears if a stylesheet is used that formats the XML file by element type:



Containers

- Container1
  - Description:
  - Model Path: "\"
- Container2
  - Description:
  - Model Path: "\Container1\"
- Model
  - Description: The base container for the project
  - Model Path: "\"

Data Elements

- ScalarD
  - Description:
  - Model Path: "\Container1\Container2\"
  - Value: 100 m3
- VectorD
  - Description:
  - Model Path: "\Container1\Container2\"
  - Region:
    - East: 10 kg
    - North: 12 kg
    - South: 8 kg

Expression Elements

- X
  - Description:
  - Model Path: "\Container1\Container2\"

Reservoir Elements

- Pond
  - Description:
  - Model Path: "\Container1\Container2\"

Note: The actual stylesheets used to produce these two formats, along with some additional information on how to edit the XML file to use the stylesheets, are provided in an article within the GoldSim Model Library (https://support.goldsim.com/hc/en-us/articles/360001007328).

Creating a GoldSim Player File

The GoldSim Player is a special version of GoldSim that allows you to "play" or “read” an existing GoldSim model without having to license the GoldSim software. In general, the user interface for the GoldSim Player is identical to that

of the full GoldSim version, with a number of menu options and controls for editing the model removed or disabled.

The GoldSim Player can be downloaded (for free) from the GoldSim website. It is also automatically installed on your machine when you install GoldSim (and is available via the Windows Start menu).

The GoldSim Player can not read a normal GoldSim file (a .gsm file). Rather, the GoldSim Player can only read Player files (.gsp). You can save a copy of a GoldSim model as a Player file by selecting **File|Save Player File…** from the main menu.

When you do so, a wizard will appear to assist you in creating the Player file. The first page of the wizard simply provides some explanatory text. The second page of the wizard prompts you for the Author's Name, a Model Description, and a Model Title. The Author's Name, Model Title, and Model Description can be viewed via a menu item in the Player (and the Model Title also appears in the title bar of any Dashboards you create). The third page of the wizard allows you to specify the properties of the Player file:

If the **Allow to browse the model** option is checked, the Player user is allowed to leave any Dashboard(s) and browse the structure of the model. Note that if the model does not have at least one Dashboard and/or the Dashboard includes a Button control that jumps to a Container or an element, the model is automatically browsable and this option will be checked on and grayed out.

If the **Allow the user to run the model** option is checked, the Run Control toolbar within the Player will be active and the user can use this to run (and save) the model. If this option is off, the Run Control toolbar is grayed out and the Player user will be able to view the model, but will not be able to run (or save) it. If the user can run the model, you can also choose whether to **Allow changes to the Time Settings** and **Allow changes to the Monte Carlo settings**. These allow the Simulation Settings of the model to be edited within the Player.

The final field in the third page of the wizard determines what will be displayed when the Player user opens the file. If the Player file has no Dashboards, the only option is "Top-level Container". However, if the file contains one or more Dashboards, you can specify the ***Default Dashboard*** ; that is, the Dashboard that will be displayed when the file opens in the Player. The drop-list contains all Dashboards in the model. If the model is browsable, it also contains "Top-level Container".

The final page of the wizard is used to specify the path and filename of the Player file.

Player files can be saved with or without results. If you try to create a Player file while you are in Edit Mode, GoldSim will first check the model for errors. If it finds errors, it will not allow you to create the Player file.

A Player file cannot be read by GoldSim; it can only be read by the GoldSim Player. You can view and navigate a Player file using the GoldSim Player just as you would view and navigate a GoldSim model file in GoldSim. This includes the ability to open most GoldSim dialogs (e.g., in order to examine how an element has been defined).

Note: If the model file from which the Player file is created was password-protected, the Player file will also be password-protected, and the user will need to enter a password to open the file.

Read more: Password-Protecting a Model File (page 65).

As pointed out above, the user interface for the GoldSim Player is identical to that of the full GoldSim version, with a number of menu options and controls for editing the model removed. Instructions for using the GoldSim Player are described within the program's online help system, as well as the **GoldSim Player User's Guide**.

Creating a Player File Using the Dashboard Authoring Module

The GoldSim Dashboard Authoring Module provides tools that allow a GoldSim modeler to design and construct a "dashboard" interface for models.

The interfaces can be designed to look like "dashboards" or "control panels", with buttons, gauges, sliders and display panels, and the author can embed instructions, tool-tips and graphics to provide instructions on the use of the model.

Such an interface allows a model to be easily used by someone without requiring them to be familiar with either the GoldSim modeling environment or the details of the specific model.

When such "dashboarded" models are saved as Player files, Player users can not only view and navigate the model, but they can also modify the model (through the dashboards), save the changes, and run the model.

The Dashboard Authoring Module is described in detail in the **GoldSim Dashboard Authoring Module Users Guide**.

Chapter 10: Advanced Modeling Concepts

These are much deeper waters than I had thought.

Sherlock Holmes (Sir Arthur Conan Doyle),
The Reigate Squires

Chapter Overview

This chapter describes a number of advanced and powerful GoldSim features. They have been saved for last since in order to use them, you must have a good understanding of the basic GoldSim features. Although you can build many kinds of models without using these features, once you become comfortable with GoldSim, many of these advanced features will seem indispensable, and you will want to take advantage of some of them in all of your models.

In this Chapter

The following topics are discussed in this chapter:

- Using Vectors and Matrices
- Understanding Locally Available Properties
- Solving Convolution Integrals
- Generating Stochastic Time Histories
- Using Resources
- Script Elements
- Using Conditional Containers
- Using External Application Elements
- Localizing Containers
- Cloning Elements
- Referencing an Output's Previous Value
- Using Looping Containers
- Understanding the Causality Sequence
- Using SubModels to Embed Models Within Models
- Customized Importance Sampling Using User-Defined Realization Weights
- Dynamically Revising Distributions Using Simulated Bayesian Updating
- Tracking Model Changes

- Linking Elements to a Database
- References

Using Vectors and Matrices

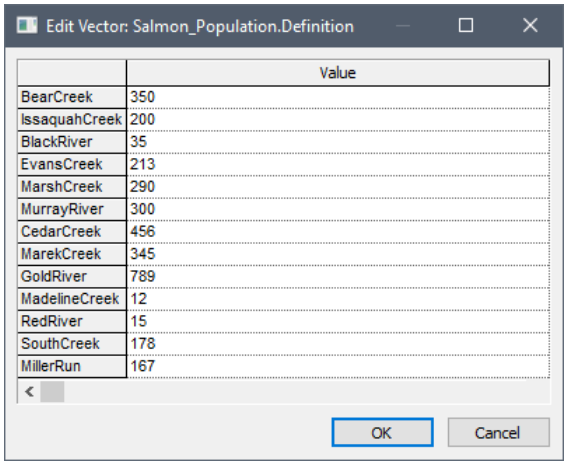
In many systems, you will want to create and manipulate elements that represent collections of data, rather than individual items. For example, you may want to create an element that represents your company's revenue for each of the last five years, or an element that represents the salmon population in each of 20 streams.

One way to do this, of course, would be to create separate elements for each object you wanted to model (e.g., five elements representing revenue, 20 elements representing salmon populations).

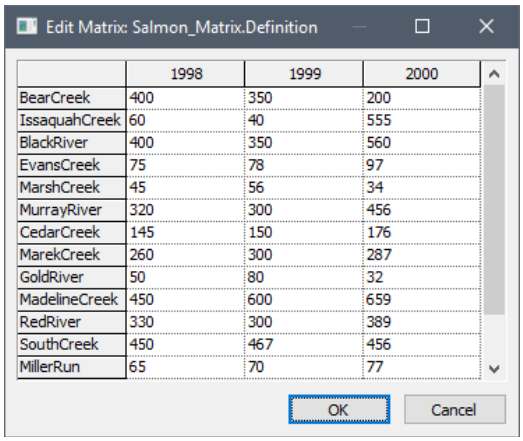
Such an approach, however, is not desirable for two reasons:

- It could require you to create a very large number of elements (e.g., if you wanted revenues for the past 25 years or wanted to evaluate salmon populations in 200 streams). This could result in very large, cluttered models.
- Usually, you will want to carry out the same types of calculations and operations on all related objects in such a collection (e.g., multiply all revenues by 2, compute the number of salmon eggs this year for all 20 streams based on the current salmon population). Having to do this individually for every object in a large collection would be very cumbersome and time-consuming.

To address these kinds of problems, GoldSim allows you to create and manipulate vectors and matrices (collectively referred to as arrays). For example, you could create a vector element that represented the salmon populations in each of a number of streams:



You could also create a matrix element that represented the salmon population in each of streams over a period of three years:



In addition to adding data in the form of vectors and matrices, you can manipulate these arrays in equations. For example, you could create an Expression element, and define it as:

2 * Salmon_Population

The output of the Expression would be an array, identical to the Salmon_Population array, except each item of the array would be two times greater.

If you did not use arrays to carry out this calculation, rather than creating 2 elements, you would need to create 40 elements (20 Data elements and 20 Expression elements) to accomplish the same thing!

Vectors and matrices are applicable to almost any kind of system, and you will likely want to take advantage of this feature in most of your models.

An example model which uses vectors and matrices within different elements (Arrays.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu). In addition, ArrayTimeSeries.gsm (in the Time Series subfolder of General Examples) includes examples of how Time Series elements can be used to generate arrays.

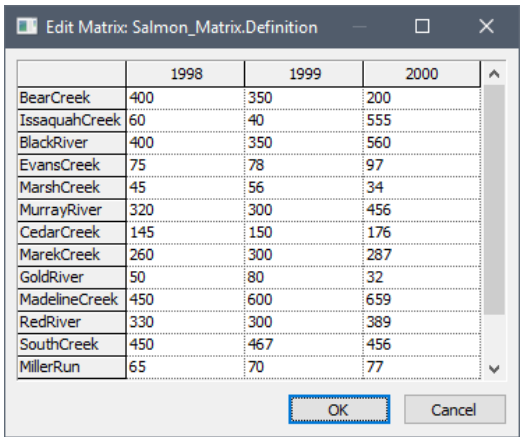
The following sections describe how you can create and use vectors and matrices in your models.

Understanding Array Labels

When you define a vector or a matrix, it must be defined relative to a particular set of array labels. A set of array labels is simply a collection of labels for the items of the array. The labels can be numbers (1, 2, …, 10) or words (apples, oranges, peaches, pears). When you define an element which has an array as an output, you must specify the sets of array labels upon which the array is based.

You define and reference a particular item of an array by using these labels. Vectors require a single set of array labels, and matrices require two sets of array labels (one for the rows, one for the columns).

As an example, consider a matrix that represents the salmon population in each of a number of streams over a period of 3 years:



	1998	1999	2000
BearCreek	400	350	200
IssaquahCreek	60	40	555
BlackRiver	400	350	560
EvansCreek	75	78	97
MarshCreek	45	56	34
MurrayRiver	320	300	456
CedarCreek	145	150	176
MarekCreek	260	300	287
GoldRiver	50	80	32
MadelineCreek	450	600	659
RedRiver	330	300	389
SouthCreek	450	467	456
MillerRun	65	70	77

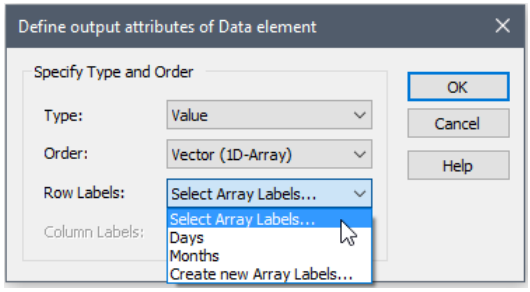
The matrix is defined relative to two sets of array labels: the rows are labeled using a "stream" set, and the columns are labeled using a "year" set. The labels or members for the "stream" set are BearCreek, IssaquahCreek, BlackRiver, and so on. The labels for the "year" set are the numbers 1998, 1999, and 2000.

You would reference the (scalar) item in the third row and second column of the matrix as Salmon_Population[BlackRiver, 1999].

Creating and Editing Array Labels

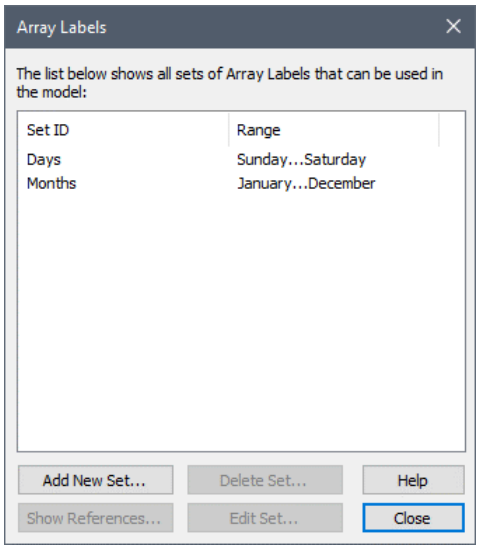
You can create (and edit) sets of array labels by selecting **Model|Array Labels…** from the main menu or by pressing the Array Labels button in the Advanced toolbar:

You can also create array label sets directly from the dialog for defining the Output Attributes for an element by selecting “Create new Array Labels…” from the drop-list:



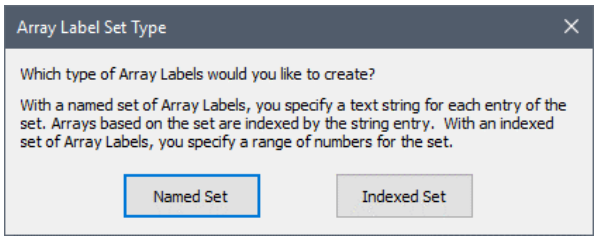
Read more: Defining Vectors and Matrices Using Data Elements (page 856).

Regardless of how you do so, the following dialog for defining the array labels will be displayed:

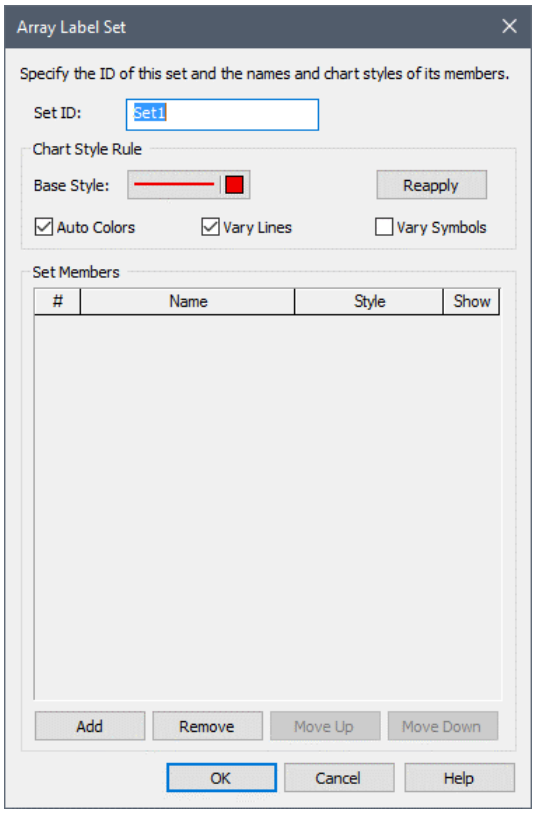


For convenience, GoldSim provides two commonly-used sets of array labels: Days has seven items (the days of the week); and Months has twelve items (the months of the year). GoldSim extension modules may also add some special sets (e.g., the Contaminant Transport Module adds a Species and an Elements set).

To add a new set of array labels, press **Add New Set…**. A dialog for specifying the type of array labels is displayed:



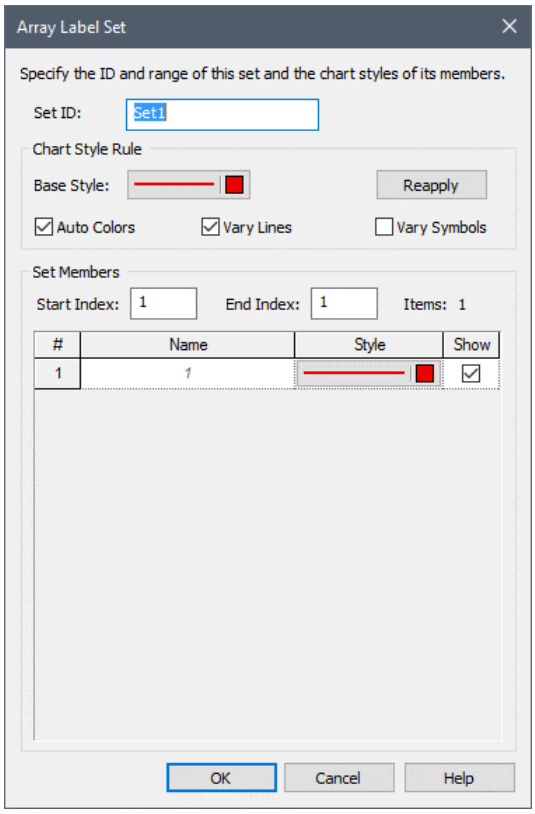
You must select whether you wish to define a Named Set or an Indexed (numbered) Set. If you choose to create a Named Set of array labels (or select an existing Named set to be edited), a dialog for editing the set will be displayed:



You can assign a name to a new set of array labels (by default it will be named Set*n*). You add and remove entries using the **Add** and **Remove** buttons. Holding the **Ctrl** key down changes the **Remove** button to a **Remove All** button, so you delete all entries. You can also paste a column of labels (e.g., from a spreadsheet) within this dialog by pressing **Ctrl+V**.

After you add two or more entries, the **Move Up** and **Move Down** buttons become available, allowing you to move entries up or down in the list. If you reorder the items, any items in existing elements using the set will automatically be re-sorted to the new sequence.

If you choose to create an Indexed set of array labels (or select an existing Indexed set to be edited) a dialog for editing the set will be displayed.



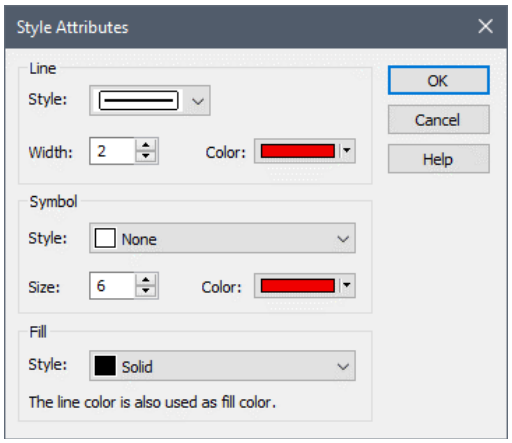
You can assign a name to the new set of array labels (by default it will be named Set*n*).

You must then enter a **Start index** (e.g., 1) and an **End index** (e.g., 100). When you press the **Reapply** button, GoldSim will then create all the entries for the set.

If you are editing an existing indexed set which is already referenced by some elements for which data has been defined, and change the Start index, GoldSim will prompt you for how you would like to adjust the values in existing Data elements that reference that set.

Read more: Changing the Start Index for an Indexed Set that is Already Being Referenced (page 854).

The Array Label editing dialog also allows you to define the Styles that are used when an element based on the set is displayed in a result chart. The **Base Style**, in combination with the **Auto Colors**, **Vary Lines** and **Vary Symbols** options allow you to automatically generate the Styles by pressing the **Reapply** button. Alternatively, you can click on any **Style** in the list to manually specify the Style attributes:



Read more: Using and Managing the Color Palette (page 437).

Note: The Array Label Set dialog can also be accessed when viewing results (in order to access the Chart Style attributes). When accessed in this manner, in some cases, the Chart Style options may be hidden (if editing them is not applicable).

The **Show** checkbox determines whether or not the item is displayed in result charts.

Read more: Viewing Time Histories for Array Outputs (page 615); Viewing a Vector Chart (page 757); Viewing a Matrix Chart (page 760).

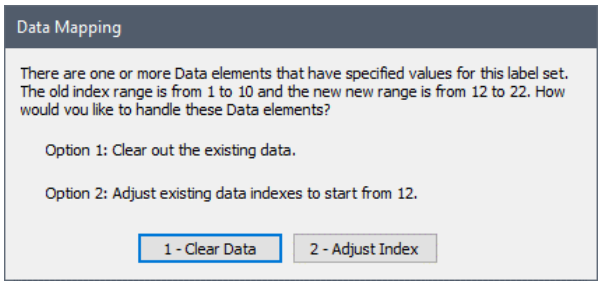
Note: Array label sets are saved with your model. If you wish to use the same set of array labels in different models, you must recreate it in each model. Alternatively, you can copy a set of array labels from one model file to another by copying an element that uses the set. Note, however, that GoldSim will only allow you to do so if a set of the same name does not exist in the model file into which the element is being copied.

To edit an existing set of array labels, select the set from the list in the Array Labels dialog and press **Edit Set…**. The Array Label Set dialog will then appear for editing.

Changing the Start Index for an Indexed Set that is Already Being Referenced

If you are editing an existing indexed set which is already referenced by some elements for which data has been defined, and change the Start index, GoldSim will prompt you for how you would like to adjust the values in existing Data elements that reference that set.

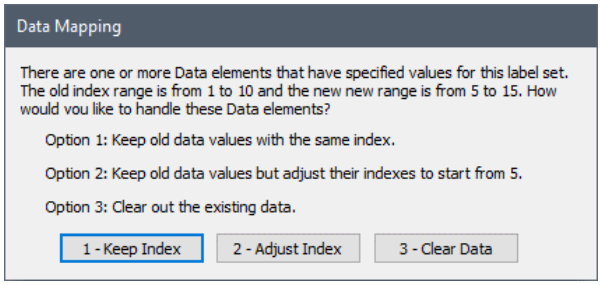
In particular, if the new range does not overlap with the old range, a dialog like this will appear to allow you to specify how the data is to be mapped to the new index values:



If you select Option 1, all data in existing Data elements will be cleared out (set to 0).

If you select Option 2, existing data will be mapped such that any data associated with the old Start Index will be mapped to the new Start Index, and so on. If the new range is shorter, data at the end of the range will be lost. If the new range is longer, zeros will be added to the new items.

If the new range does overlap with the old range, a slightly different dialog will be displayed for mapping the data:



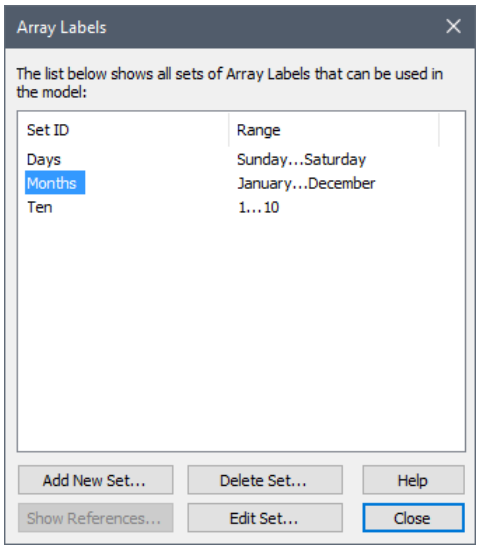
If Option 1 is selected, GoldSim will only map entries for items in the old set which match items in the new set. For example, if the original set was 1 through 20, and the new (edited) set was 15 through 34, for any elements that referenced the set, only entries 15 through 20 would be mapped to the new set (as the first five entries), and entries associated with items 1 through 14 in the original set would be lost. The remaining entries associated with the new set (16 through 34) would all be set to zero.

If you select Option 2, existing data will be mapped such that any data associated with the old Start Index will be mapped to the new Start Index, and so on. If the new range is shorter, data at the end of the range will be lost. If the new range is longer, zeros will be added to the new items.

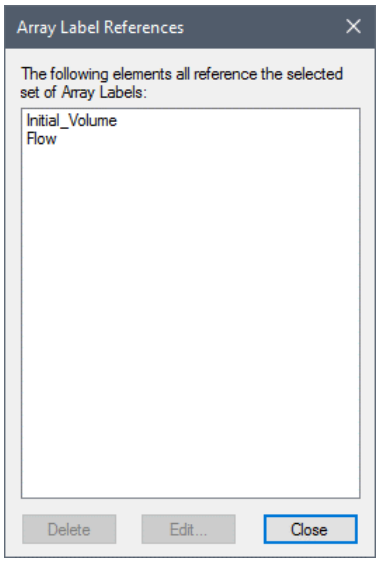
If you select Option 3, all data in existing Data elements will be cleared out (set to 0).

Deleting a Set of Array Labels

You can delete a set of array labels by selecting the set in the Array Labels dialog and pressing **Delete Set…**.



Note, however, that this button will be grayed out if the set is being referenced somewhere in the model (you can not delete a set if it is referenced by an element). If a set is used in the model, the **Show References…** button will be available (otherwise, it is grayed out). Pressing this button displays a dialog that provides a list of all of the elements which reference the set, and allows you to edit or delete each element:

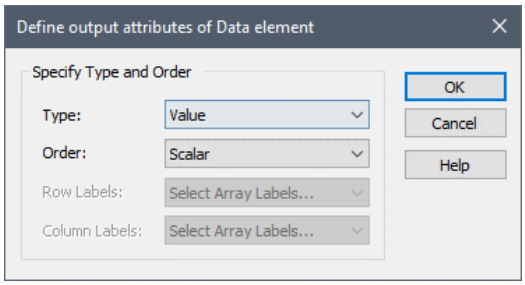


After selecting an element in this list, you can choose to either **Delete** or **Edit** it.

Defining Vectors and Matrices Using Data Elements

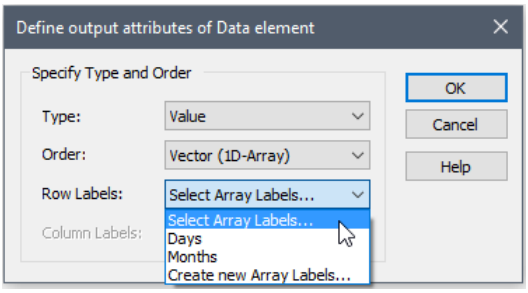
Once you have defined the sets of array labels that you wish to use, you can create vectors and matrices. The primary way to create vectors and matrices is to define them using Data elements. Once these exist, other vectors and matrices can be created by other kinds of elements based on these (e.g., by using these as inputs).

You specify that a Data element is to be a vector or a matrix when you define its output attributes (by pressing the **Type…** button in the element's properties dialog). The dialog for specifying output attributes for an element looks like this:

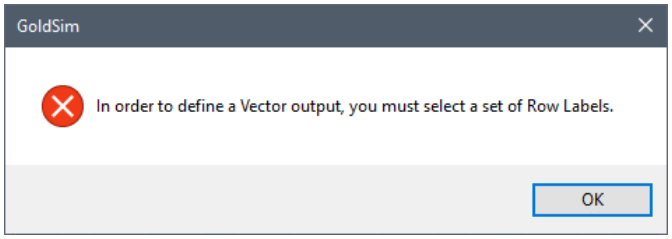


The **Order** drop-list provides three choices: "Scalar" (the default), "Vector (1D-Array)", and Matrix (2D-Array)".

If you wish to create a vector, select "Vector (1D-Array)". If you wish to create a matrix, select "Matrix (2D-Array)". If you select "Vector (1D-Array)", the **Row Labels** field becomes available. If you select "Matrix (2D-Array)", both the **Row Labels** and **Column Labels** fields become available. These two fields contain lists of all of the sets of array labels defined in your model:



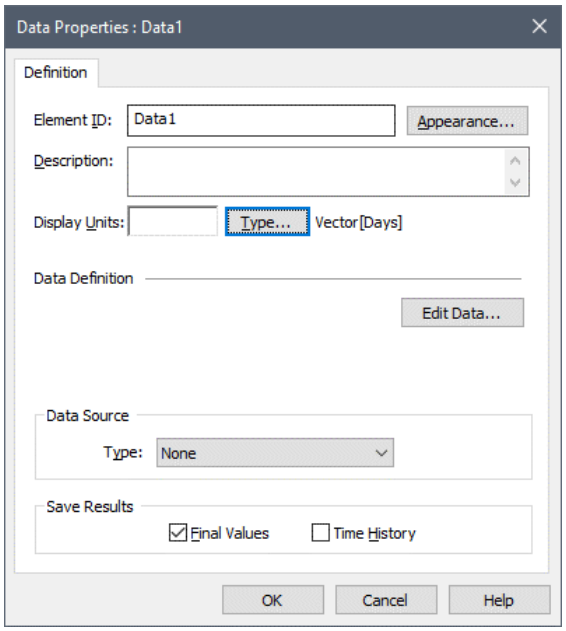
If you have defined the **Order** as a vector or a matrix (i.e., if the Row Labels or Column Labels fields are active), you must select a set of array labels (or GoldSim will display a warning message when you try to close the Output Attributes dialog).



Note that within the drop-list for the Row and Column labels is the choice to "Create new Array Labels…". If you click this option, the dialog for defining new array labels will be displayed. After leaving the Array Labels dialog, you will be returned to the dialog for defining output attributes.

Read more: Creating and Editing Array Labels (page 850).

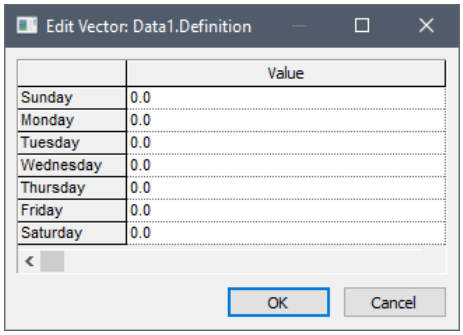
To illustrate how you would create a vector or a matrix Data element, consider the following example. Suppose that you defined the **Order** as "Vector (1D-Array)", and defined the **Row Labels** as "Days". The properties dialog for the Data element would look like this.



Note that this dialog is different from the standard Data element dialog for a scalar.

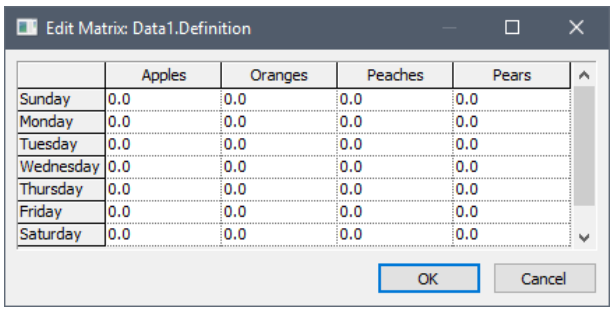
Read more: Data Elements (page 156).

In particular, because it is an array, you cannot directly edit the Data input field. To edit the vector, you must press **Edit Data…**, which will display the following dialog.



This dialog displays all items of the vector (in this case, seven). Each field is a standard edit field (you can enter a number, an expression or a link), although typically you would enter just a number (with units).

Note that the equivalent dialog for a matrix looks like this (in this example using a set of array labels for the Column Labels named Fruit with members Apples, Oranges, Peaches and Pears):



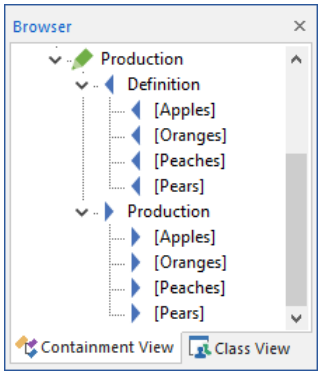
Although you would typically enter constants (numbers) into the input fields defining a vector or a matrix, the fields accept links and expressions. For example, you could create a vector of Stochastics by entering a link to a Stochastic for each item in a vector.

Note: You can paste data from a spreadsheet, a Word table, or a tab-delimited text file directly into a vector or matrix grid. To do so, copy the data to the clipboard, select the cell in the vector or matrix representing the upper left-hand corner of the range into which you wish to paste (by single-clicking in it), and press **Ctrl+V**.

Note: You can resize the columns of the editing dialog by dragging the lines separating columns right or left. You can also resize the entire dialog by dragging a side (or a corner).

Viewing an Array in a Browser or Interface

When you view a vector or a matrix in a browser or an interface, the inputs and outputs can be expanded to show the individual items.



Note: Element inputs and outputs are only shown in the browser if you choose to **Show element subitems** (accessed via the browser context menu by right-clicking in the browser).

Note that placing the cursor over an item of the array displays the Current Value (if in Edit Mode) or the Last Value (if in Result Mode). The Current Value is computed as the expected value of the item. The Last Value is the final value (i.e., the value at the end) of the last realization.

Read more: Understanding Result Mode (page 578).

Referencing an Item of an Array

If required, you can access a particular item of the array in an expression. You do this by using brackets [ ].

For example,

Data1[Monday]

references a single (scalar) value representing the second item of the vector Data1 (defined by the set “Days”, which begins with Sunday).

Similarly,

Data2[Monday, Peaches]

references a single (scalar) value representing the item in the second row and third column of the matrix Data2 (with the rows defined by the set "Days", and the columns defined by the set "Fruit", which consists of Apples, Oranges and Peaches).

When referencing array items, you can also use variables as the arguments. For example, if Data1 was a vector of "Days", and X was a scalar value, you could write the following in an expression:

Data1[X]

If X was 3, it would return the 3rd item in the vector (i.e., Data1[Tuesday]).

GoldSim rounds to the nearest integer when evaluating an array argument, so in this example, as long as the rounded value of X was between 1 and 7 inclusive, GoldSim would be able to evaluate the expression. If X evaluated to a number outside of that range, GoldSim would display a fatal error. Of course, X could change with time (or any other variable in your model).

This functionality can also be used with matrices. As an example, if Data2 was a matrix with the rows defined by the set "Days", and the columns defined by the set "Fruit" (with 3 entries), you could reference the following in an expression:

Data2[X, Y]

In this case, X would need to be an integer between 1 and 7, inclusive, and Y would need to be an integer between 1 and 3 inclusive. If X was 3 and Y was 2, it would return the item in row 3, column 2 of the matrix (i.e., Data2[Tuesday, Peaches] assuming Peaches was the second array label for "Fruit").

When using variables to reference array items, the following points should be noted:

- If the array is based on a named set, the variable represents the ordinal item in the set (i.e., the row or column number). For example, if Data1 was vector of "Days", and X was 3, then Data1[X] would return the 3rd item in the vector (i.e., Data1[Tuesday]).
- If the array is based on an indexed set, the variable represents the actual item with that number label in the set. For examples, if Data9 was a vector defined by an indexed set with labels 3, 4, 5 and 6, and X was 3, then Data9[X] would return the first item in the vector (i.e., Data9[3]).

Finally, when using this with matrices, you can use * as a wildcard. Using the example above,

Data2[*, Y]

would return column Y (a vector of Days). Similarly,

Data2[X, *]

would return row X (a vector of Fruit).

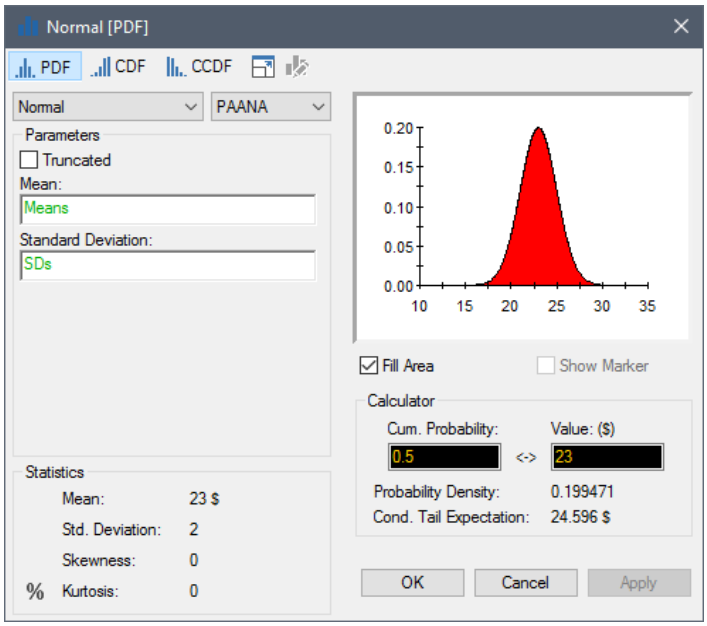
This ability to use variables when referencing array items is particularly powerful when using this feature in conjunction with array constructor functions.

Read more: Defining Arrays in an Input Field Using Array Constructor Functions (page 861).

Defining Vectors Using Stochastic Elements

In addition to using Data elements to create vectors, you can also create vectors using Stochastic elements. If you define a Stochastic element as a vector, rather than inputting a single probability distribution, you specify a set of probability distributions (one for each item of the vector).

If you specify the Stochastic as a vector (by specifying a set of array labels via the **Type…** button), the dialog for defining the distribution (accessed via the **Edit Distribution…** button) will look similar to this:



All the inputs to the Stochastic must be vectors.

Read more: Creating a Stochastic Vector (page 189).

Defining Arrays in an Input Field Using Array Constructor Functions

One of the quickest ways to create an array is to use array constructor functions. These are functions that can be entered into an input field that generate an array (a vector or a matrix) by specifying the array label set(s) and values as arguments.

For example, the following expression generates a vector based on the Days array label set, in which all the items have a value of 1m:

Vector(days, 1m)

The following expression generates a matrix based on the Days array label set (for rows) and the Months array label set (for columns), in which all the items have a value of 0 g:

Matrix(days, months, 0g)

Note: You do not have to specify the array label set(s) when using an array constructor. If you omit them, GoldSim will assume that the constructed array has the same order and set(s) as that of the input field where it is being defined. For example, if you created an Expression defined as a vector with array label set "days", then to create a vector of zeros, you could enter either "Vector(days, 0)" or simply "Vector(0)".

In addition to creating an array in which all the values for the items are identical (and hence specified by a single argument), you can also specify each item separately:

Vector(days, 1m, 3m, 0m, 5m, 6m, 2m, 7m)

In this example, since the Days array label set was specified, seven items are defined.

Note: When defining a matrix using an array constructor, the first argument represents the row array label set (having n items), the second argument is the column label set (having m items), and if all of the values are specified separately, they are defined as follows: r_1c_1, r_1c_2,…r_1c_m, r_2c_1,…r_nc_m. That is, the items are listed left-to-right-then-down through the matrix.

The units for the values of a constructor do not need to be identical (although the dimensions do). The following expression is valid:

Vector(days, 1m, 3ft, 0km, 5mm, 6m, 2ft, 7m)

Vector and matrix values may be specified as links. For example, if X was a scalar with dimensions of length, it could be inserted into the example above (i.e., defining the second item in the vector):

Vector(days, 1m, X, 0km, 5mm, 6m, 2ft, 7m)

Note that links such as X do not have to represent constants. They can be functions (including of time).

In addition, when using the Matrix constructor, you can specify vector arguments. That is, you can use the Matrix constructor to build a matrix from specified vectors (either one vector for each row or one vector for each column). The rules for doing so are as follows:

- If you create a matrix that has a different number of rows than columns, you can define the matrix by providing vectors for either all of the rows, or all of the columns. GoldSim automatically determines based on the array label sets whether the vectors should be treated as rows or columns).
- When creating a matrix using vectors, the array label set of the vectors provided do not need to match the array label set specified in the output attributes for the matrix being defined. What does need to match is the number of items in the array label sets.
- If the matrix is square, the provided input vectors load by columns (i.e. they are treated as column vectors). There is one exception to this: if the array label set of the provided vectors match ONLY the column array label set of the matrix (i.e., the row label set being different), the vector values are loaded into the matrix by row.

These rules can best be illustrated through some examples. These examples utilize array label sets called AL2 and AL2a with two items and AL3 with three items, and vectors V2a, V2b, V2c, V3a and V3b defined below:

V3a = [1, 2, 3], based on AL3

V3b = [6, 7, 8], based on AL3

V2a = [10, 20], based on AL2

V2b = [12, 22], based on AL2

V2c = [30, 40], based on AL2

Expression	Resulting Array	Comments
Matrix(AL2, AL3 , V2a, V2b, V2c)	10 12 30 20 22 40	Expression output attributes defined with AL2 as rows and AL3 as columns. Automatically treats vectors as columns.
Matrix(V2a, V2b, V2c)	10 12 30 20 22 40	Expression output attributes defined with AL2 as rows and AL3 as columns. Automatically treats vectors as columns.
Matrix(V2a, V2b, V2d)	10 12 30 20 22 40	Expression output attributes defined with **AL2a** as rows and AL3 as columns. Automatically treats vectors as columns. Although input vectors are based on AL2, they have two items so can be automatically mapped to AL2a.
Matrix(AL2, AL3 , V3a, V3b)	1 2 3 6 7 8	Expression output attributes defined with AL2 as rows and AL3 as columns. Automatically treats vectors as rows.
Matrix(V3a, V3b)	1 2 3 6 7 8	Expression output attributes defined with AL2 as rows and AL3 as columns. Automatically treats vectors as rows.
Matrix(V2c, V2c)	30 30 40 40	Expression output attributes defined with AL2 as rows and AL2 as columns. Vectors loaded by columns.
Matrix(V2c, V2c)	30 40 30 40	Expression output attributes defined with **AL2a** as rows and AL2 as columns. Vectors loaded by rows.

When using array constructors, you can also utilize two specialized variables: *row* and *col*. These variables can be used to define values based on the row and the column being referenced. Within constructors, these variables are defined as follows:

- If the array label set representing the row variable is based on a named set, *row* represents the the row number. Likewise, if the array label set representing the column variable is based on a named set, *col* represents the column number.
- If the array label set representing the row variable is an indexed set, *row* represents the actual item label. Likewise, if the array label set representing the column variable is an indexed set, *col* also represents the actual item label.

They are best illustrated through some examples. These examples utilize a named array label set called Set1 with 3 items (A, B and C), an indexed array label set called Set2 with 4 items (1,2,3 and 4), and an indexed array label set called Set3 with 3 items (3,4,5).

Expression	Resulting Array
Vector(Set1,row)	1 2 3
Vector(Set3,row)	3 4 5
Vector(Set1, if(row>=2,1,0))	0 1 1
Vector(Set3, if(row>=2,1,0))	1 1 1
Matrix(Set1, Set2, row)	1 1 1 1 2 2 2 2 3 3 3 3
Matrix(Set1, Set2, col)	1 2 3 4 1 2 3 4 1 2 3 4
Matrix(Set2, Set2, if(col>=row,1,0)	1 1 1 1 0 1 1 1 0 0 1 1 0 0 0 1

One powerful use of array constructors is to take advantage of the ability of arrays to reference variables as arguments. For example,

Vector(days, if(row<=4, A[row], B[row]))

would create a vector of days in which the first 4 items would be drawn from the vector A, and the last 3 items would be drawn from the vector B.

Read more: Referencing an Item of an Array (page 859).

Warning: If you have elements with the names Row or Col, GoldSim will link to the element rather than use the keyword. Therefore, if you want to use these keywords, you should ensure that no elements exist in your model with these names.

Using a Vector as a Lookup Table

Two array functions are available in GoldSim whose primary application is to allow you to create dynamic lookup tables (in which the values for the independent and/or dependent variables are changing with time).

Although GoldSim provides a specialized Lookup Table element, this element does not support dynamic tables (all the values must be constant values).

Read more: Using Lookup Table Elements (page 307).

Using the array functions vIndex and vInterp provides a mechanism for creating a dynamic lookup table using a vector.

vIndex(vector, value) requires the first argument to be a vector, and the second argument to be a value (with the same dimensions as the vector). It searches for the specified value within the provided vector, and returns the dimensionless *index* at which the value is found. It treats the vector as a continuous function, linearly interpolating where necessary between the defined points in the vector, and as a result, the returned index value is not necessarily an integer. For example, if the vector's values were [3m, 4m, 5m, 6m], then vIndex(vector, 5.1m) would return an index value of 3.1. Similarly, vIndex(vector, 10ft) would return an index value of 1.048. If the array labels are indexed, the appropriate index value is returned; if the array labels are named, the first entry in the array has an index value of 1.

If the value is outside of the range of values in the vector, a fatal error is displayed. If the value exists multiple times in the vector (e.g., a sine function), the first matching value is used.

vInterp(vector, index) requires the first argument to be a vector, and the second argument to be a dimensionless index. It interpolates into the vector using the specified index value. It treats the vector as a continuous function, linearly interpolating where necessary between the defined values in the vector, and returns a value (with the same dimensions as the vector). For example, if the vector's values were [3m, 4m, 5m, 6m] then vInterp(vector, 3.1) would return a value of 5.1m.

If the index is outside of the range of indices for the vector, a fatal error is displayed.

These two functions can be used in conjunction to create a dynamic lookup table. To do so, you would create two vectors using the same array label set, which would typically be indexed (e.g., 1 through 10). One of the vectors (named VectorInd here) would contain the independent variables, and the other vector (named VectorDep here) would contain the corresponding dependent variables. The values of these could change dynamically. At any time, if you wanted to obtain the dependent variable for a particular value of the independent variable (say, X), you could do so using the following expression:

vInterp(VectorDep, vIndex(VectorInd, X))

This would look up the index of X in the vector representing the independent variable and return the corresponding value from the vector representing the dependent variable.

A reverse lookup into the same table could be carried out using this expression:

vInterp(VectorInd, vIndex(VectorDep, Y))

This would look up the location of Y in the vector representing the dependent variable and return the corresponding value from the vector representing the independent variable.

An example model which illustrates how these functions can be used to create dynamic lookup tables DynamicLookup.gsm) can be found in the General Examples/LookupTable folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Manipulating Vectors and Matrices with Other Elements

Although you often will use Data elements to create arrays in your models, the real power of arrays is that they can be manipulated using other elements. In general, when you manipulate arrays in other elements, GoldSim carries out the calculations in parallel for each item of the array. GoldSim also provides a wide variety of special array functions which allow you to manipulate arrays

In this section, the various operators and functions that can be used to build expressions involving arrays are discussed. The manner in which various elements can manipulate array inputs is also described.

Manipulating Arrays in Expressions Using Mathematical Operators

The manner in which the standard operators in GoldSim can be used with arrays is summarized below:

Addition and Subtraction of Arrays. The addition (+) and subtraction (-) operators can be used between arrays if and only if the two arrays have the same dimensions and order, and are defined using the same set of array labels. GoldSim carries out the operation term-by-term and produces an array of the same order. For example, if A was a vector based on the set "Days", and B was a vector based on the set "Days", C=A + B would also produce a vector based on the set "Days". The first item of C would be the sum of the first item of A and the first item of B; the second item of C would be the sum of the second item of A and the second item of B, and so on. You cannot add or subtract an array to/from a scalar.

Multiplication or Division of an Array by a Scalar. The multiplication (*) and division (/) operators can be used between arrays and a scalar. Each item of the array is multiplied or divided by the scalar. For example, you could create the expression 2 * A, where A was a vector. The output of the Expression would be a vector, identical to the A vector (and its output attributes would need to be defined accordingly), except each item of the vector would be two times as great. Note that not only can you divide an array by a scalar, but you can also divide a scalar by an array. In both cases, the result is an array.

Multiplication and Division of Arrays of Same Order. When the multiplication (*) and division (/) operators are used between arrays that have the same order (and are defined using the same set of array labels), GoldSim carries out the operation term-by-term and produces an array of the same order as the original arrays. For example, if A was a vector based on the set "Days", and B was a vector based on the set "Days", C=A * B would also produce a vector based on the set "Days". The first item of C would be the product of the first item of A and the first item of B, etc.

Multiplying and/or Dividing the Rows or Columns of a 2-D Array (Matrix) by a 1-D Array (Vector). The following operations are supported in GoldSim for manipulating matrices: Matrix*Vector, Vector*Matrix, and Matrix/Vector. In these cases, the array label set of the Vector must match the array label set of either the rows or columns for the Matrix. If it matches that of the rows, then each row of the matrix is multiplied (or divided) by the corresponding term in the Vector. If it matches that of the columns, then each column of the matrix is multiplied (or divided) by the corresponding term in the Vector. If it matches both, the operation is carried out on the rows. In either case, the result is a Matrix of the same order as the original matrix.

Note: The operation described here is quite different from the linear algebra operation of multiplying a Vector by a Matrix (or vice versa), with the result being a Vector. That particular operation can be carried out using the specialized array function "Mult".

Read more: Array Functions (page 868).

Raising an Array to a Power. You can use the exponentiation operator (** or ^) to raise the items of an array to a power. GoldSim carries out the operation term-by-term and produces an array of the same order. For example, you could create an expression named C defined as A^2, where A was a vector. C must have the same order and set of array labels as A. The first item of C would be the first item of A squared, the second item of C would be the first item of A squared, etc.

Using Relational Operators with Arrays. Relational operators (e.g., >, <, =, ==, >=) can be used between arrays if and only if the two arrays have the same dimensions and order, and are defined using the same set of array labels. GoldSim carries out the operation term-by-term and produces an array of conditions. For example, if A was a vector based on the set "Days", and B was a vector based on the set "Days", the Expression C defined as A > B would produce a vector based on the set "Days". The first item of C would be the outcome (true or false) of the expression "first item of A" > "first item of B"; the second item of C would be the outcome (true or false) of the expression "second item of A" > "second item of B", and so on.

Relational operators can also be used between arrays and scalars. For example, if A was a vector based on the set "Days", and W was a scalar, the Expression D defined as A > W would produce a vector based on the set "Days". The first item of D would be the outcome (true or false) of the expression "first item of A" > "scalar value W"; the second item of D would be the outcome (true or false) of the expression "second item of A" >"scalar value W", and so on.

Using Arrays in If Statements. If statements can use mixtures of arrays and scalars. The rules for how such statements are interpreted are as follows:

1. The first argument (the condition) can be an array or scalar. If it is an array, then the second and third argument can either be arrays with the same set of array labels as the condition or scalars. Scalars are treated as arrays of identical values with the same set of array labels as the condition. If the first argument is an array, GoldSim does an item by item evaluation to construct the output array.
2. If the condition is scalar, and the second and third arguments are arrays, they must be of the same order, and the output has the same order as these arguments. Either one array or the other is output in its entirety as the result.
3. If the condition is a scalar, one of the latter two arguments can be a scalar, and one can be an array. The output of the If statement is then an array, and the scalar is treated as an array of identical values. Either one array or the other is output in its entirety as the result.

Read more: Entering and Editing Expressions in Input Fields (page 81).

Array Functions

Most of the built-in functions in GoldSim can also operate on arrays. In most cases, these functions carry out the operation term-by-term and produce an array of the same order as the input argument. For example, if A was a vector based on the set "Days", C=sin(A) would also produce a vector based on the set "Days". The first item of C would be the sine of the first item of A, the second item of C would be the sine of the second item of A, and so on.

Several functions (max, min, mod, tdist, tprob, bess, beta) accept multiple array arguments. For these functions, the arguments must all be scalars, or must be arrays of the same order that are defined using the same set of array labels. GoldSim carries out the operation term-by-term and produces an array of the same order. For example, if A was a vector based on the set "Days", and B was a vector based on the set "Days", C=min(A, B) would also produce a vector based on the set "Days". The first item of C would be the minimum of the first item of A and the first item of B; the second item of C would be the minimum of the second item of A and the second item of B, and so on.

Two specialized functions (occurs and changed) cannot accept arrays as arguments.

If X and Y are arrays (of the same order and using the same set of array labels), the If(C, X, Y) function can manipulate the arrays in two different ways:

- If C is a scalar condition, the output of the If function is either the array X (if C is true) or the array Y (if C is false).
- If C is an array (of the same order and using the same set of array labels as X and Y), GoldSim will carry out a term-by-term if,then computation to produce the output array. That is, if the first item of C is true, the first item of the output would be equal to the first item of X, otherwise it would be equal to the first item of Y, and so on.

Read more: Built-in Functions (page 126).

In addition to the standard functions mentioned above, GoldSim also provides a wide variety of special array functions which allow you to manipulate arrays (accessible from the context menu for an input field).

These special array functions are listed below:

Function	Description	Result
GetItem(VC,n)	Returns the nth item in the vector.	scalar
GetItem(MC,n, m)	Returns the item in the nth row and mth column of the matrix.	scalar
GetRow(VC,n)	Returns the nth item in the vector. (If first argument is a vector, this function is identical to GetItem).	scalar
GetRow(MC,n)	Returns the nth row of the matrix.	vector
GetColumn(MC,m)	Returns the mth column of the matrix.	vector
GetRowCount(VC)	Returns the number of items in the vector.	scalar
GetRowCount(MC)	Returns the number of rows in the matrix.	scalar
GetColumnCount(MC)	Returns the number of columns in the matrix.	scalar

Function	Description	Result
sumv(VC, X)	Sums the items of the vector. If the arguments are conditions, ORs the conditions. X is optional. If positive, the calculation is applied to the first X terms; if negative, the calculation applies to the last X terms. X is ignored if 0 or greater than array size.	scalar
prodv(VC, X)	Computes the product of the items of the vector. If the arguments are conditions, ANDs the conditions. X is optional. If positive, the calculation is applied to the first X terms; if negative, the calculation applies to the last X terms. X is ignored if 0 or greater than array size.	scalar
minv(V)	Computes the smallest item in the vector.	scalar
maxv(V)	Computes the largest item in the vector.	scalar
meanv(V)	Computes the mean of the items in the vector.	scalar
sdv(V)	Computes the standard deviation of the items in the vector.	scalar
rowmin(V)	Computes the index of the smallest item in the vector (i.e., 1, 2, 3, etc.).	scalar
rowmax(V)	Computes the index of the largest item in the vector (i.e., 1, 2, 3, etc.).	scalar
sort123(V)	Sorts the items in the vector from smallest to largest.	vector
sort321(V)	Sorts the items in the vector from largest to smallest.	vector
dot(V1,V2)	Dot (inner) product of V1 and V2. The first vector is assumed to be a row vector and the second vector is assumed to be a column vector. The two vectors must be based on the same set of array labels.	scalar
vvmatrix(V1,V2)	Vector multiplication (to produce a matrix).The first vector is assumed to be a column vector and the second vector is assumed to be a row vector. This is equivalent to vector multiplication of V1 by the transpose of V2.	matrix[A,B], where A is the set of array labels for V1 and B is the set of array labels for V2

Function	Description	Result
vIndex(V1,X)	Vector lookup. The second argument must be a value (with the same dimensions as the vector). It searches for the specified value within the provided vector, and returns a dimensionless *index* at which the value is found. It treats the vector as a continuous function, linearly interpolating where necessary between the defined points in the vector.	scalar
vInterp(V1,n)	Vector interpolation. The second argument must be a dimensionless index. It interpolates into the vector using the specified index value. It treats the vector as a continuous function, linearly interpolating where necessary between the defined values in the vector, and returns a value (with the same dimensions as the vector).	scalar
sumr(MC, X)	Sums the items across each row of the matrix. If the arguments are conditions, ORs the conditions. X is optional. If positive, the calculation is applied to the first X terms; if negative, the calculation applies to the last X terms. X is ignored if 0 or greater than array size.	vector[A], where A is the set of array labels for the rows in the original matrix
prodr(MC, X)	Computes the product of the items across each row of the matrix. If arguments are conditions, ANDs the conditions. X is optional. If positive, the calculation is applied to the first X terms; if negative, the calculation applies to the last X terms. X is ignored if 0 or greater than array size.	vector[A], where A is the set of array labels for the rows in the original matrix
minr(M)	Computes the smallest item in each row of the matrix.	vector[A], where A is the set of array labels for the rows in the original matrix
maxr(M)	Computes the largest item in each row of the matrix.	vector[A], where A is the set of array labels for the rows in the original matrix
meanr(M)	Computes the mean of the items in each row of the matrix.	vector[A], where A is the set of array labels for the rows in the original matrix
sdr(M)	Computes the standard deviation of the items in each row of the matrix.	vector[A], where A is the set of array labels for the rows in the original matrix

Function	Description	Result
sumc(MC, X)	Sums the items down each column of the matrix. If the arguments are conditions, ORs the conditions. X is optional. If positive, the calculation is applied to the first X terms; if negative, the calculation applies to the last X terms. X is ignored if 0 or greater than array size.	vector[B], where B is the set of array labels for the columns in the original matrix
prodc(MC, X)	Computes the product of the items down each column of the matrix. If the arguments are conditions, ANDs the conditions. X is optional. If positive, the calculation is applied to the first X terms; if negative, the calculation applies to the last X terms. X is ignored if 0 or greater than array size.	vector[B], where B is the set of array labels for the columns in the original matrix
minc(M)	Computes the smallest item in each column of the matrix.	vector[B], where B is the set of array labels for the columns in the original matrix
maxc(M)	Computes the largest item in each column of the matrix.	vector[B], where B is the set of array labels for the columns in the original matrix
meanc(M)	Computes the mean of the items in each column of the matrix.	vector[B], where B is the set of array labels for the columns in the original matrix
sdc(M)	Computes the standard deviation of the items in each column of the matrix.	vector[B], where B is the set of array labels for the columns in the original matrix
trans(MC)	Transpose of matrix. trans(MC1[A,B]) = MC2[B,A]	matrix[B,A], where A is the set of array labels for the rows in the original matrix and B is the set of array labels for the columns
inv(M)	Inverse of matrix. inv(M1[A,B]) = M2[B,A]	matrix[B,A], where A is the set of array labels for the rows in the original matrix and B is the set of array labels for the columns
mult(M1,M2)	Matrix multiplication. The columns of the first matrix must be based on the same set of array labels as the rows of the second matrix. Mult(M1[A,B] , M2[B,C]) = M3[A,C].	matrix[A,C], where A is the set of array labels for the rows in matrix M1 and C is the set of array labels for the columns in matrix M2

Function	Description	Result
mult(M,V)	Matrix times vector. The vector is automatically treated as a column vector. The vector must be based on the same set of array labels as the columns of the matrix. Mult(M[A,B] , V[B]) = V[A]	vector[A], where A is the set of array labels for the rows in matrix M
mult(V,M)	Vector times matrix. The vector is automatically treated as a row vector. The vector must be based on the same set of array labels as the rows of the matrix. Mult(V[A] , M[A,B]) = V[B]	vector[B], where B is the set of array labels for the columns in matrix M

V, V1, V2: Vector of values
VC: Vector. Can be value or condition.
M, M1, M2: Matrix of values
MC, MC1, MC2: Matrix. Can be value or condition.
X: Scalar value.
n,m: a dimensionless value; can be specified as a number, equation or a link. Real values are rounded to the nearest integer.

Note that the GetItem, GetRow, and GetColumn functions can, in most cases. more easily be implemented by referencing items of an array directly using variables. That is, if A was based on a named set or an indexed set that started with 1, GetItem(A, X) is identical to A[X].

Note, however, that in his example, if A was an indexed set that did not start with 1, GetItem(A, X) would not be identical to A[X]. GetItem(A,X) would return the Xth row. A[X] would return the item whose label was X. These are only the same if the indexed set starts with 1.

Another difference is that the first argument of the GetItem, GetRow and GetColumn functions can itself be an expression. To implement this using arrays with variable arguments would therefore require you to create a second element. That is, to reproduce this expression:

GetItem(A * B, X),

you would first need to create a vector C = A*B, and then reference C[X].

Read more: Referencing an Item of an Array (page 859).

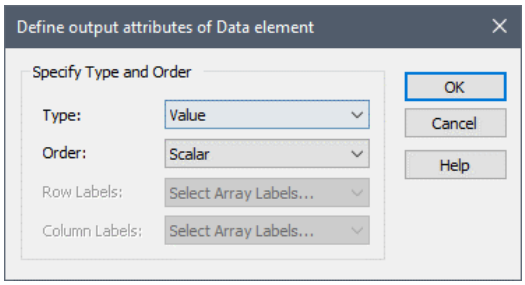
Elements That Can Manipulate Arrays

Many of the GoldSim elements can manipulate and produce vectors and matrices. For example, you can sum a number of matrices using the Sum element, or compute the peak value of each item of a vector using the Extrema element.

In general, if the outputs for an element are an array, its inputs must be arrays (defined by the same sets of array labels), and GoldSim carries out the element's calculations in parallel for each item of the array.

Note: If an input field of an element requires a vector, and the vector only has a single item, GoldSim allows you to enter a scalar as the input. Of course, if you then add items to the set of array labels (such that it consists of more than one item), the scalar input will no longer be valid.

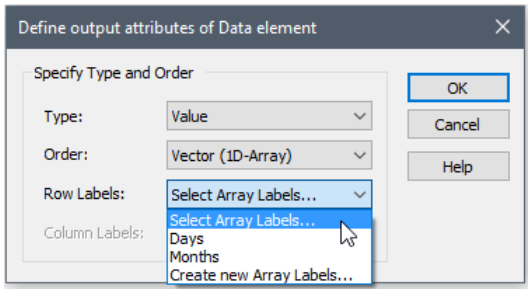
In order for an element to output an array, you must specify that it is to be a vector or a matrix when you define its output attributes (by pressing the **Type…** button in the element's properties dialog). The dialog for specifying output attributes for an element looks like this:



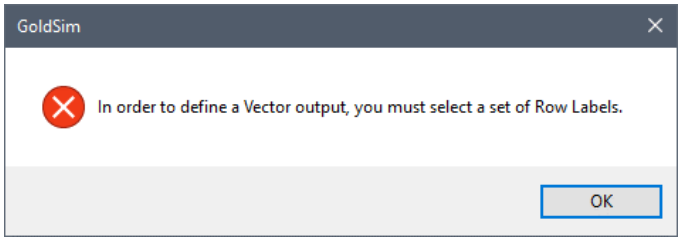
The **Order** drop-list provides three choices: "Scalar" (the default), "Vector (1D-Array)", and Matrix (2D-Array)":

If you wish to create a vector, select "Vector (1D-Array)". If you wish to create a matrix, select "Matrix (2D-Array)". If you select "Vector (1D-Array)", the **Row Labels** field becomes available. If you select "Matrix (2D-Array)", both the **Row Labels** and **Column Labels** fields become available.

These two fields contain lists of all of the sets of array labels defined in your model:



If you have defined the **Order** as a vector or a matrix (i.e., if the **Row Labels** or **Column Labels** fields are active), you must select a set of array labels (or GoldSim will display a warning message when you try to close the Output Attributes dialog):

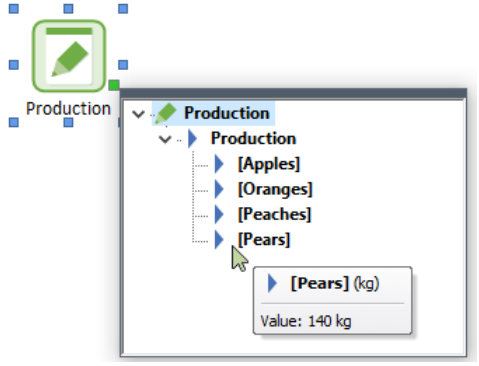


Within the drop-list for the Row and Column labels is the choice to "Create new Array Labels…". If you click this option, the dialog for defining new array labels will be displayed. After leaving the Array Labels dialog, you will be returned to the dialog for defining output attributes.

Read more: Creating and Editing Array Labels (page 850).

Viewing Results for Arrays

If an element has an output which is an array, you can view the values of specific items of the array by holding your cursor over the item in a browser or the output interface.



Note: Element inputs and outputs are only shown in the browser if you choose to **Show element subitems** (accessed via the browser context menu by right-clicking in the browser).

You can also view array output results in table form or chart form (e.g., as bar or column charts). GoldSim provides two different result views for arrays (Final Value results and Array results). In general, Final Value results are more powerful in this regard (Array results are a legacy feature).

Read more: Viewing Final Value Results (page 694); Viewing Array Results (page 754).

Copying Array Elements Between Models

When you copy an element defined using a set of array labels (i.e., an element with vector or matrix outputs) to another model, you must ensure that the set(s) of array labels referenced by the element in the two models are consistent. In particular, GoldSim imposes the following rules:

- If the set(s) of array labels referenced by the element already exist in the model into which it is being pasted, the number of items in the set(s) must be identical in both models. Note that it is not necessary that the set labels be identical, as long as the number of items is identical.
- If the set(s) of array labels referenced by the element do not exist in the model into which it is being pasted, GoldSim will automatically create them in the new model.

Read more: Copying Elements Between Model Files (page 104).

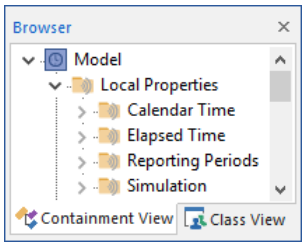
Understanding Locally Available Properties

Locally available properties are special attributes of some elements in GoldSim. Locally available properties are similar to element outputs in that they have a data type (e.g., value, condition), order (e.g., scalar, vector) and dimensions (i.e., units). However, they do not appear as outputs of the element to which they belong. Rather, they are only visible in browsers (the main browser, or the Insert Link browser).

Note: Locally available properties are only shown in the main browser if you choose to **Show element subitems** (accessed via the browser context menu by right-clicking in the browser).

Locally available properties derive their name from the fact that they may only be available, or they may take on different values (i.e., be over-ridden), in "locally available" parts of your model (e.g., within particular Containers).

Containers are often providers of locally available properties. In fact, the Run Properties are actually locally available properties belonging to the Model Container:

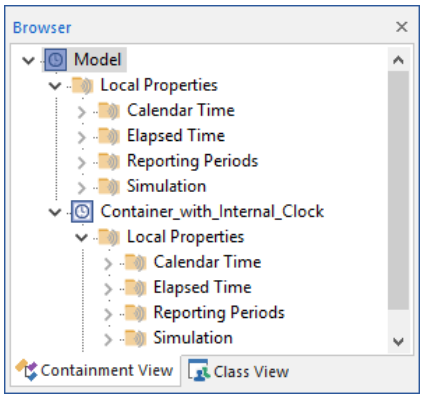


Read more: Understanding and Referencing Run Properties (page 505).

These properties are "broadcast" to the entire model. A Run Property (like ETime) is an example of a type of locally available property that is available throughout a model, but can take on different values in different parts of the model. In particular, some of the Run Properties can be over-ridden locally if a Container is defined to have an internal clock (a local timestep).

Read more: Specifying Containers with Internal Clocks (page 493).

In such a case, the Container with the internal clock also possesses Run Properties:

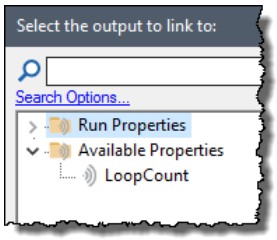


If you define an internal clock for a Container, and then within that Container, reference ETime, GoldSim will automatically connect to the "locally available" ETime (the ETime in the Container), rather than the global ETime (the ETime associated with the "root" or Model Container). Hence, the actual locally available property that it linked to is a function of where it is referenced from.

Some locally available properties are only available in specific locations. A good example of this is the loop count for a Looping Container.

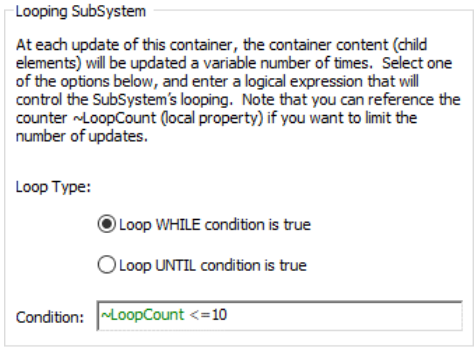
Read more: Using Looping Containers (page 1036).

Within the looping Container itself (or in its property dialog), it is often necessary to reference the loop count. However, this variable has no meaning whatsoever outside of the looping Container. As a result, it can only be referenced inside the Container (including in its property dialog). If you right-click in an input field within the looping Container and select **Insert Link** to view the Insert Link browser, the loop count will appear in an Available Properties folder:



If you invoke the Insert Link browser from outside of the Container, however, the loop count is not visible and cannot be referenced.

Locally available properties are referenced in expression by adding the ~ prefix. For example, when you insert the loop count for a looping Container into a field, it appears as follows:



Note: Run Properties represent a special instance of locally available properties that do not require the "~" prefix. These properties can be referenced directly (e.g., as ETime, or DayofWeek).

Modeling Aging Chains

In some situations, it is necessary to keep track of the age structure of a stock of material or objects. For example, you may want to track the number of people in each of a number of age groups, the number of people in a company at different experience levels (e.g., new hire, experienced, expert), or the number of trucks of different age groups on the road.

To model such a situation, you cannot use a single Stock (e.g., a Reservoir). Rather, you must disaggregate the total stock into multiple categories (referred to as cohorts). Each cohort "graduates" to the next cohort over time (and can only move in one direction). However, each cohort may grow and shrink for other reasons (e.g., if you were modeling a population of people, a particular category could grow due to immigration, and shrink due to emigration and death). Note that these rates of growing and shrinking are likely a function of the specific cohort (e.g., death rates).

Depending on your conceptual model, there are three fundamental ways to model such a chain:

- Using a series of Reservoirs or Pools.
- Using a series of Material Delays.
- Using a series of Integrators.

These three methods are discussed briefly in the following sections.

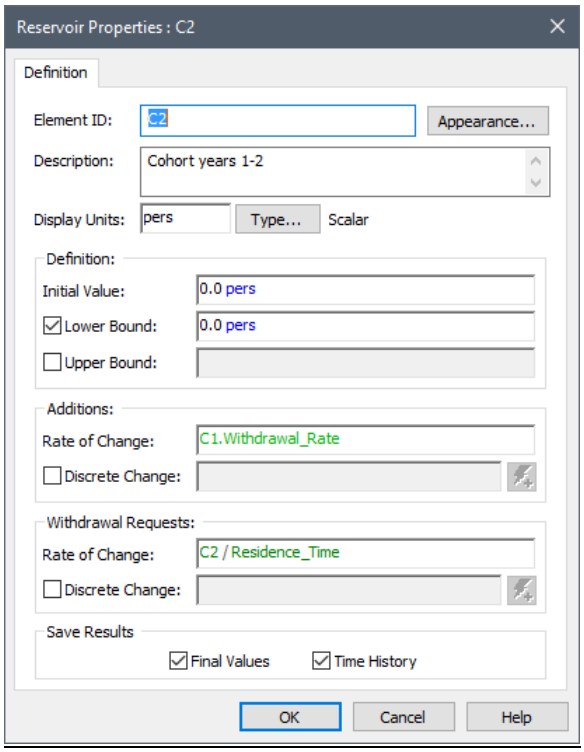
Example files which illustrate how aging chains can be modeled (AgingChain.gsm and AgingChainArray.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Modeling Aging Chains Using a Series of Reservoirs or Pools

Perhaps the simplest way of modeling aging chains is to create a series of Reservoirs (or Pools; the example here uses Reservoirs). The transition rate from one cohort (say C2) to the next, is set equal to C2/Residence_Time (a first-order rate), where C2 is the quantity in cohort 2, and Residence_Time is the average residence time in cohort 2.

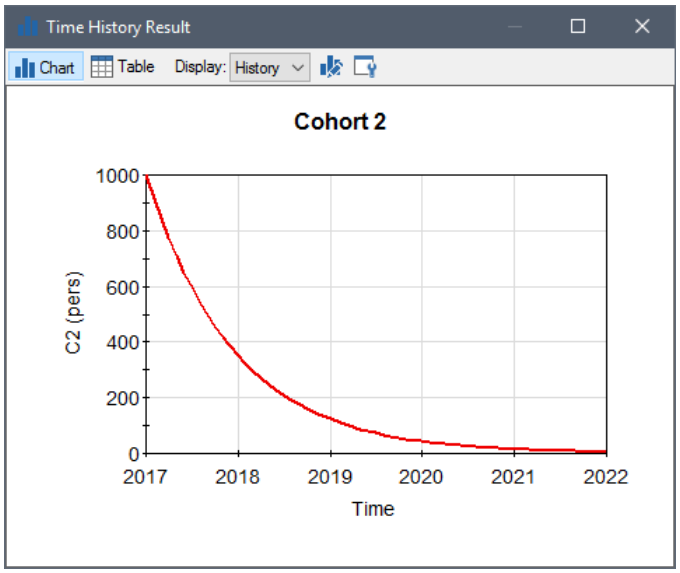
Read more: Reservoir Elements (page 240); Pool Elements (page 258).

In such a situation, the Reservoir for cohort 2 would look like this:



In this example, the cohort represents people aged 1 to 2 years. Hence, the Residence_Time is equal to 1 year. The rate of addition is the withdrawal rate from the previous cohort (C1), and the rate of withdrawal is C2/Residence_Time. Note that this simple representation does not represent any losses (e.g., due to death). To do so, you would simply need to add an additional withdrawal (which typically would be some fraction of C2).

It is important to understand that due to the nature of a Reservoir, such a representation results in a behavior which is typically inappropriate for modeling specific age groups. To illustrate this, let's assume 1) that cohort 2 starts with 1000 one-year olds; 2) there is no addition to the cohort (C1 has an initial value of 0), and 3) there is no death rate. Cohort 2 only decreases due to graduations to the next cohort. Under these circumstances, the number of people in cohort 2 would look like this:



As can be seen, rather than staying at 1000 for the first year, and then abruptly changing to 0 (when all of the one-year olds actually become 2 and hence should immediately graduate to the next cohort), the number of one-year olds gradually decays over a period of 5 years. As a result, modeling an aging chain in this manner is most appropriate when the residence time in the cohort represents an average time, with some people leaving earlier and some later. This is the case, for example, if the cohort represents a group of employees (e.g., inexperienced), rather than a specific age group (e.g., between 1 and 2 years old). One of the other two methods of modeling aging chains (using Material Delay or Integrators with discrete pushes) should generally be used when modeling specific age groups.

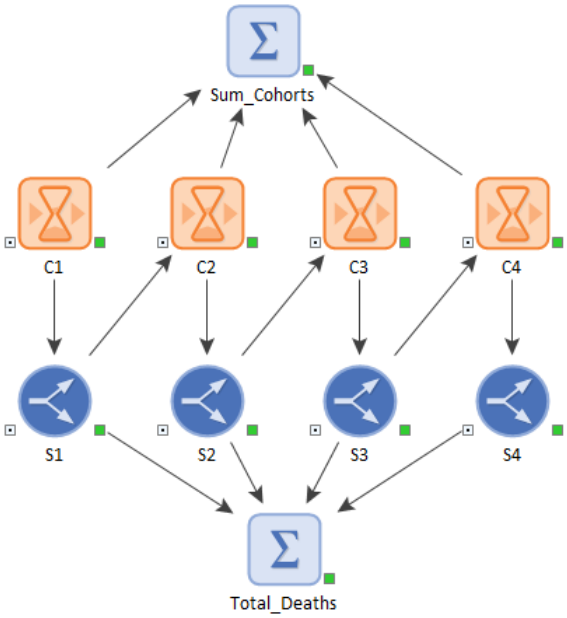
An example file which illustrate how aging chains can be modeled using a series of Reservoirs (AgingChain.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Modeling Aging Chains Using a Series of Material Delays

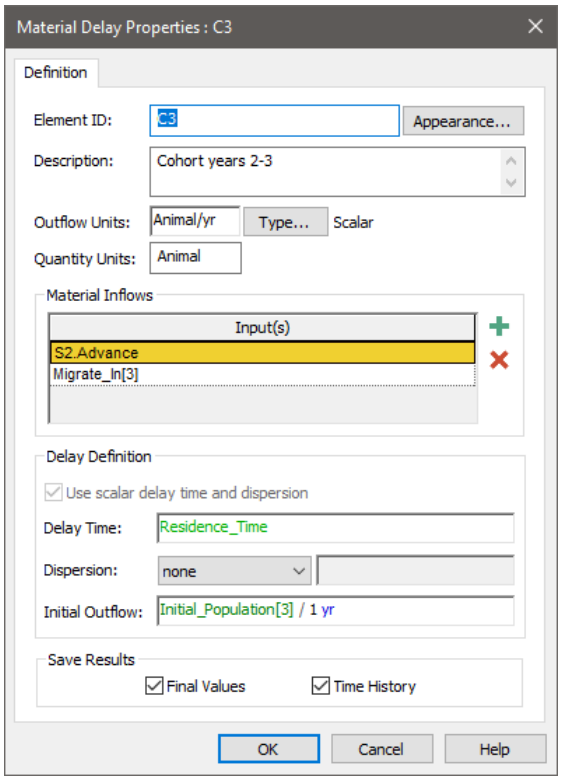
When modeling an aging chain consisting of specific age groups (e.g., 0 – 1 years, 1 – 2 years, etc.), it is often most appropriate to model the chain using a series of Material Delays.

Read more: Material Delay Elements (page 343).

Each Delay has a fixed delay time (with no dispersion) corresponding to the age cohort (e.g., 1 year). As such, the residence time in the cohort does not represent an average; it is an exact time required to "transit" the cohort. The structure of the model would typically look something like this:



Note that each Delay does not flow into the next Delay in the series. Rather, it flows through a Splitter, so that losses (e.g., due to deaths) can be accounted for prior to graduating to the next cohort. Of course, there could also be additional flows into and out of a cohort (due to immigration and emigration). The Material Delay dialog for a typical cohort for this simple would look like this:



An example file which illustrate how aging chains can be modeled using a series of Material Delays (AgingChain.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Modeling Aging Chains Using Integrators with Discrete Pushes

In some types of aging chains, you would like to instantaneously "graduate" all the members of one cohort to the next cohort at a specific time (e.g., every year), and repeat the process for all cohorts. For example, if you had 6 age groups, at the beginning of each year, you might want to transition all the age groups to the next cohort (e.g., cohort 5 graduates to cohort 6, cohort 4 graduates to cohort 5, cohort 3 graduates to cohort 4, etc.).

To facilitate this, GoldSim provides specialized capabilities for Discrete Change and Integrator elements.

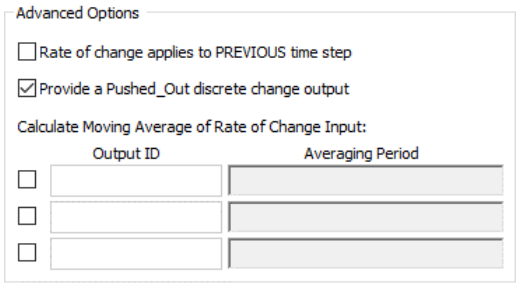
Read more: Integrator Elements (page 233); Discrete Change Elements (page 398).

One of the Instruction options for a Discrete Change transaction is a "Push":

Push instructions can subsequently be processed by Integrators (by specifying the discrete change output as an input in the **Discrete Change** input field of the Integrator).

Note: Push discrete change outputs can only be processed by Integrator elements. Splitters and Allocators can also accept Push discrete changes, as they don't actually process them; they simply pass them on (preserving the instruction). However, directing a Push discrete change to any other element (e.g., a Reservoir) will result in a fatal error.

When processing a Push discrete change signal, you must specify (under the Advanced options for an Integrator) that the Integrator itself, in turn, provides a"Pushed_Out" discrete change output:

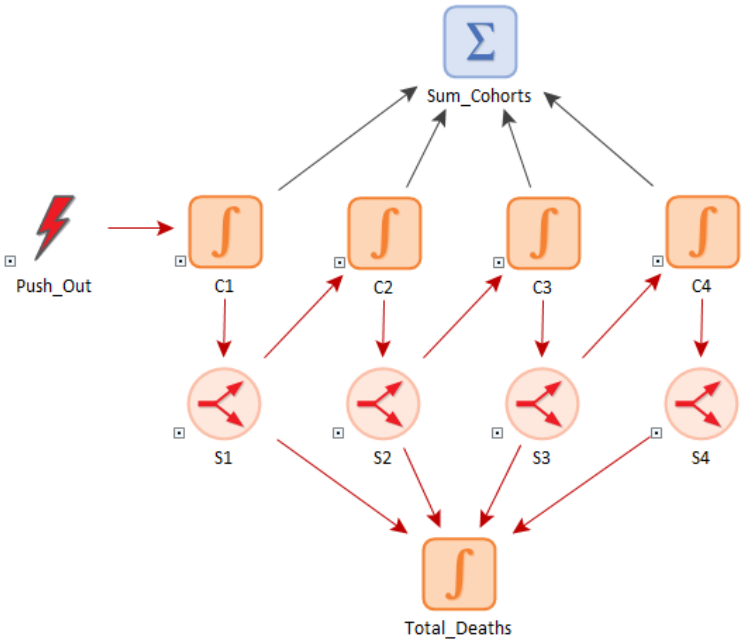


Doing so adds a new output called "Pushed_Out" to the element.

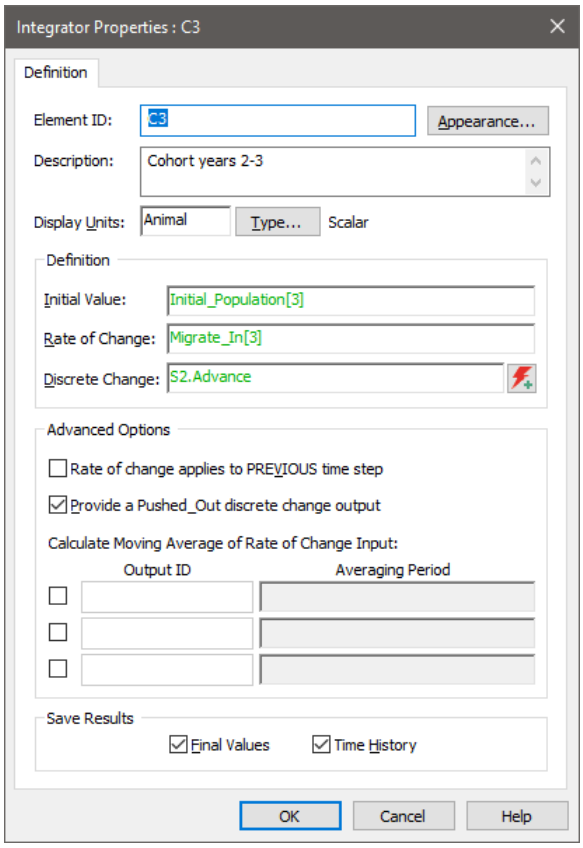
When an Integrator receives a Push discrete change signal (and the "Provide a Pushed_Out discrete change output" is checked), the following occurs:

1. The current value of the Integrator is instantaneously "pushed out" and replaced with value specified by the incoming discrete change signal.
2. The element produces a discrete change output named "Pushed_Out"that has a "Push" Instruction and a Value equal to the value of the Integrator prior to receiving the discrete change signal. This can subsequently be directed to another Integrator.

By creating a series of Integrators connected by Push discrete changes (triggered, for example, once per year), you can create an aging chain that instantaneously "graduates" all the members of one cohort to the next cohort at a specific time (e.g., every year). The structure would look something like this:



Note that each Integrator does not push into the next Integrator in the series. Rather, it flows through a Splitter, so that losses (e.g., due to deaths) can be accounted for prior to graduating to the next cohort. The Integrator representing one of the cohorts would look like this:



Note: When a scalar Integrator receives a Push discrete change signal and the "Provide a Pushed_Out discrete change output" is NOT checked, the discrete change is treated as if it had an Add instruction (since it has nowhere to "push" the current value). Hence, the Integrator simply accumulates the changes.

An example file which illustrates how aging chains can be modeled (AgingChain.gsm) using a series of scalar Integrators can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Although this type of approach can represent specific age groups very accurately, it can be cumbersome if there are a large number of groups. An alternative to this approach that is much better at simulating a large number of age groups is to use an Integrator *array* that processes discrete pushes.

In this approach, instead of using a series of Integrators, you use a single Integrator that is a vector. A discrete change signal with a Push instruction is sent to the Integrator. When it receives the instruction, the Value associated with the discrete change is "pushed" into the first item of the vector. Each value in the vector is then pushed downward to the next item of the vector. That is, the value that was in item 1 is pushed to item 2; the value that was in item 2 is pushed to item 3, and so on.

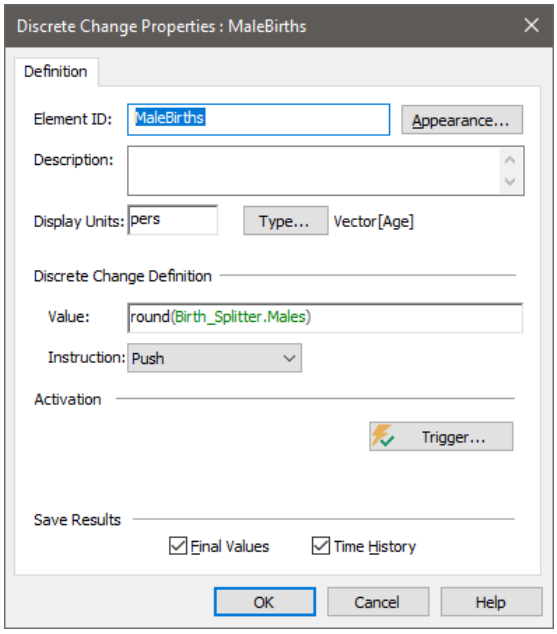
If "Provide a Pushed_Out discrete change output" is checked for the Integrator, the element produces a discrete change output named "Pushed_Out" that has a "Push" Instruction and a Value equal to the value of the last item in the

Integrator vector prior to receiving the discrete change signal. This can subsequently be directed to another Integrator. If "Provide a Pushed_Out discrete change output" is NOT checked for the Integrator, the final item in the Integrator vector accumulates all of the "pushes" that it receives.

When implementing such a vector aging chain, the Discrete Change element that generates the initial "push" into the Integrator must be defined in a specific manner. In particular, it must be defined as follows:

- The Instruction must be "Push";
- The Value must be a scalar value; and
- The Type must be defined to match the Type of the Integrator that will receive the discrete change. Hence, although the Value itself is a scalar (since it represents the value being pushed into the first item of the vector), the Discrete Change element must be defined as a vector (as it will be an input to a vector Integrator).

An example of this is shown below:



This approach allows you to replace a series of Integrators with a single vector Integrator, and therefore facilitates simulation of chains with a large number of cohorts.

An example file which illustrates how aging chains can be modeled (AgingChainArray.gsm) using a vector Integrator can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

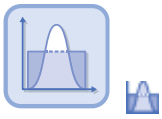
This approach can be extended to utilize a matrix Integrator. In this case, a discrete change signal (whose Value is defined as a vector) with a Push instruction is sent to the Integrator. When it receives the instruction, the Value associated with the Discrete Change is "pushed" into the first *row* of the matrix. Each row in the matrix is then pushed downward to the next row of the matrix. That is, the values that were in row 1 are pushed to row 2; the values that were in row 2 are pushed to row 3, and so on.

If "Provide a Pushed_Out discrete change output" is checked for the Integrator, the element produces a discrete change output named "Pushed_Out"that has a Push Instruction and a Value equal to the value of the last row in the Integrator matrix prior to receiving the Discrete Change signal. This can subsequently be directed to another Integrator. If "Provide a Pushed_Out discrete change output" is NOT checked for the Integrator, the final row in the Integrator matrix accumulates all of the "pushes" that it receives.

When implementing such a matrix aging chain, the Discrete Change element that generates the initial "push" into the Integrator must be defined in a specific manner. In particular, it must be defined as follows:

- The Instruction must be "Push";
- The Value must be a vector having the same Array Label Set as the columns of the matrix into which it is being pushed ; and
- The Type must be defined to match the Type of the Integrator that will receive the Discrete Change. Hence, although the Value itself is a vector (since it represents the values being pushed into the first row of the matrix), the Discrete Change element must be defined as a matrix (as it will be an input to a matrix Integrator).

Solving Convolution Integrals



Convolution elements are highly specialized elements in GoldSim that solve *convolution integrals*. Convolution integrals have many important applications in engineering, science and business.

The Convolution element is discussed in detail below.

What is a Convolution Integral?

Before describing how to use a Convolution element, it is first important to understand exactly what the element does mathematically, and what this mathematical operation represents conceptually.

Consider a dynamic system, in which an input signal, say x(t), enters a "black box", S, and is output as y(t):

Mathematically, we represent the "black box" system as S:

$$y(t) = S[x(0 \text{ to } t)]$$

where y(t) represents the output signal at time t, and x(0 to t) represents the time history of the input signal. If the "black box" represents a convolution, it means that S takes on the following mathematical form:

$$y(t) = S[x(0 \text{ to } t)] = \int_0^t x(\tau)\, h_\tau(t-\tau)\, \delta\tau$$

In this equation $h_\tau(t - \tau)$ is the *transfer function* (also referred to as the *impulse response function*). $t - \tau$ is referred to as the *lag*, as it represents the time lag between the input and the output time. The transfer function is given a subscript τ to indicate that the function itself may take on different forms at different points in time. That is, the response to an input impulse at $t = \tau_1$ could have a different form than the response to an impulse at $t = \tau_2$.

Convolution elements require that you supply the input signal, x(t), and the transfer function, $h(t - \tau)$. The element then computes the output signal, y(t). Note that the convolution integral is a linear operation. That is, for any two functions $x_1(t)$ and $x_2(t)$, and any constant a, the following holds:

$$S[x_1(t) + x_2(t)] = S[x_1(t)] + S[x_2(t)]$$

$$S[ax_1(t)] = a\,S[x_1(t)]$$

Having defined mathematically what a convolution integral does, let us now try to understand what it represents conceptually. Perhaps the simplest way to think about the convolution integral is that it is simply a linear superposition of response functions, $h(t - \tau_i)$, each of which is multiplied by the impulse $x(\tau_i)\delta\tau$.

A more common way to interpret the convolution integral is that the output represents a weighted sum of the present and past input values. We can see this if we write the integral in terms of a sum (and assume here that the system is discretized by a single unit of time):

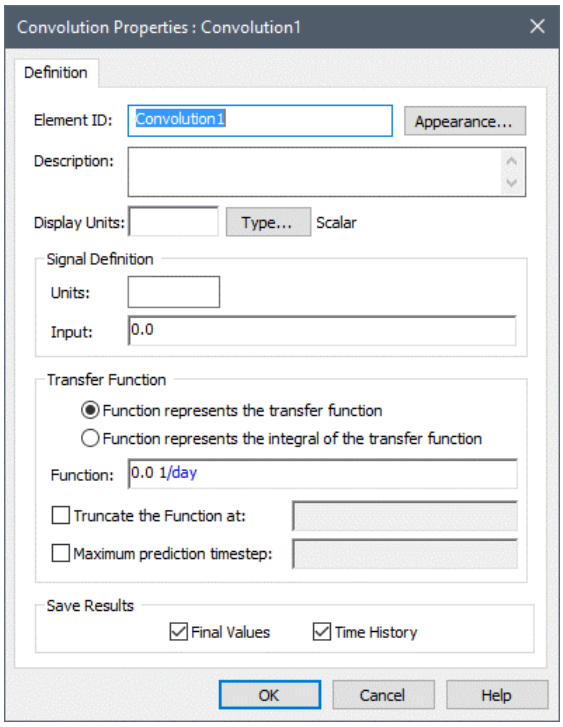
$$y(t) = x(0)h(t) + x(1)h(t-1) + x(2)h(t-2) + \ldots$$

The convolution operation may also be thought of as a *filtering* operation on the signal x(t), where the transfer function is acting as the filter. The shape of the transfer function determines which properties of the original signal x(t) are "filtered out."

Note that if the transfer function was a constant, the integral would collapse and the output signal would just be a scaled version of the input signal. Integration is necessary when the transfer function is not constant. Conceptually, this indicates that the system has memory and does not respond instantaneously to a signal. Rather, the response is delayed and spread out over time.

Using the Convolution Element

The property dialog for a Convolution element looks like this:



Convolution elements have a single output. You can specify these attributes by pressing the **Type…** button. By default, a new Convolution element is a scalar,

dimensionless value. You can also use Convolution elements to operate on and/or create vectors and matrices.

Read more: Using Vectors and Matrices (page 848); Convolution Elements Defined as Arrays (page 887).

The **Display Units** field refers to the display units of the output signal (which may have different dimensions than the input signal).

You can save the results for a Convolution element by clicking **Final Values** and/or **Time Histories**.

Under *Signal Definition*, you first specify the **Input** signal. You must also specify the dimensions of the input signal (by defining **Units**). This facilitates error checking. The **Input** signal will be a direct or indirect function of time.

You then define the Transfer **Function**. In some cases, it may be easier to define the integral of the transfer function, rather than the transfer function itself, and the two radio buttons on the dialog allow you to choose between these two options.

The transfer function essentially "spreads out" or "disperses" a unit impulse over time. In many cases, the transfer function may be a continuous function with a long "tail". That is, 99% of output produced by an impulse may be generated within 10 days of the impulse, with the remainder being spread out over the remaining 1000 days. Such a transfer function can have a significant computational impact on your model. Hence, GoldSim provides a way to "cut off" a transfer function after a certain lag time. If you check the **Truncate the Function at** checkbox, you can then enter a time after which the transfer function will be truncated. In the above example, you might, for example, specify this as 10 days. This input can be a function of time (e.g., if the transfer function changes with time, you may need to adjust the truncation time accordingly).

The Convolution element works by generating and continuously adding to a projected future history of its output. At each timestep the incremental input is convolved with the transfer function and added to that output history. The history stores projected results for every scheduled timestep of the model, and also inserts additional points where necessary to ensure that the difference between successive time points is never greater than 10% of the **Truncate the Function at** value.

However, if your model generates unscheduled updates and if the duration of the transfer function is short, it is possible that the projected future history will not have enough time points to deliver accurate results. In this situation you can use the optional input **Maximum prediction timestep** to ensure sufficient accuracy of this history. The must be specified as a time, and cannot have any links. It should be short enough so that it can reasonably approximate the shape of the transfer function.

Note that in the definition of a convolution integral, the transfer function is mathematically defined not as a function of time, but as a function of a time difference, $(t - \tau)$, or lag time. In order to write such an equation in GoldSim, you reference the time difference $t - \tau$ using a special locally available property of the Convolution element called "Lag". It must be referenced as "~Lag".

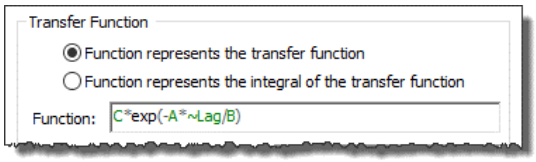
Note: As indicated by the way it is referenced, the Lag is an example of a locally available property. As such, it only has meaning inside the Transfer **Function** field, and cannot be referenced anywhere else.

Read more: Understanding Locally Available Properties (page 874).

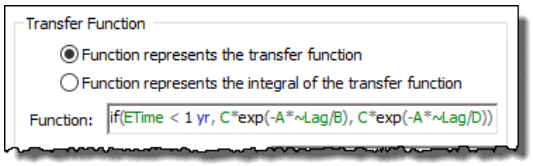
For example, if your transfer function was the following equation:

$$h(t-\tau) = Ce^{-a(t-\tau)/b}$$

then you would reference the lag time (t – τ) as "~Lag":



The transfer function does not have to be time-invariant. That is, the function can be defined to change as a function of time. Referring to the example above, if the response was different at later times in the simulation (e.g., after 1 yr), the transfer function could be written as follows:



GoldSim checks to ensure that the dimensions of the various inputs and outputs are related as follows:

Output = Transfer Function * Input Signal * time

If the integral of the transfer function is specified, GoldSim checks to ensure that the dimensions of the various inputs and outputs are related as follows:

Output = Integral of Transfer Function * Input Signal

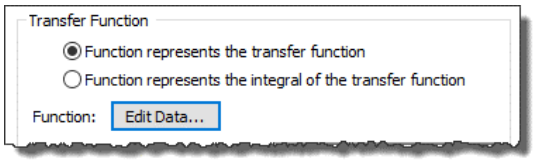
For example, if the element display units were specified as $ and the input signal display units were specified as g/yr, then GoldSim would require that the transfer function had dimensions of currency/mass (e.g., $/g).

Several points should be noted regarding the numerical implementation of the Convolution element within GoldSim:

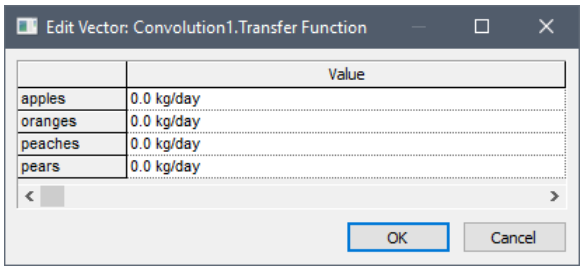
- During the numerical integration, GoldSim does not actually start the integration from 0. Instead, it starts the integration from a very small number. This allows the transfer function to be a function of the inverse of the lag without causing numerical problems (i.e., divide by zero errors)
- The numerical integration approach used by GoldSim assumes that the input function varies linearly between time steps; and
- To have acceptable accuracy, the simulation timestep should be short relative to the rate of change of the transfer function. Note, however, that your model may run much slower if the timestep is too small, as the computational effort for solving a Convolution element goes up as the square of the number of timesteps.

Convolution Elements Defined as Arrays

A convolution element can be defined to output an array. In this case, the dialog appears like this:



In this case, the Input Signal must be specified as an array. Pressing the **Edit Vector…** button (or **Edit Matrix…**button if it is a matrix) provides access to a dialog for defining the scalar transfer function for each separate item of the array:



Examples of the Use of the Convolution Element

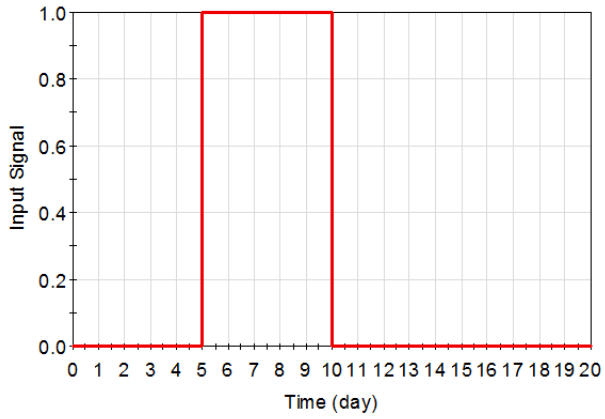
In order to fully understand how to use Convolution elements, it is helpful to explore several examples. The three examples discussed here can be found in the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu), in a file named Convolution.gsm.

We examine three simple examples below:

- A simple filter;
- Computing costs associated with warranties; and
- Computing response of a structure due to an earthquake.

Convolution Example: A Simple Filter

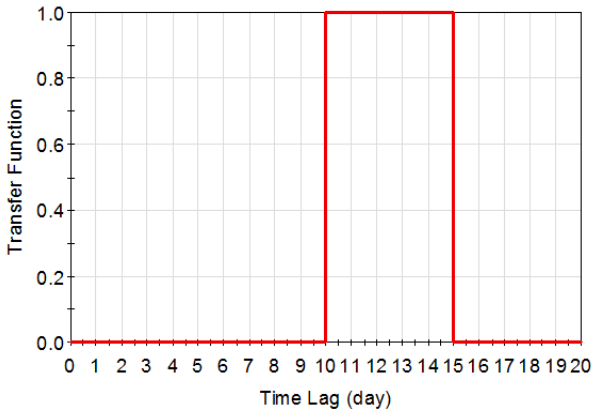
This example shows how a simple input signal can be filtered to alter its shape. In this example, the input signal is a square "boxcar" function:



Mathematically, this can be expressed in GoldSim as follows:

If(ETime < 5 days OR ETime > 10 days, 0, 1)

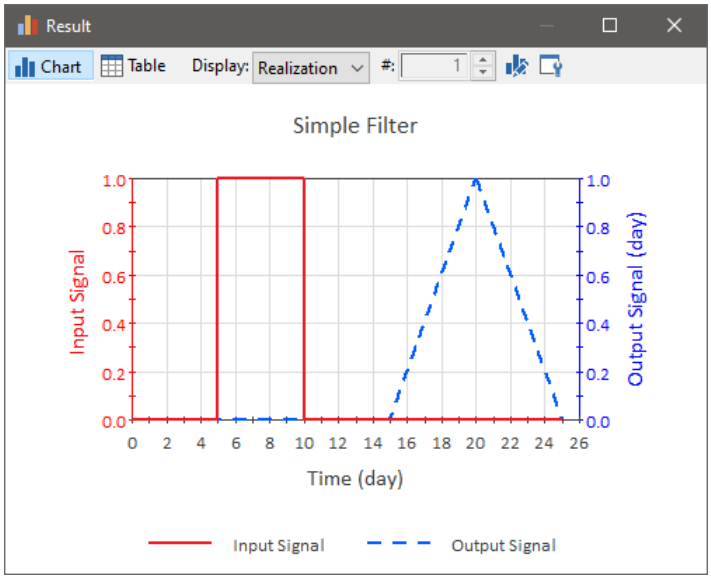
The Transfer function is also a square "boxcar" function, in which any impulse is delayed for 10 days, and then spread out evenly over 5 days:



Mathematically, this can be expressed in GoldSim as follows:

If(~Lag < 10 days OR ~Lag > 15 days, 0, 0.2)

This input signal and transfer function produce the following output signal:

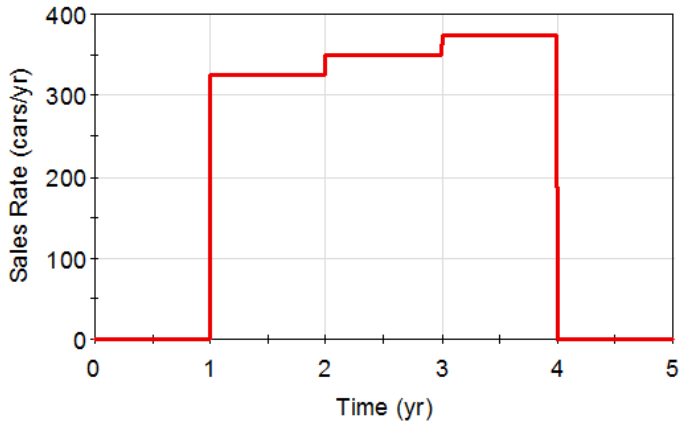


Note that the output signal in this case has dimensions of time (since the input signal and the transfer function were defined as being dimensionless).

Convolution Example: Warranty Costs

This example shows how warranty costs for a product (e.g., a vehicle) can be computed based on a product sales rate and the expected warranty cost time history for a product using a Convolution element.

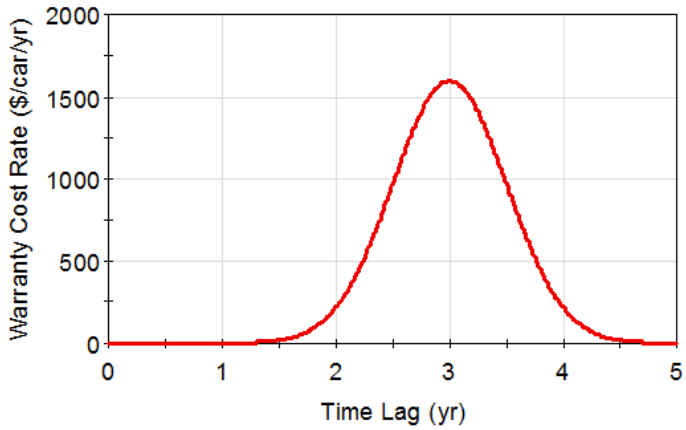
In this example, the input signal is the sales rate of the vehicle:



Sales will start one year in the future, and ramp slowly up for three years. The vehicle is only assumed to be produced for three years.

This can be entered into GoldSim as a Time Series.

The Transfer function represents, on average, how warranty costs are expected to be incurred in the future (per vehicle):



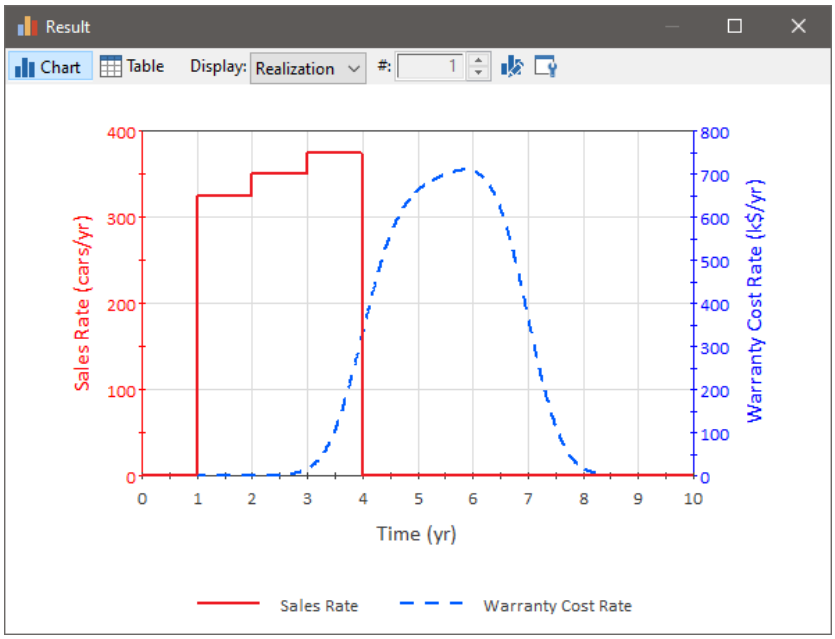
This curve indicates that warranty costs start to be incurred about 1.5 years after the sale, reach a peak at 3 years after the sale, and no more costs can be expected to occur after about 4.5 years after the sale. Note that the units on the transfer function are $/car/yr (the curve integrates to 2000 $/car).

The output signal will then have dimensions of $/yr:

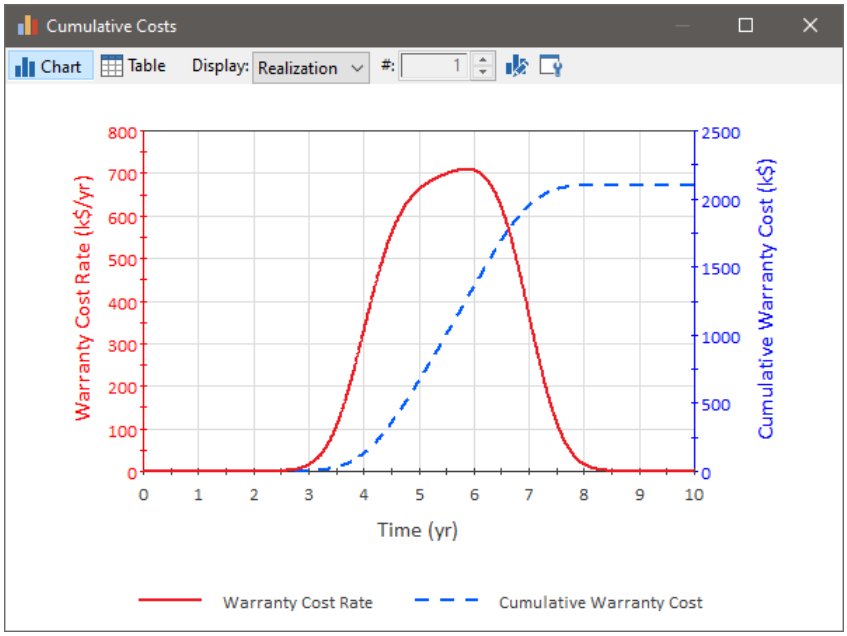
Output = Transfer Function * Input Signal * time

Output = $/car/yr * cars/yr * yr = $/yr

That is, the output represents the rate at which we can expect to incur warranty costs for all of the vehicles sold:



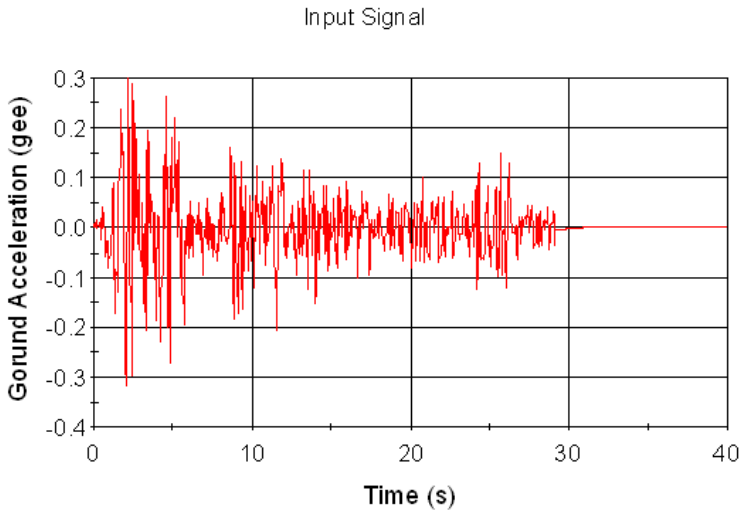
If we integrate the warranty cost rate (using an Integrator), we can compute the cumulative warranty costs:



Convolution Example: Earthquake Response

This example shows how a Convolution element can be used to simulate how a structure responds to an earthquake. The input signal is an accelerogram (a time history of ground accelerations). The output signal is the displacement of a building (illustrating how the building oscillates from side to side in response to the earthquake).

The input signal (the accelerogram) is taken from an actual earthquake in Southern California in 1940 (the El Centro earthquake):

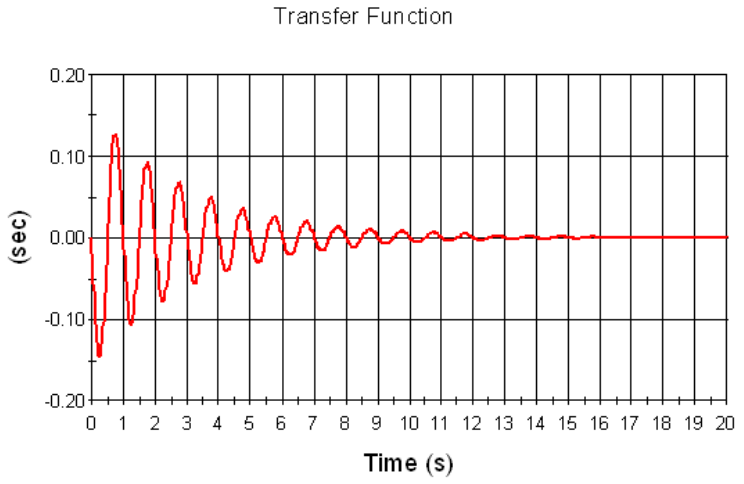


As can be seen, the earthquake lasted about 30 seconds.

For simplicity, the building is treated as a damped spring. The transfer function under such an assumption is represented by the following equation:

$$\frac{-e^{[-n(t-\tau)]}}{W_d}\sin[W_d(t-\tau)]$$

where n is the coefficient of decay (in radians/sec), and W_d is the damped frequency (in radians/sec). A plot of this transfer function looks like this:



The transfer function represents the ratio of a displacement response to a "pulse" of ground velocity, and has dimensions of time.

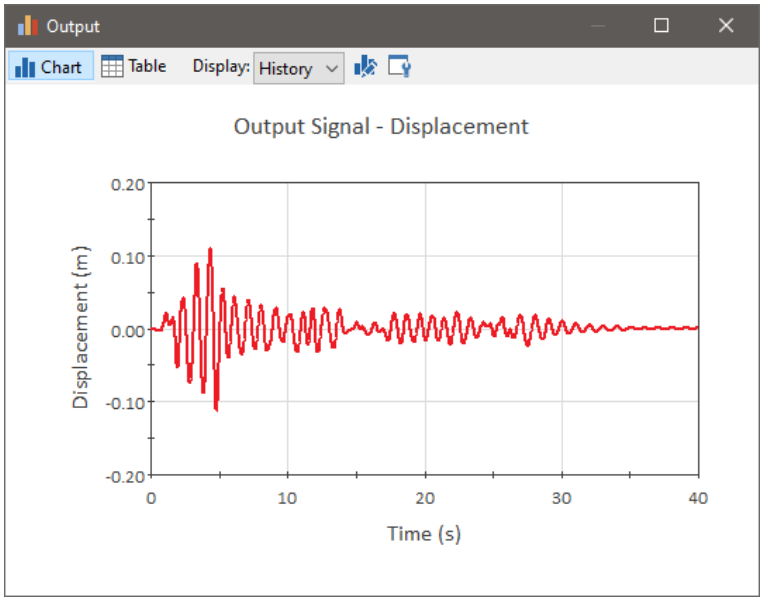
This curve indicates that once excited by an impulse, the building oscillates with the oscillations dying out within about 15 seconds.

The output signal will have dimensions of length:

Output = Transfer Function * Input Signal * time

Output = sec * m/sec^2 * sec = m

That is, the output represents the displacement of the building in response to the earthquake:



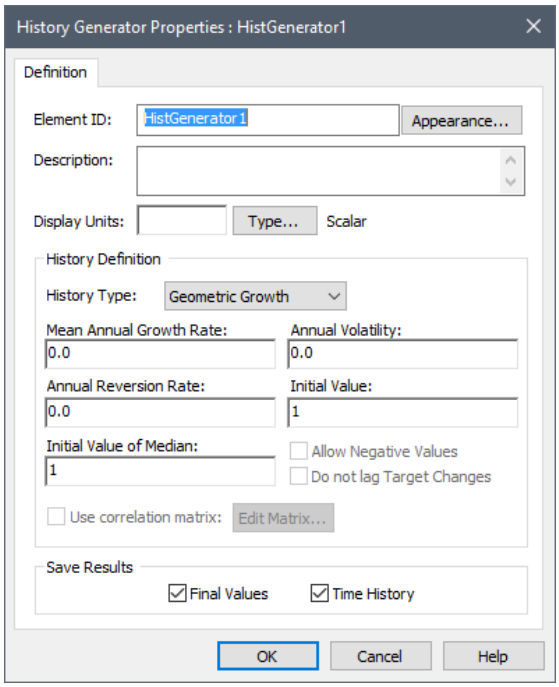
Generating Stochastic Time Histories

It is sometimes necessary to generate stochastic time histories of variables. A stochastic time history is a random time history that is generated according to a specified set of statistics. For example, for one type of stochastic time history, the "random walk", the variable can be thought of as taking successive steps, each in a random direction. The overall trend (up or down) and the size of the steps are controlled by the statistical measures specified by the user.

GoldSim provides a specialized element to generate such time histories, the History Generator. This element is primarily envisioned as a tool to allow users to simulate financial and economic variables (e.g., security prices, interest rates), but has many applications in other arenas.

The default icon for the History Generator element looks like this:

The property dialog looks like this:



Like all GoldSim elements, you first specify an **Element ID** and a **Description**.

Below the **Description** field, you specify the **Display Units** you wish to use.

To the right of the **Display Units**, you can specify the **Type**. By default, a History Generator provides a scalar output (and requires scalar inputs). However, via this button, you can also specify it to have vector (1-D array) output (and require vector inputs).

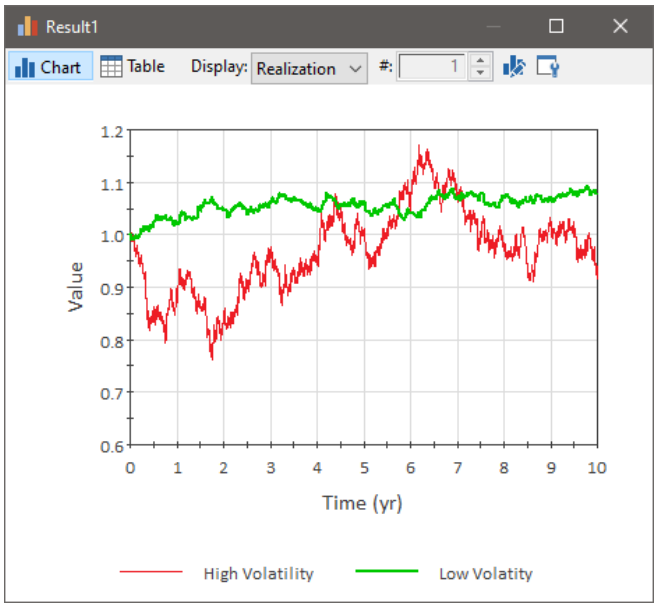
The "History Definition" portion of the History Generator dialog is used to specify the characteristics of the stochastic history. The **History Type** field is used to select the general type of stochastic history. GoldSim currently provides two options: "Geometric Growth" and "Random Walk". The details of how the History Definition fields are specified are provided below.

An example file which illustrates the use of History Generator elements (HistoryGenerator.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Types of Stochastic Time Histories

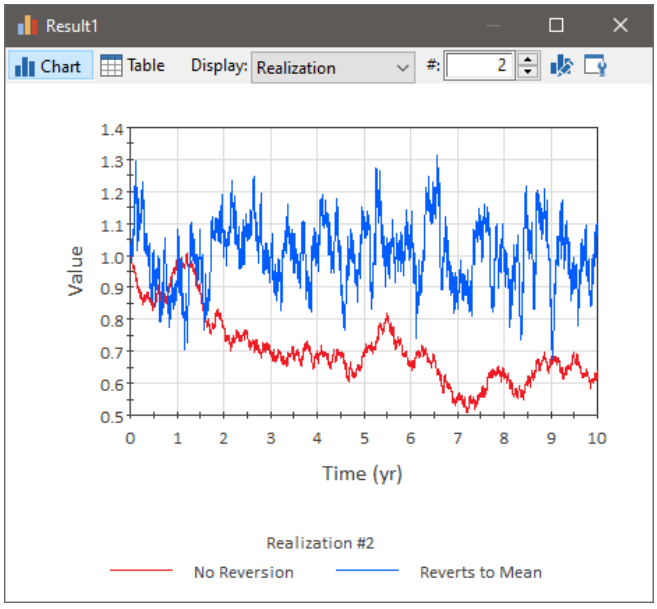
Before creating stochastic time histories using the History Generator element, it is instructive to briefly summarize the different kinds of time histories that can be generated.

Consider the stochastic time histories below:



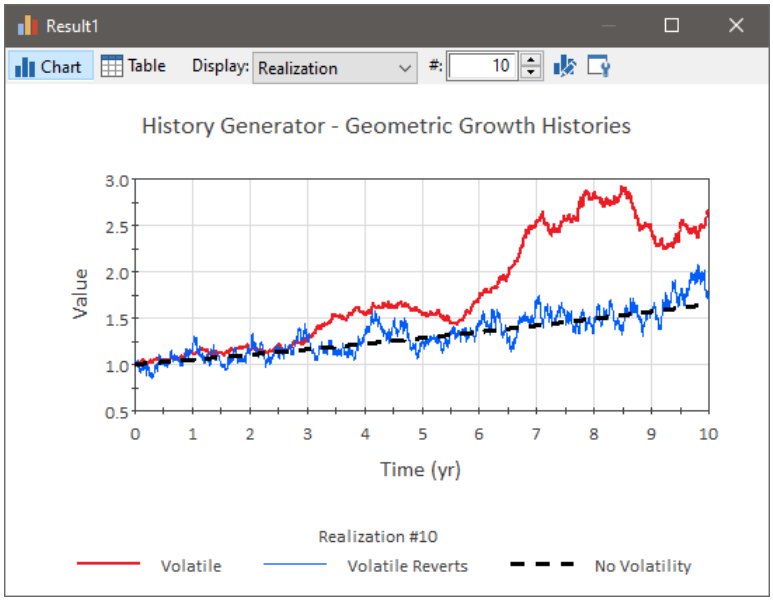
These are random histories that follow no particular trend. They simply randomly walk through time. Clearly one of the curves has larger random fluctuations than the other. For certain types of variables (e.g., stock prices), the variability of the time history as a function of time is described in terms of a volatility. The history with greater fluctuations is said to be more "volatile".

Note that the volatility is often a function of the unit of time on which it is based. In the examples shown above, the volatility increases with time (i.e., the annual volatility is greater than the daily volatility). For other types of stochastic variables, however, the volatility may stay constant with time. In the example below, the variable represented by the upper curve is target-reverting. That is, the value reverts to some underlying target (in this case, a constant value of 1). As a result, the volatility is constant in time.



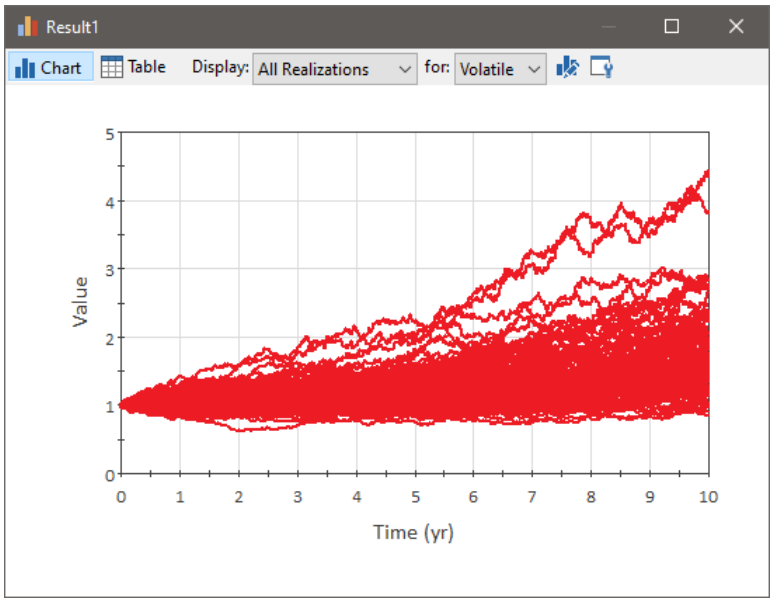
The histories in the two examples above either move randomly through time, or move randomly around some constant target. Other stochastic histories may follow a trend.

The histories below grow geometrically at a rate of 5% per year (this is referred to as geometric Brownian motion):

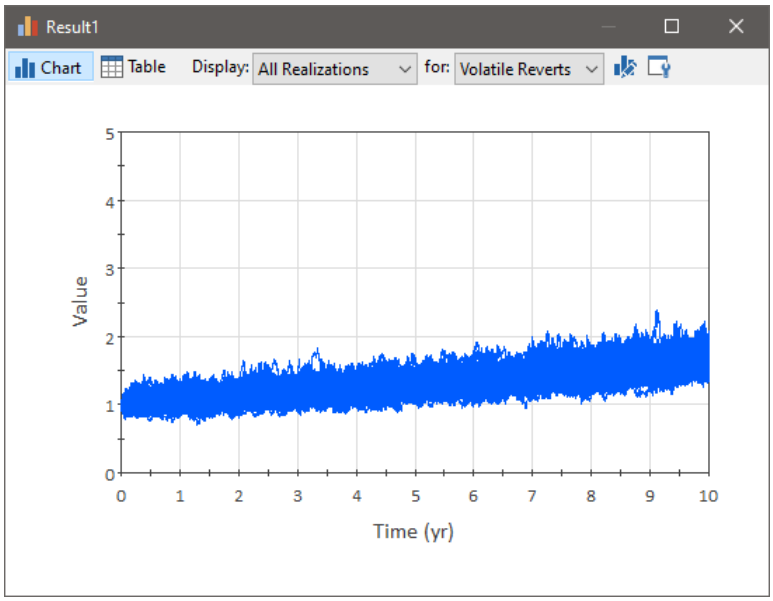


The dark smooth line is growth with no volatility. The other two lines both are volatile. In one, the volatility grows with time. In the other, the volatility stays constant.

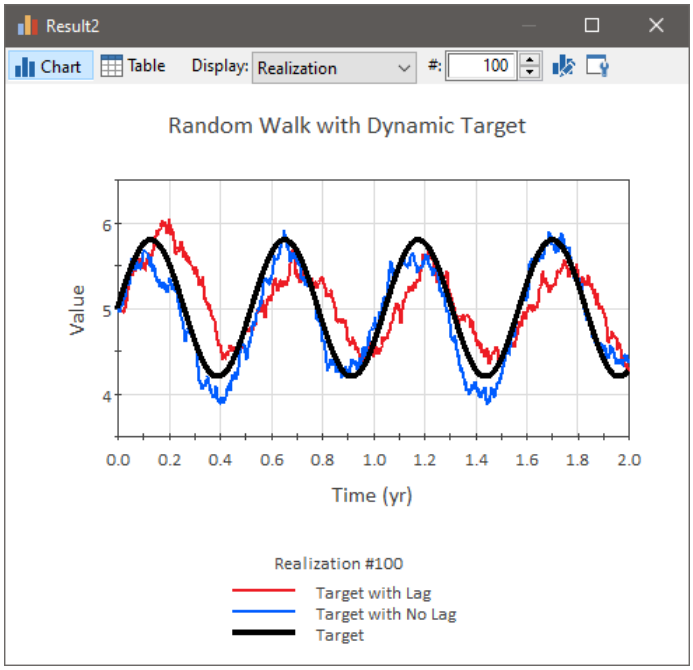
If we were to run multiple realizations of the time history whose volatility grows with time, the growth in the volatility as a function of time would be more noticeable:



Compare this to multiple realizations of the time history whose volatility stays constant with time:



Of course, the underlying trend does not need to be growth (positive or negative). The histories below follow a cyclical trend:

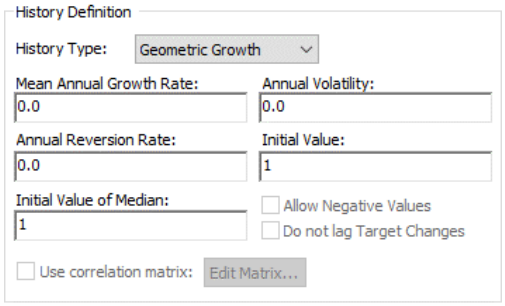


The dark smooth line is the signal with no volatility. The other two lines are both volatile. In one, the history lags the underlying trend. In the other, there is no lag.

The History Generator element can be used to generate all of these types of stochastic time histories.

Generating Geometric Growth Histories

Selecting "Geometric Growth" for the **History Type** field of a History Generator element allows you to define a history that grows geometrically with time. This means that the rate of growth and the amount of volatility are proportional to the current value. Among other things, this type of history is appropriate for variables such as security prices.



In its simplest form, this type of history requires three inputs (**Mean Annual Growth Rate**, **Annual Volatility**, and **Initial Value**). The other two inputs (**Annual Reversion Rate** and **Initial Value of Median)** are only required if you wish the history to revert toward its median (and this is discussed in the next section).

Mean Annual Growth Rate. This is the mean annual *logarithmic* growth rate (μ'), where V_i is the value at time i:

$$\mu' = \frac{\sum_{i=t-n+1}^{t} \ln\left(\frac{V_{i+1}}{V_i}\right)}{n}$$

Although this is a rate (i.e., time-based), because it is "hard-wired" to be an annual value, this input is dimensionless. That is, it represents the logarithmic growth rate over a year. It can be positive, negative, or zero.

If the logarithmic growth rate is measured over a different time period (e.g., monthly), this can be scaled by direct multiplication. For example a mean monthly logarithmic growth rate can be converted to a mean annual logarithmic growth rate by multiplying it by 12.

Annual Volatility. This is the standard deviation of the annual logarithmic growth rate (σ'):

$$\sigma' = \sqrt{\frac{\sum_{i=t-n+1}^{t} \left[\ln\left(\frac{V_{i+1}}{V_i}\right) - \mu'_t\right]^2}{n-1}}$$

This is a dimensionless value that must be non-negative.

Note: As pointed out above, the volatility for a geometric growth history is, by definition, dimensionless. This is different than the volatility for a random walk history, which has dimensions.

If the logarithmic volatility is measured over a different time period (e.g., monthly), and the rate of reversion to the median is zero, this can be scaled by the square root of the time period. For example, a mean monthly logarithmic volatility can be converted to a mean annual logarithmic volatility by multiplying it by √12.

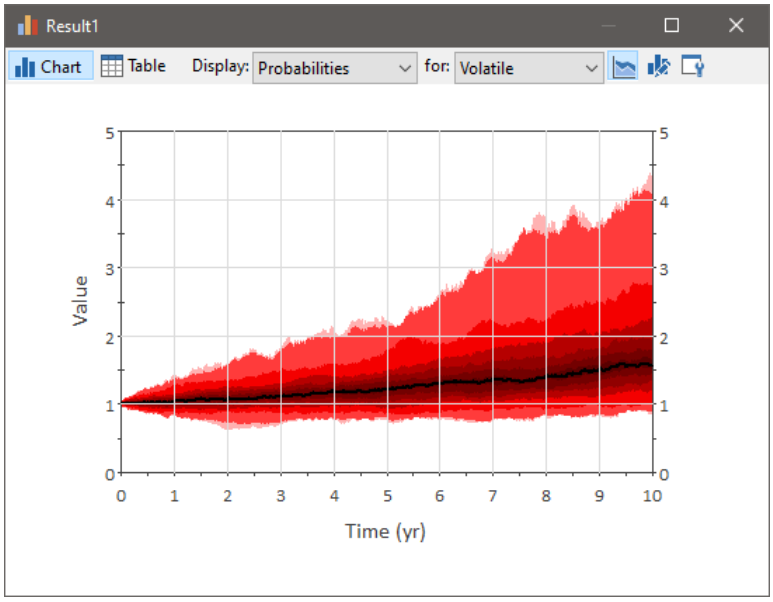
Initial Value. This is the initial value of the time history (the value at time zero). It has the same dimensions as the output. It must be a positive number.

If the **Annual Reversion Rate** is set to zero (the default), GoldSim generates successive values as follows:

$$V_{new} = V_{old} \exp\left(\mu' \Delta t + \varepsilon \sigma' \sqrt{\Delta t}\right)$$

where V_{new} is the new value, V_{old} is the previous value, Δt is the time between the two values, ε is a random standard normal value (sampled from a distribution with mean 0 and standard deviation 1), and μ' and σ' are as defined above.

For constant values of the **Mean Annual Growth Rate** and **Mean Annual Volatility**, this results in a history that (on average) grows exponentially, and whose standard deviation of the logs increases as the square root of time:



At any given time, the distribution of values is log-normal.

The logarithmic input definitions for the Growth Rate and Volatility, as used by GoldSim, are those typically used by academic financial analysts. However, it may be difficult to find data expressed using these formal definitions. Some simple approaches for converting available data to these forms are as follows:

Converting from Geometric Mean Returns. Typically, the performance of individual securities is reported as "average annual total returns". Mathematically, this actually represents the geometric mean of the annual returns over a period:

$$\mu_g = \left(\prod_{i=t-n+1}^{t} \left(\frac{V_{i+1} - V_i}{V_i} + 1 \right) \right)^{1/n} - 1$$

You can use GoldSim's built in gm2cm function to convert a geometric mean annual return to an arithmetic mean log annual return.

If the standard deviation of the average annual total returns is also available:

$$\sigma = \sqrt{\frac{\sum_{i=t-n+1}^{t}\left[\left(\frac{V_{i+1}-V_i}{V_i}\right)-\mu_a\right]^2}{n-1}},$$

$$\text{where } \mu_a = \frac{\sum_{i=t-n+1}^{t}\left(\frac{V_{i+1}-V_i}{V_i}\right)}{n}$$

then this can be used (in conjunction with the geometric mean of the returns) to compute the volatility using GoldSim's geo2vol function.

Read more: Financial Functions (page 130).

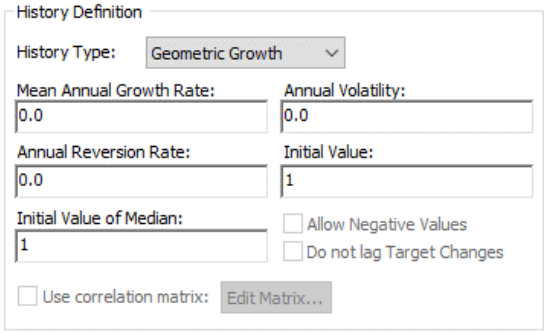
Converting from Arithmetic Mean Returns. In some cases, you may have return rate statistics reported in terms of the arithmetic mean of the annual return over a period (μ_a, defined above).

You can use GoldSim's built in ari2cm function to convert an arithmetic mean annual return (and a standard deviation) to an arithmetic mean log annual return, and the ari2vol function to convert a standard deviation (and an arithmetic mean) of the annual return to the standard deviation of the log annual return (the volatility).

Generating Geometric Growth Histories with Median Reversion

By default, the standard deviation of a geometric growth type history increases with the square root of time. In some cases, when simulating a stochastic history that increases geometrically, you may not want the standard deviation to grow in this way. Rather, you may want it to stabilize at a constant value.

You can accomplish this by forcing the stochastic history to revert towards its median value at a specified rate. To do so, you must use the **Annual Reversion Rate** and **Initial Value of Median** input fields.



Annual Reversion Rate. This is the annual fractional rate at which the history reverts towards its median. Although this is a rate, because it is "hard-wired" to an annual value, this input is dimensionless. That is, it represents the fractional rate per year. It must be non-negative.

Initial Value of Median. In most cases, the initial value of the time history is unlikely to be at the median. Hence, this is the initial value of the median of the time history (the value at time zero). It has the same dimensions as the output. It must be a positive number.

If the **Annual Reversion Rate** is non-zero, GoldSim generates successive values as follows:

$$V_{new} = V_{old} \exp\left(\mu' \Delta t + \left(1 - e^{-r\,\Delta t}\right)\left(\ln T_{old} - \ln V_{old}\right) + \varepsilon\sigma' \sqrt{\frac{1 - e^{-2\,r\,\Delta t}}{1 - e^{-2\,r\,(1\,yr)}}} \right)$$

where V_{new} is the new value, V_{old} is the previous value, Δt is the time (in years) between the two values, ε is a random standard normal value (sampled from a distribution with mean 0 and standard deviation 1), r is the reversion rate, and μ' and σ' are the logarithmic growth rate and volatility, respectively. T is the median (a function that grows geometrically from the specified Initial Value of Median using the mean annual growth rate). T_{old} is the previous value of the median.

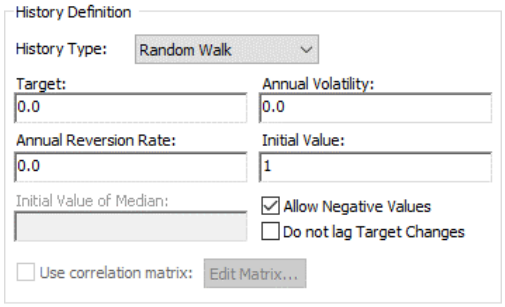
In practical terms, specifying a non-zero Annual Reversion Rate has two effects:

- The history tracks the median, and if the Initial Value differs from the Initial Value of Median, the history approaches the median history with a half-life of ln(2)/Annual Reversion Rate.
- The standard deviation of the logs initially grows, approaching a constant value with a similar half-life. The "steady-state" standard deviation of the log of the values stabilizes at a value of:

$$\sigma' \sqrt{\frac{1}{1 - e^{-2\,r}}}$$

Generating Random Walk Histories

Selecting "Random Walk" for the **History Type** field of a History Generator element allows you to define a history that randomly walks through time.



In its simplest form, this type of history requires two inputs (**Annual Volatility**, and **Initial Value**). The other two inputs (**Target** and **Annual Reversion Rate**) are only required if you wish the history to track an underlying target or trend (and this is discussed in the next section).

Annual Volatility. This is the standard deviation of the annual values (σ):

$$\sigma = \sqrt{\frac{\sum_{i=t-n}^{t} [V_i - \mu]^2}{n-1}}$$

where μ is the mean of the annual values:

$$\mu = \frac{\sum_{i=t-n}^{t} V_i}{n}$$

If the volatility is measured over a different time period (e.g., monthly), this can be scaled by direct multiplication. For example a mean monthly volatility can be converted to a mean annual volatility by multiplying it by $\sqrt{12}$.

It has the same dimensions as the output, and must be non-negative.

Initial Value. This is the initial value of the time history (the value at time zero). It has the same dimensions as the output and can be positive, negative or zero.

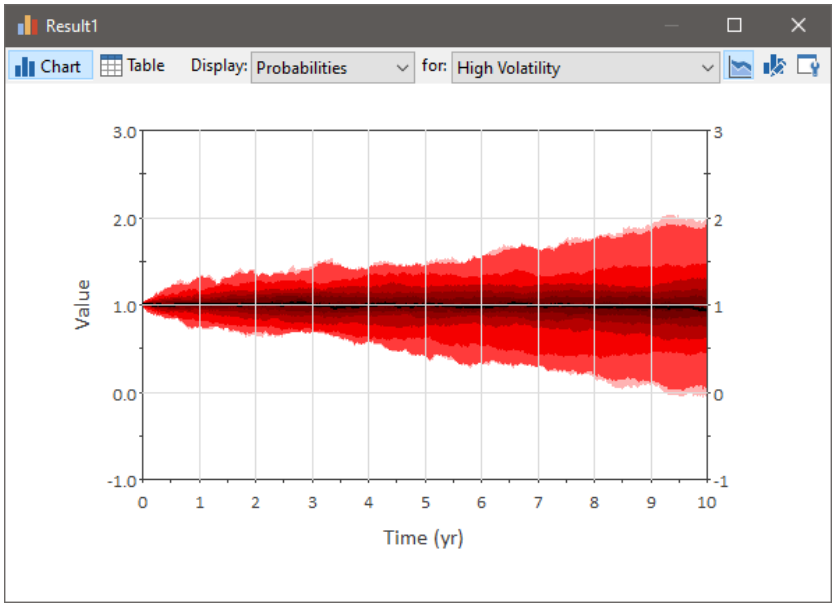
You can control whether your history can take on negative values using the **Allow Negative Values** checkbox (which defaults on). If this box is cleared, negative values are "truncated". Note that this has the effect of artificially reducing the standard deviation of the values.

If the **Annual Reversion Rate** is set to zero (the default), GoldSim generates successive values as follows:

$$V_{new} = V_{old} + \varepsilon\sigma\sqrt{\Delta t}$$

where V_{new} is the new value, V_{old} is the previous value, Δt is the time (in years) between the two values, ε is a random standard normal value (sampled from a distribution with mean 0 and standard deviation 1), and σ is the volatility.

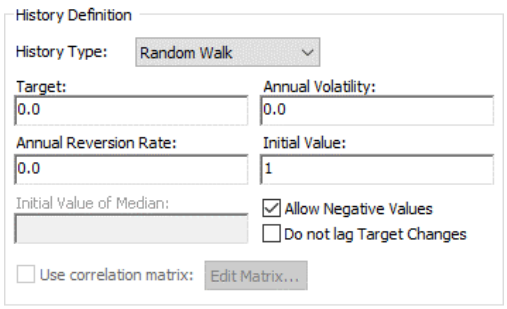
For constant values of the **Annual Volatility**, this results in a history whose standard deviation increases as the square root of time.



Generating Random Walk Histories with Target Reversion

By default, the standard deviation of a random walk type history increases with the square root of time. In some cases, when simulating such a history, you may not want the standard deviation to grow with time. Rather, you may want it to stabilize to a constant value around an underlying target.

You can accomplish this by forcing the stochastic history to revert towards a target value at a specified rate. To do so, you must use the **Annual Reversion Rate** and **Target** input fields.



Target. This is the underlying target that the history will revert to (i.e., track). It can be a constant value or a function of time. It has the same dimensions as the output. It can take on any value.

Annual Reversion Rate. This is the annual fractional rate at which the history reverts to its target. Although this is a rate, because it is "hard-wired" to an annual value, this input is dimensionless. That is, it represents the fractional rate per year. It must be non-negative.

If the **Annual Reversion Rate** is non-zero, GoldSim generates successive values as follows:

$$V_{new} = V_{old} + \left(1 - e^{-r\,\Delta t}\right)\left(T_{new} - V_{old}\right) + \varepsilon\sigma\sqrt{\frac{1 - e^{-2\,r\,\Delta t}}{1 - e^{-2\,r\,(1yr)}}}$$

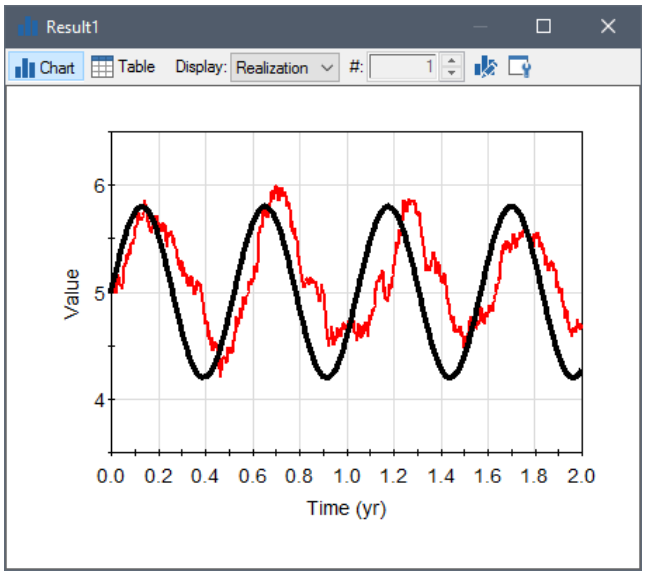
where V_{new} is the new value, V_{old} is the previous value, Δt is the time (in years) between the two values, ε is a random standard normal value (sampled from a distribution with mean 0 and standard deviation 1), r is the reversion rate, and σ is the volatility. T_{new} is the current (new) value of the underlying target (which may change with time).

In practical terms, specifying a non-zero Annual Reversion Rate has two effects:

- The history tracks the target, and if the Initial Value differs from the initial value of the Target, the history approaches the target history with a half-life of ln(2)/Annual Reversion Rate.
- The standard deviation initially grows, but eventually stabilizes to a constant value with a similar half-life. The "steady-state" standard deviation stabilizes at a value of:

$$\sigma\sqrt{\frac{1}{1 - e^{-2\,r}}}$$

By default, when an Annual Reversion Rate is specified, the history actually lags the target, and as a result, the signal is "dispersed" such that the peaks and valleys of the history are (on average) smaller than that of the target:

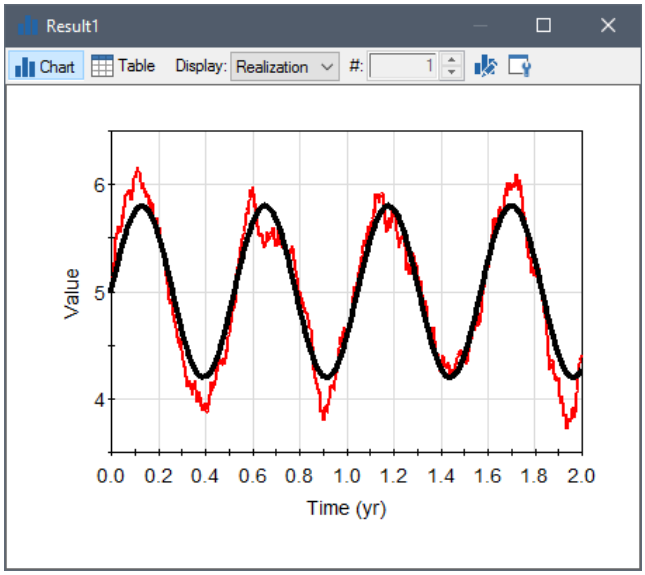


The time lag increases as the **Annual Reversion Rate** decreases.

In some cases, you may not want such a time lag. The **Do not lag Target Changes** checkbox (if checked) eliminates this lag. In this case, GoldSim generates successive values as follows:

$$V_{new} = V_{old} + \left(1 - e^{-r\,\Delta t}\right)\left(T_{old} - V_{old}\right) + \varepsilon\sigma\sqrt{\frac{1 - e^{-2r\,\Delta t}}{1 - e^{-2r\,(1yr)}}} + \left(T_{new} - T_{old}\right)$$

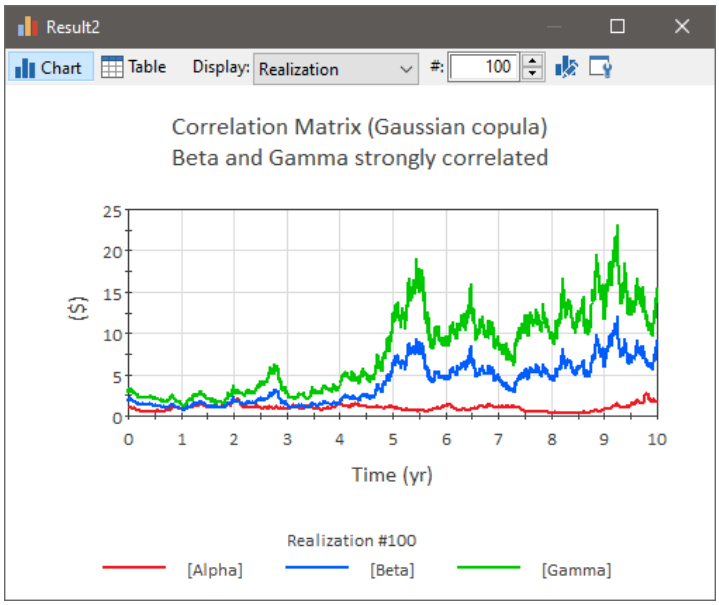
As can be seen below, this has the impact of eliminating the lag (and the dispersion):



Simulating Correlated Arrays of Stochastic Histories

A History Generator can be specified to represent a 1-D array of variables (i.e., a vector). In this case, the various input parameters must be specified as vectors.

This most common application of this is to simulate an array of correlated variables (e.g., a portfolio of investments). When variables are correlated, their random movements (as typically quantified by the volatility) are linked to a greater or lesser degree. For example, consider the three time series below:



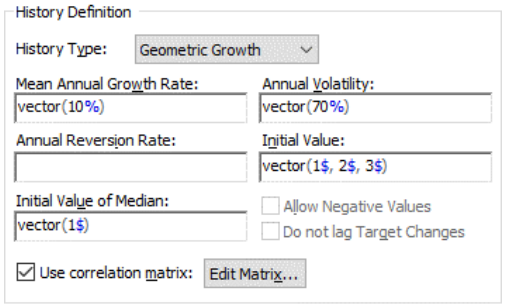
In this example, the volatile movements of Beta and Gamma are strongly correlated, and are both uncorrelated to Alpha.

The correlations between the members of an array are specified via a correlation matrix. A correlation matrix specifies the correlations between variables, and generally has the following form:

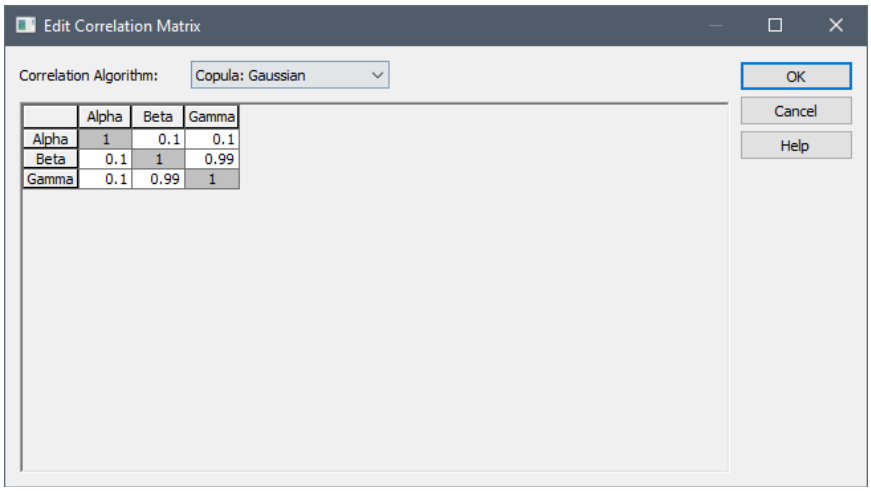
	Alpha	Beta	Gamma
Alpha	1	0.1	0.1
Beta	0.1	1	0.99
Gamma	0.1	0.99	1

Note that by definition, a correlation matrix is symmetric around its diagonal (since the cross diagonal terms define the same correlation coefficient).

If you specify that the History Generator represents a 1-D array of variables (i.e., a vector), then the **Use correlation matrix** checkbox becomes available on the History Generator dialog:



If this box is checked, the **Edit Matrix…** button becomes available. This button provides access to a dialog for specifying the correlation matrix:



By default, all off-diagonal correlation coefficients are zero. The matrix is symmetrical, so you need only define one of the cross-diagonal terms. The value represents a rank correlation coefficient, and must vary between -1 and 1. It must be a number (i.e., you cannot specify a link).

Note: When you define a correlation matrix, it is important to ensure that it is internally consistent. For example, if you specified that A was positively correlated to B, and B was positively correlated to C, but that A was negatively correlated to C, the correlation matrix would be inconsistent (since in this case, A should also be positively correlated to C). When this occurs, GoldSim will produce a fatal error message.

GoldSim provides several different algorithms for correlating the members of the vector. These are selected from the **Correlation Algorithm** drop-list at the top of the dialog. The various correlations algorithms are discussed in detail in Appendix B.

Using Resources

One of the advanced features in GoldSim is the ability to create and interact with Resources. A ***Resource*** is something that has a limited supply (e.g., spare parts, fuel, skilled personnel, money) and is required in order for elements of the modeled system to carry out certain actions.

For example, in order for a manufacturing process to proceed, perhaps two different parts and a skilled operator must be available. This could be modeled by defining an Event Delay (to represent the process) with three Resource requirements that must be met in order for the element to process the event.

Alternatively, in order for a project task to continue to operate, perhaps a certain amount of cash must be available. This could be modeled by defining a Conditional Container (to represent the task) with a single Resource requirement (a spend rate) that must be met in order for the task to continue (i.e, for the Container to stay active).

Only certain elements in GoldSim can interact with Resources (two of these are mentioned in the examples above: an Event Delay and a Conditional Container). Elements can consume, borrow, and in some cases, generate Resources.

Using Resources involves three different steps:

- You must define a Resource Type (e.g., Gasoline, Electricians, Pump Motors) and specify its characteristics (discrete or continuous).
- You must specify where the ***Stores*** for that particular Resource exist in your model. Stores represent stockpiles or places where the actual Resource (e.g., parts, personnel) is stored or located when not being used. That is, Resource Stores can be thought of as having physical locations in the system you are modeling.
- You must specify how particular elements in the model interact with (consume, borrow from, or add to) the Resource Stores.

The sections below discuss the use of Resources in detail.

A simple example which illustrates the use of Resources (Resources.gsm) can be found in the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Defining Resource Types and Creating Resource Stores

A ***Resource*** is something that has a limited supply (e.g., spare parts, fuel, skilled personnel, money) and is required in order for elements of the modeled system to carry out certain actions.

Creating a Resource requires two distinct steps:

1. First you must define the type of Resource (e.g., Gasoline, Electricians, Pumps, Motors) and specify its characteristics (discrete or continuous).
2. Then you must specify where the ***Stores*** for that particular Resource exist in your model.

Stores represent stockpiles or places where the actual Resource (e.g., parts, personnel) is stored or located when not being used. That is, Resource Stores can be thought of as having physical locations in the system you are modeling.

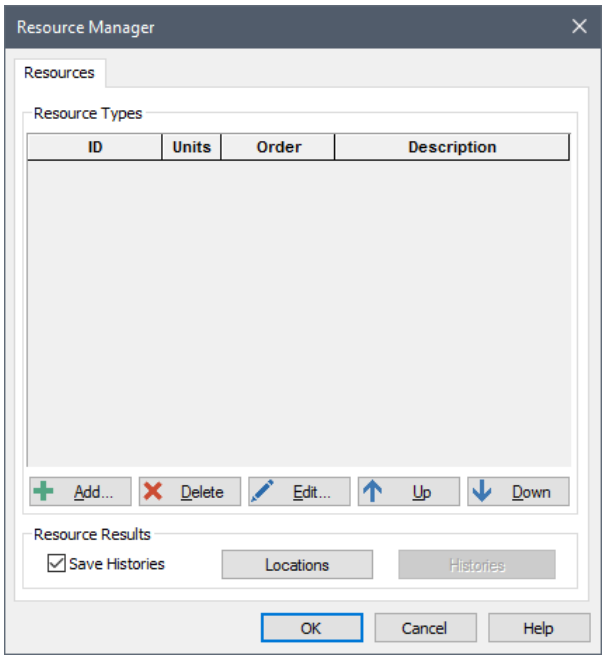
There are two types of Stores that can be created: ***Global Stores*** and ***Local Stores***. Global Stores are available to all elements in your model. Local Stores are associated with specific Containers, and are only available to elements inside the Container (or in the case of a Conditional Container, to the Container itself).

A Resource Type can have multiple Stores in a model. For example, you could define multiple Local Stores, or perhaps a Global Store and several Local Stores.

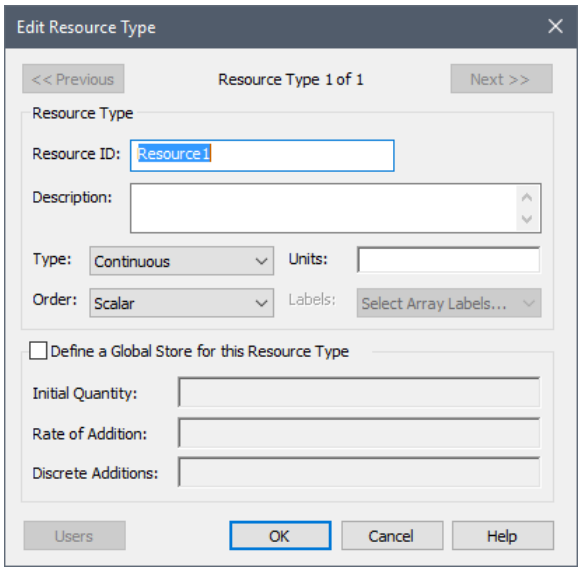
These two steps are described in the sections below.

Defining and Editing Resource Types

You define or edit Resource types by using the Resource Manager, which is accessed via the main menu (**Model | Resources…**) or by pressing **F8**. The following dialog will be displayed:



Pressing the **Add…** button displays the following dialog for defining a new Resource Type:



Each Resource Type requires a unique **Resource ID**. Resource IDs follow the same rules as elements names (e.g., no spaces, letters, only numbers and the underscore character can be used; cannot start with a number). You should also provide a brief **Description**.

A Resource has the following attributes:

Type: This can be "Continuous" or "Items". Continuous should be used for things that are not discrete (e.g., fuel). Items should be specified for things that are discrete (e.g., parts, personnel).

Units: If the Resource is specified as Continuous, in most cases you will want to specify units (e.g., m^3, kg). If the Resource is specified as Items, units are not applicable.

Order: A Resource can be defined as a scalar or a vector. Defining a Resource as a vector is most useful, for example, if you have a large number of individual parts. Defining these as a vector is much easier than defining a separate Resource for each part.

Read more: Using Vectors and Matrices (page 848).

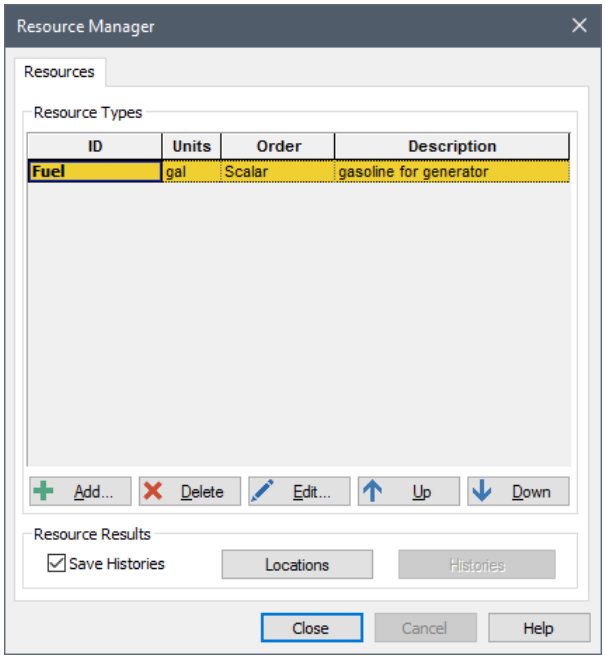
Labels: If you define the Resource as a vector, you need to specify a set of Array Labels from the Labels drop-list.

Read more: Understanding Array Labels (page 849).

Note: The bottom part of the dialog provides an option to create a "Global Store" of this particular Resource. This is discussed in detail in the next section.

If multiple Resource Types are defined, you can move between them using the **Previous** and **Next** buttons.

After you have finished defining the Resource, press the **OK** button to return to the Resource Manager dialog:

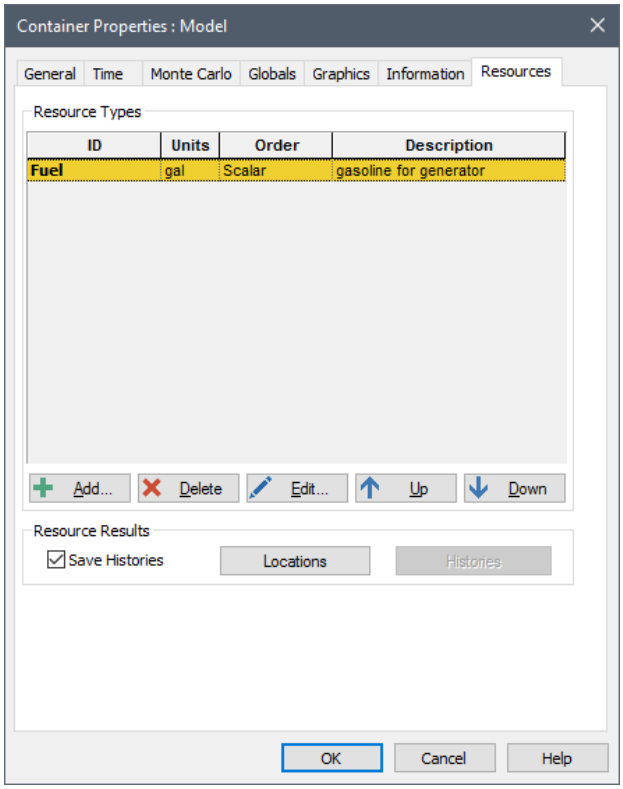


You can delete and edit existing Resource Types using the **Delete** and **Edit** buttons, respectively.

Note: If a selected Resource Type is being used by an element in the model, or has a Local Store defined, GoldSim will display an error message if you try to delete it. You can only delete Resource Types that are not being used.

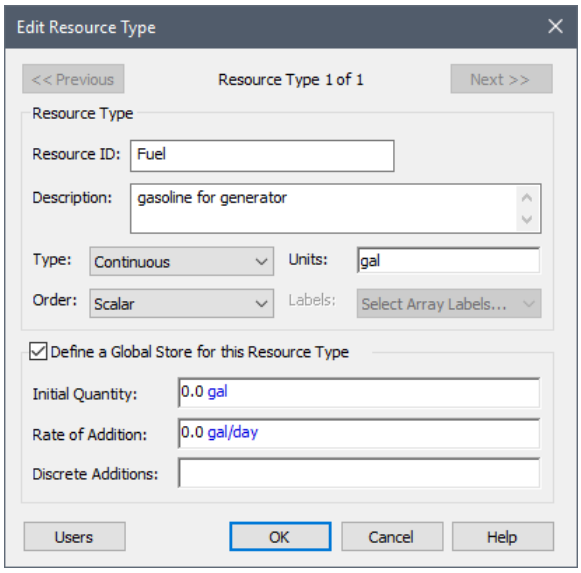
The **Up** and **Down** buttons move Resources up and down the list (this is simply cosmetic; the order in which they are listed has no impact).

Note that you can also access the Resource Manager by right-clicking in the graphics pane at the top level of the model and selecting Properties. The Resource Manager is available as a tab on the Model Properties dialog:



Creating and Editing Global Resource Stores

Global Resource Stores are available to all elements in your model. Global Stores are created within the Resource Manager (accessed via **Model| Resources…** or by pressing **F8**).When you **Add** or **Edit** a Resource Type, you have the option to define a Global Store for that Resource by checking **Define a Global Store for this Resource**:



This creates a Global Store and provides access to the three input fields to define the Store: the **Initial Quantity**, the **Rate of Addition** and **Discrete Additions**.

The Initial Quantity must have the same attributes (order and dimensions) as the Resource Type.

Note: The Initial Quantity must be a number or a link from a static variable (e.g., a constant Data element or a Stochastic).

The Rate of Addition allows you to add to your Resource Store in a continuous manner. It is not provided if the Resource Type is "Items". It must have the same order as the Resource Type, but the dimensions must represent a rate of change (e.g., if the Resource Type has units of mass, the Rate of Addition must have units of mass per time). The Rate of Addition must be entered as a non-negative value. A negative value for this input during a simulation will result in a fatal error.

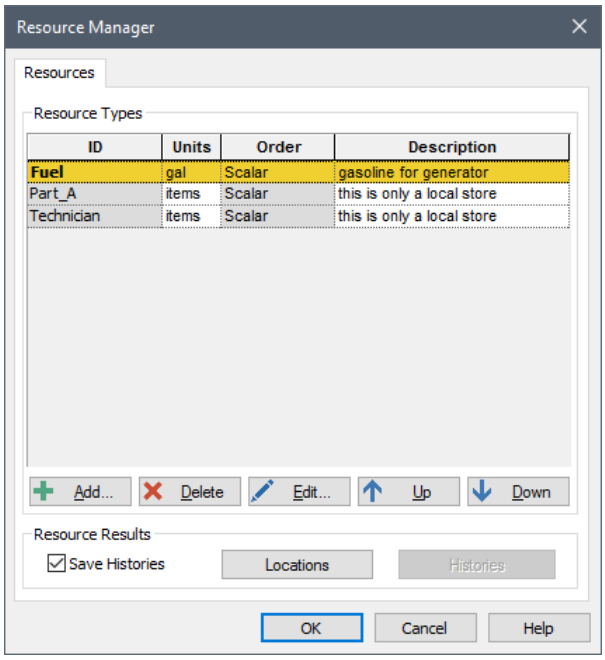
Note: The specified Rate of Addition represents a constant rate over the next timestep. Hence, if the Rate of Addition was defined as "if(time > 10 day, 2 m^3/day, 1 m^3/day)", and you were using a 1 day timestep, the rate would not actually change to 2 m^3/day until time = 11 days. That is, since at time = 10 days, the if statement indicates that the rate is equal to 1 m^3/day, GoldSim would assume that the rate was equal to 1 m^3/day between 10 days and 11 days. If you wanted the rate to change at 10 days, you would write the if statement as "if(time >= 10 day, 2 m^3/day, 1 m^3/day)".

In addition to a continuous Rate of Addition, Resource Stores can also accept discrete changes, so that your Resource Store can change in a discrete manner. The Discrete Additions field only accepts discrete change signals (e.g., the output of a Discrete Change element). The discrete change signal must have a non-negative value. However, it can have either an Add instruction or a Replace instruction.

The **Users** button summarizes the properties of the Store, and lists all the elements that directly use this Store.

Read more: Summarizing Resource Locations and Users (page 924).

After you have created a Global Store, you will notice that Resource Types that have Global Stores are marked in bold in the Resource Manager:



The **Locations** button summarizes the properties of all of the Resource Stores in the model, as well as all of the elements that directly use those Stores.

Read more: Summarizing Resource Locations and Users (page 924).

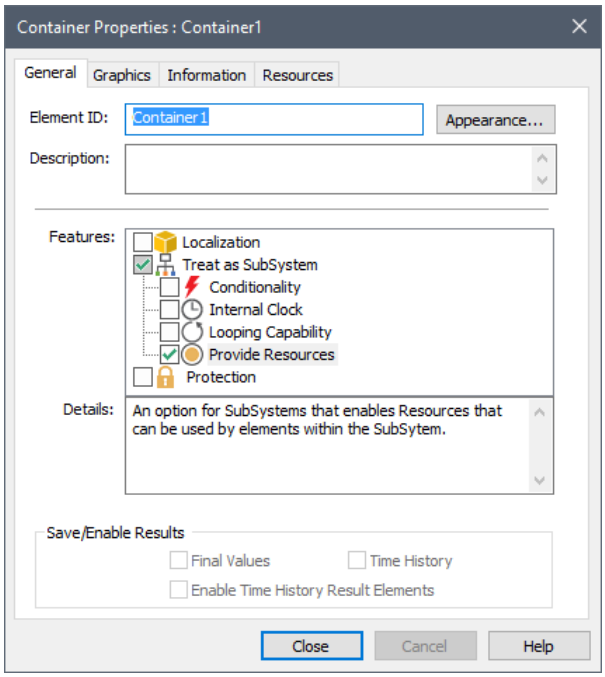
If **Save Histories** is checked, GoldSim saves time histories of all of the Resource Stores in the model and users of those Stores. After the model is run, these histories can be viewed via the **Histories** button.

Read more: Viewing Resource Results (page 927).

Creating and Editing Local Resource Stores

Local Resource Stores are associated with specific Containers, and are only available to elements inside the Container (or in the case of a Conditional Container, to the Container itself).

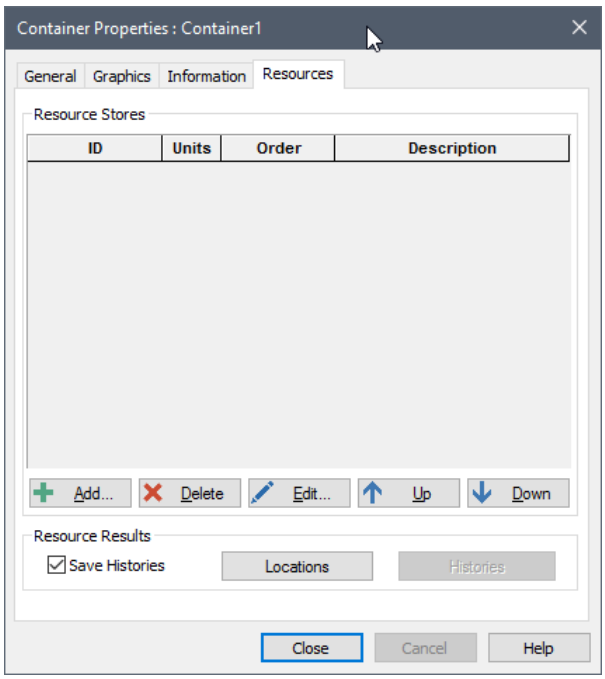
Local Stores are created via the Container dialog. Selecting the **Provide Resources** checkbox adds a **Resources** tab to the Container that allows you to create Local Stores:



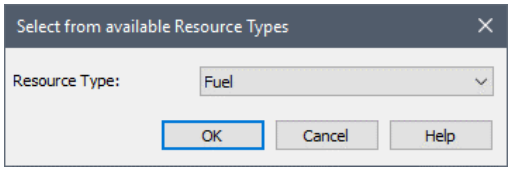
Warning: When you provide Resources to a Container, the **Treat as SubSystem** feature is also automatically selected (and cannot be deselected unless you first turn off **Provide Resources**). That is, a Container with a Resource Store, by definition, is treated as a SubSystem, and this puts certain limitations on how these Containers can be used.

Read more: Treating a Container as a SubSystem (page 140).

The Resources tab for a Container looks like this:



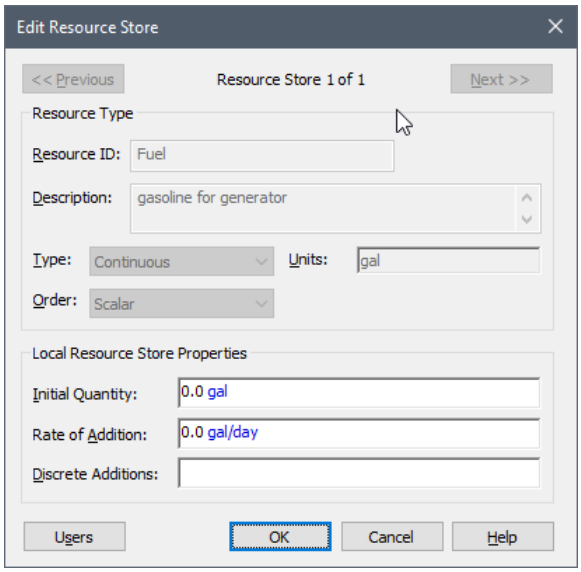
Selecting the **Resources** tab and pressing the **Add** button displays the following dialog for selecting the Resource Type for which you want to create a Local Store:



All *available* Resource Types will be listed. Note that a defined Resource Type is available as long as a Store for that Type has not already been created in the Container. That is, there can only exist a single Store of each Type in any given Container.

Note: If there is only one Resource Type in the model and it is available for use in the Container, the dialog above will be skipped and the single Resource Type will be automatically selected.

After selecting the Resource Type, the following dialog will be displayed:



This creates a Local Store and provides access to the three input fields to define the Store: the **Initial Quantity**, the **Rate of Addition** and **Discrete Additions**.

The Initial Quantity must have the same attributes (order and dimensions) as the Resource Type.

Note: The Initial Quantity must be a number or a link from a static variable (e.g., a constant Data element or a Stochastic).

The Rate of Addition allows you to add to your Resource Store in a continuous manner. It is not provided if the Resource Type is "Items". It must have the same order as the Resource Type, but the dimensions must represent a rate of change (e.g., if the Resource Type has units of mass, the Rate of Addition must have units of mass per time). The Rate of Addition must be entered as a non-

negative value. A negative value for this input during a simulation will result in a fatal error.

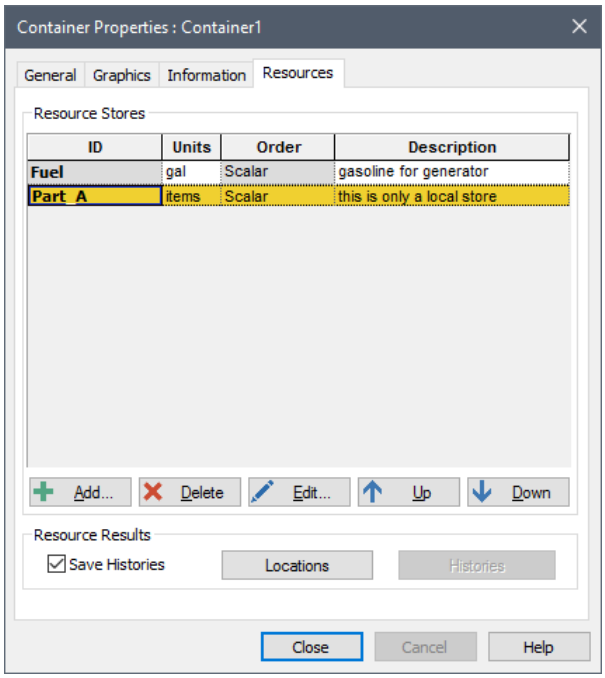
Note: The specified Rate of Addition represents a constant rate over the next timestep. Hence, if the Rate of Addition was defined as "if(time > 10 day, 2 m^3/day, 1 m^3/day)", and you were using a 1 day timestep, the rate would not actually change to 2 m^3/day until time = 11 days. That is, since at time = 10 days, the if statement indicates that the rate is equal to 1 m^3/day, GoldSim would assume that the rate was equal to 1 m^3/day between 10 days and 11 days. If you wanted the rate to change at 10 days, you would write the if statement as "if(time >= 10 day, 2 m^3/day, 1 m^3/day)".

In addition to a continuous Rate of Addition, Resource Stores can also accept discrete changes, so that your Resource Store can change in a discrete manner. The Discrete Additions field only accepts discrete change signals (e.g., the output of a Discrete Change element). The discrete change signal must have a non-negative value. However, it can have either an Add instruction or a Replace instruction.

The **Users** button summarizes the properties of the Store, and lists all the elements that directly use this Store.

Read more: Summarizing Resource Locations and Users (page 924).

After you have added one or more Local Stores, the **Resource** tab for a Container shows all of the Resource Stores associated with the Container:



You can delete and edit existing Resource Stores using the **Delete** and **Edit** buttons, respectively.

Note: If a Resource Store is being used and you delete it, GoldSim will allow this, but GoldSim will display an error when you try to run the model.

The **Up** and **Down** buttons move Resources up and down the list (this is simply cosmetic; the order in which they are listed has no impact).

The **Locations** button summarizes the properties of all Stores that exist in the Container, as well as all of the elements that directly use those Stores.

Read more: Summarizing Resource Locations and Users (page 924).

If **Save Histories** is checked, GoldSim saves time histories of all of the Resource Stores in the model and users of those Stores. After the model is run, these histories can be viewed via the **Histories** button.

Read more: Viewing Resource Results (page 927).

Interacting with Resources

Once you have defined some Resources and created one or more Resource Stores, you can specify ways in which elements in your model interact with those Resource Stores.

Elements can interact with a Resource Store in three different ways:

- An element can *Spend* (consume) a Resource from the Store.
- An element can *Borrow* a Resource from the Store for a particular amount of time and then return it.
- An element can *Deposit* (generate) a Resource into a Store.

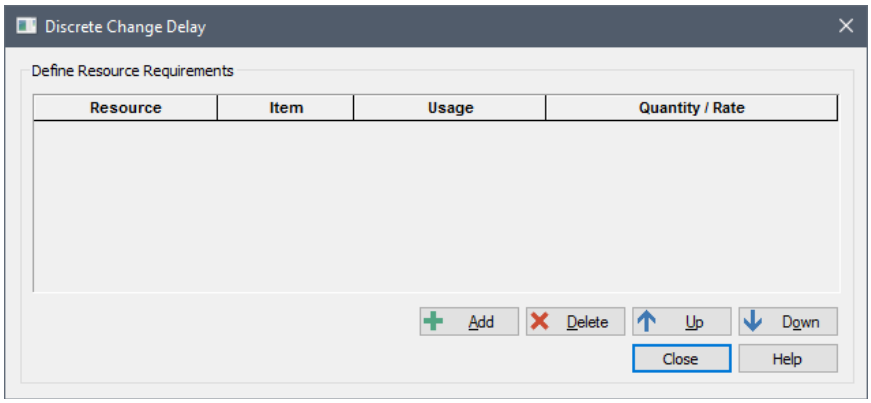
These interactions can be discrete or continuous in nature. As a result, there are actually five different kinds of possible Resource interactions:

- You can Spend a discrete amount of a Resource;
- You can Borrow a discrete amount of a Resource;
- You can Deposit a discrete amount of a Resource;
- You can Spend a Resource at a specified rate; and
- You can Deposit a Resource at a specified rate.

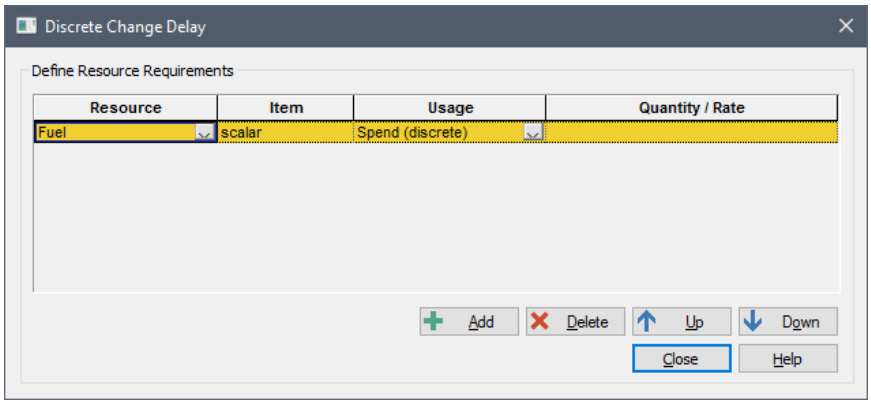
Only certain kinds of elements in GoldSim can interact with Resources, and not all five types of interactions may be available to a particular element.

Whenever an element does interact with a Resource Store, it does so through a **Resources…** button:

Depending on the context, this button is either available on the main dialog for the element or within a Trigger dialog for the element. When you press the button, the following dialog is displayed:



A Resource Requirement (or more generally, an interaction) is created by pressing the **Add** button. When you do this, GoldSim will add a row to the table of Resource Requirements:



You must then edit the row to define the Resource Requirement. The **Resource** column is a drop-list that contains all Resource Stores that are *available* to the element.

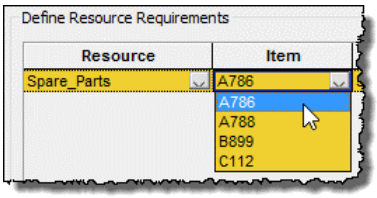
What Stores are available to an element is a function of where the element is located in the model and the defined hierarchy of Local and Global Stores. The following rules are applied:

- An element can only interact with Resource Stores that are above it or at the same level within its Container path. For example, if the element is located within Container1/Container2 (i.e., Container2 which is inside Container1), the element can only interact with Local Stores associated with Container1 or Container2, and Global Stores. The element would not be able to interact with any Local Stores associated with Container3 (a Container that was at a parallel level to Container1).
- If a Resource Type has multiple Stores within a particular Container path, the element can only access the Store that is closest to it. For example, if the element is located within Container1/Container2 (i.e., Container2 which is inside Container1), and Container1 and Container2 have Local Stores of a particular Resource Type, and there is also a Global Store of that Type, the element can only access the Store in Container2, *even if that Store becomes empty during the simulation*. If the Store in Container2 was deleted, it could then only access the Store in Container1. Only if the Store in Container1 was also deleted could it access the Global Store.

In some cases, if one Resource Store is exhausted, you may want to move Resources from another Store. This can be done, but you must manually program how and when this takes place.

Read more: Moving Resources in a Model (page 921).

The **Item** column is not editable if the Resource is a scalar. However, if it is a vector, the column provides a drop-list for you to select the item from the vector for which the Resource Requirement is defined:



The **Usage** column specifies the type of interaction (e.g., Spend, Borrow, etc.). As noted above, there are five possible types of interactions, but depending on the element type and the Resource Type, not all of these will be available (e.g., a Spend Rate is not available for Resource Types that are discrete items).

The **Quantity/Rate** column is an input field in which you specify a value that is appropriate for the particular type of Usage (e.g., discrete usages require quantities, continuous usages require rates). You can enter a value or an expression (or links to other elements). It can also be a function of time. However, the dimensions must be consistent with the specified Resource Type. Within this field, you can also reference several locally available properties pertaining to the amount of Resource that is available, or has been spent or borrowed.

Read more: Referencing Resource Availability and Use in Input Expressions (page 920).

Note: If a Resource becomes exhausted (due to Spend Rate) between scheduled updates (timesteps), GoldSim will insert an unscheduled update to accurately capture this. If you have disabled unscheduled updates (an advanced timestepping option), such that GoldSim cannot insert an unscheduled update when the Resource becomes exhausted, a fatal error will be displayed.

Read more: Understanding Timestepping in GoldSim (page 473).

A Resource Requirement can be removed by pressing the **Delete** button. The **Up** and **Down** buttons move Resource Requirements up and down the list (this is simply cosmetic; the order in which they are listed has no impact).

Note: If you have multiple Resource Requirements, they are only applied when they can all be met. For example, if you had a Spend requirement of 3 of PartB and 2 of PartC, and the Stores had enough of PartB, but not of PartC, neither PartB or PartC would be consumed (until both were available in sufficient quantities). In addition, all Spend requirements must first be met before any Deposit interactions are carried out.

Note: You can create multiple Resource interactions for the same Resource Store. For example, you might want to Borrow a certain quantity, and Consume (Spend) a different quantity.

The types of elements that can interact with Resources are summarized in the next section.

Elements That Can Interact With Resources

Only certain kinds of elements in GoldSim can interact with Resources. The table below summarizes which elements can use Resources, and how they can use them:

Element	Resource Store Interaction	Allowed Usage	Comments
Triggered Event	Interacts when triggered.	Spend (discrete) Deposit (discrete)	If triggered with a Spend Requirement and Resource is not available, trigger is held (it waits) for Resource.
Event Delay	Interacts when triggered. Borrowed items are returned when signal is released.	Spend (discrete) Borrow (discrete) Deposit (discrete)	If Requirement is Spend or Borrow, and Resource is not available, the signal is added to the queue for the element.
Discrete Change Delay	Interacts when discrete change signal is received. Borrowed items are returned when signal is released.	Spend (discrete) Borrow (discrete) Deposit (discrete)	If Requirement is Spend or Borrow, and Resource is not available, the signal is added to the queue for the element.
Conditional Container	Interacts when Activation is triggered. Borrowed items are returned when Container is deactivated.	Spend (discrete) Borrow (discrete) Deposit (discrete)	If triggered with a Spend or Borrow Requirement and Resource is not available, trigger is held (it waits) for Resource.
	Interacts while Container is Active	Spend Rate Deposit Rate	While Container is active, spends or borrows at specified rate. If Spend Rate is specified and Resource is not available, the Container deactivates until the Resource becomes available.

Specialized elements in the GoldSim Reliability Module can also interact with Resources.

Read more: Specifying Resources for a Triggered Event (page 383); Specifying Resources for an Event Delay (page 396); Specifying Resources for a Discrete Change Delay (page 410); Specifying Resources for a Conditional Container (page 976).

Controlling How Resources are Allocated Amongst Competing Requirements

In some cases, a Resource Store may have competing requirements. For example, perhaps 10 kg of a particular Resource exists in a Store, and two Triggered Events are triggered at the same time, each one having a Discrete Spend Resource Requirement of 6 kg. How does GoldSim decide which element receives the requested Resource?

GoldSim uses the the ***causality sequence*** to determine how Resources are allocated amongst competing requirements.

When you build a model, GoldSim automatically *sequences* the elements in the order that they must be computed. For example if A was a function of B, and B was a function of C, C would be sequenced first, followed by B, followed by A. This is referred to as the causality sequence. Although in this simple example, the sequence is obvious, for complex models with looping logic, the causality sequence may not be readily apparent. The causality sequence can be viewed by selecting **Model|Causality Sequence** from the main menu.

Read more: The Causality Sequence and Element Updating (page 358).

GoldSim also provides a way to manipulate the causality sequence so that elements are computed in a specified order.

Read more: Addressing Ambiguous Causality Sequences (page 1045).

Referencing Resource Availability and Use in Input Expressions

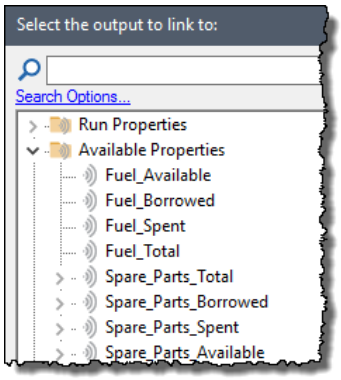
In some situations, when defining a Resource Requirement **Quantity**/**Rate**, or any other property of an element that is interacting with Resources (e.g., a trigger), you may want to make the input a function of the current state of one or more Resource Stores.

GoldSim provides four locally available properties for each Resource Store available to an element:

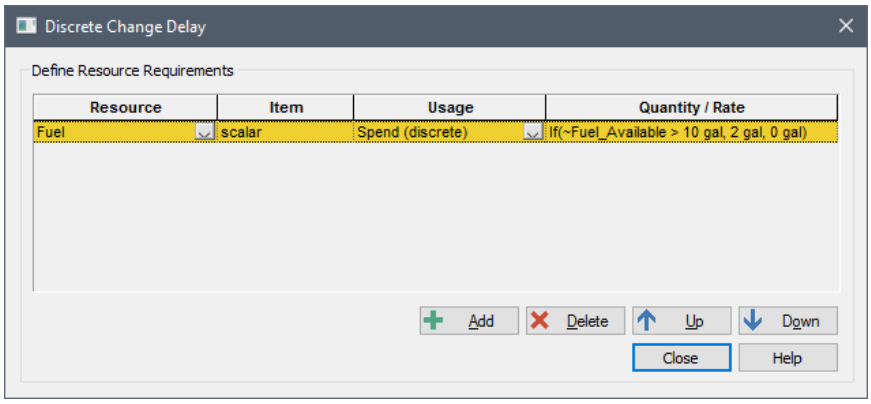
- ***ResourceName*_Available** (e.g., Fuel_Available): The quantity of the specified Resource Store that is currently available.
- ***ResourceName*_Borrowed** (e.g., Fuel_Borrowed): The quantity of the specified Resource Store that is currently borrowed.
- ***ResourceName*_Spent** (e.g., Fuel_Spent): The quantity of the specified Resource Store that has been spent.
- ***ResourceName*_Total** (e.g., Fuel_Total): The sum of *ResourceName*_Available and *ResourceName*_Borrowed.

Read more: Understanding Locally Available Properties (page 874).

Like all locally available properties, these are accessed via the Insert Link dialog, in this case by first right-clicking inside an input field of an element that can use Resources, and then expanding the Available Properties folder (displaying all of the locally available properties that can be accessed from that location):



Like all locally available properties, these appear in input fields with the prefix "~" (e.g., ~Fuel_Available):



Moving Resources in a Model

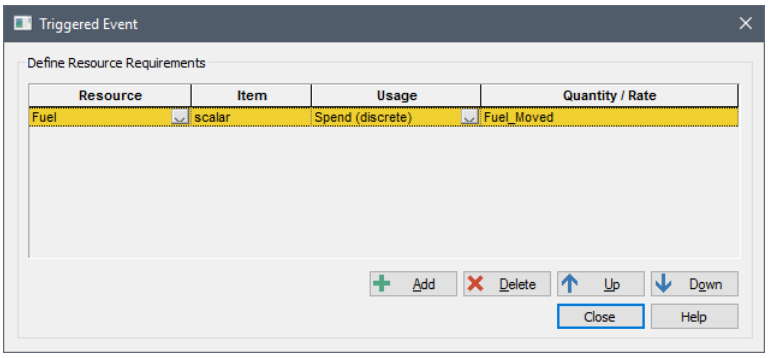
Because 1) an element can only interact with Resource Stores that are above it or at the same level within its Container path, and 2) if a Resource Type has multiple Stores within a particular Container path, the element can only access the Store that is closest to it, situations might arise where you may want to move Resources between Stores.

For example, if you had a Local Store of "Fuel", as well as a Global Store of "Fuel", if the Local Store was exhausted and the Global Store still had available Resources, elements would not be able to access the Global Store in order to meet their requirements. As long as a Local Store exists that is available to the elements, this would be the only Store that could be accessed by those elements. To access the Global Store, therefore, you would need to *move* Resources from the Global Store to the Local Store.

This can be done, but you must manually program how and when this takes place. The recommended way to do this is to use a combination of a Triggered Event and a Discrete Change element to remove the Resource from one Store (e.g., the Global Store) and deposit it in the other Store (e.g., the Local Store).

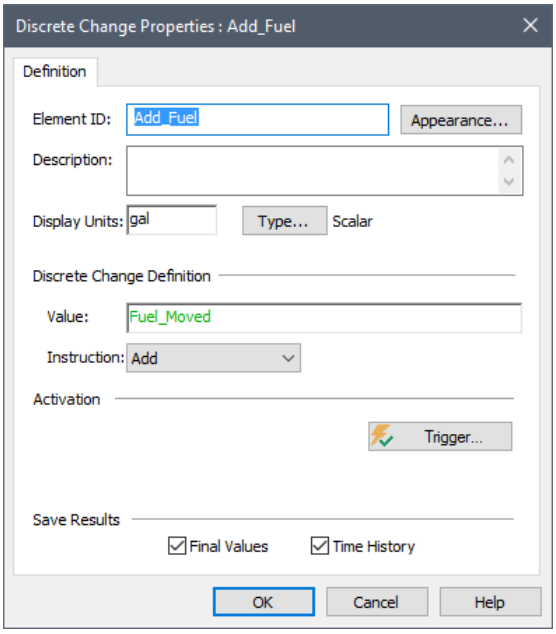
The specific steps involved in doing so are as follows:

1. Add a Triggered Event element at a location in the model such that it can access the Store from which you want to remove Resources (e.g., if you are moving from a Global Store to a Local Store, the Triggered Event element should be above the scope of the Local Store).
2. The Triggered Event element should have a Spend (Discrete) Resource Requirement that pulls Resources from the first Resource Store:

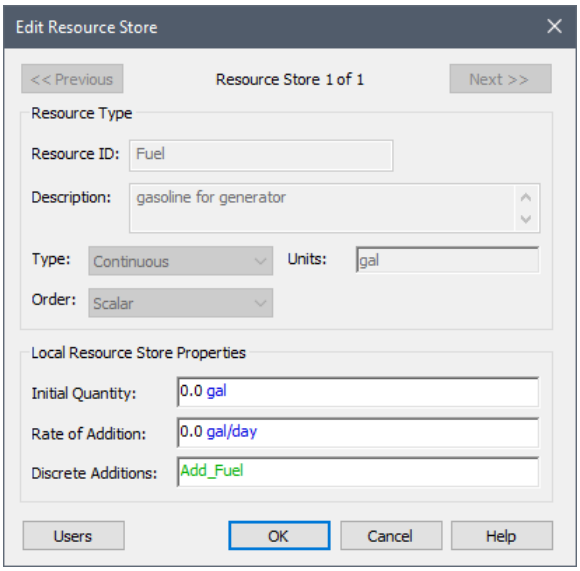


Read more: Specifying Resources for a Triggered Event (page 383).

3. Add a Discrete Change element that is triggered by the Triggered Event. This element could be located either at the same location as the Triggered Event or at the location of the Store to which the Resources are being moved. The key point is that the Value for the Discrete Change should be the same as the Quantity that was specified for the Resource Requirement for the Triggered Event:

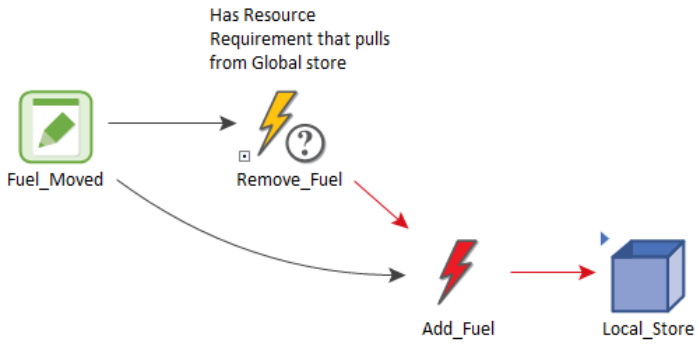


4. Within the Store to which the Resource is being moved, specify a Discrete Addition that is the output from the Discrete Change element:



Read more: Generating Resources (page 923).

A view of this structure is shown below:



Note: You cannot send (add) Resources to an inactive Container. If the Container is inactive, the Addition will be ignored.

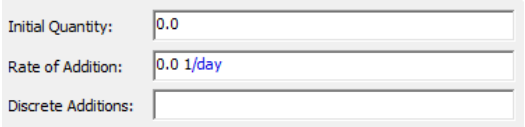
Note: If the process of moving the Resource takes time, you could represent this by adding a Discrete Change Delay after the Discrete Change element.

Generating Resources

When using Resources in your model, you will define a number of events or processes that consume those Resources. Generally, you will specify an Initial Quantity when defining the Resource Store.

In some cases, however, you may want to add Resources to a Store during a simulation. GoldSim provides two ways to do this:

- Within the Store, add a Rate of Addition or Discrete Additions.



- Specify a Deposit Rate or a Discrete Deposit when defining a Resource Interaction.

The first of these two options is perhaps the most powerful, as you have great flexibility in how you can add resources. Note that the **Discrete Additions** field also accepts discrete change signals that have a Replace instruction. This, for example, would allow you to reset a Store to a pre-specified level (e.g., its capacity) regardless of its current level.

Read more: Creating and Editing Global Resource Stores (page 910); Creating and Editing Local Resource Stores (page 912).

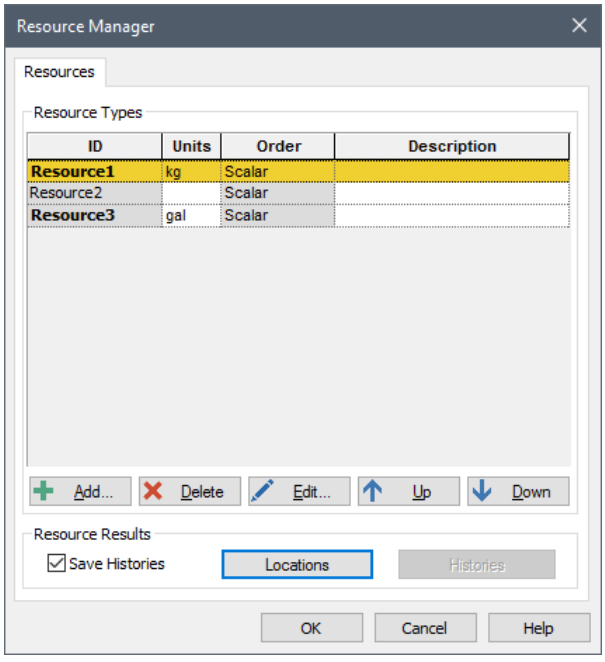
All elements that can interact with a Resource Store can add (deposit) rather than spend Resources.

Read more: Elements that Can Interact With Resources (page 919).

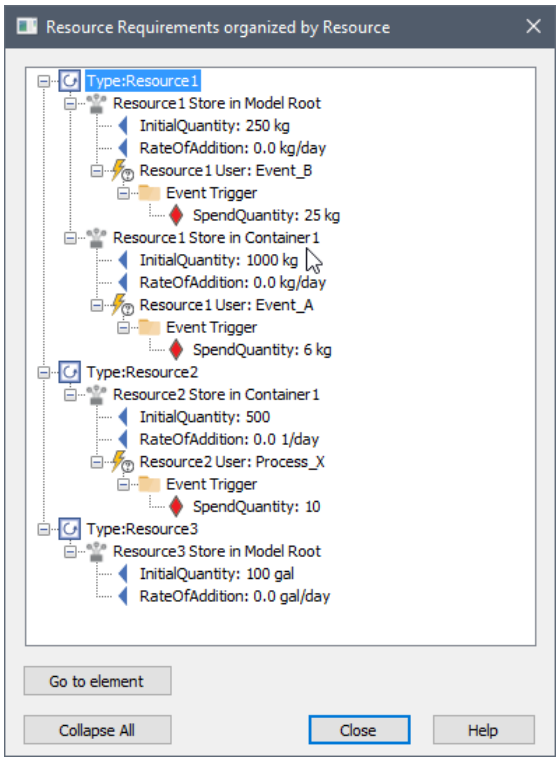
Summarizing Resource Locations and Users

After you have added a number of Resource Stores and elements that interact with those Stores to your model, it is often useful to be able to summarize the locations and users of the various Resources that exist in your model.

GoldSim provides several ways to do this. Within the Resources Manager (accessed via **Model|Resources…** or by pressing **F8**), a **Locations** button is provided:



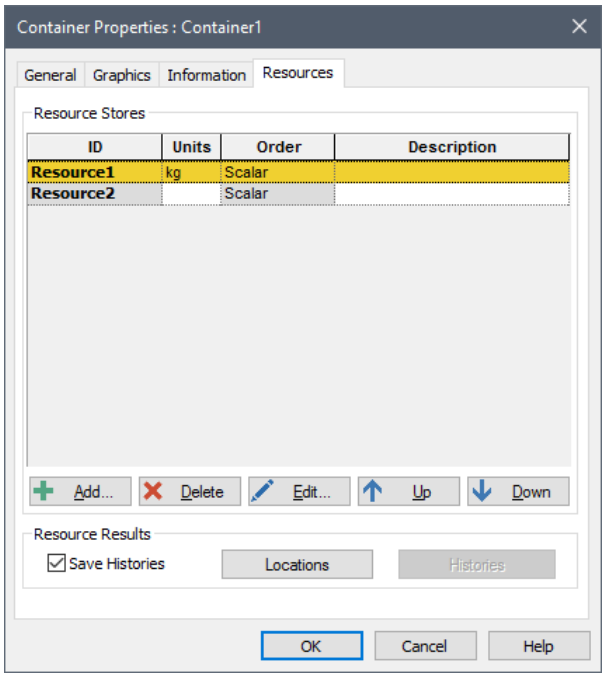
This button lists all of the Resource Stores in the model, along with all of the elements that interact with them:



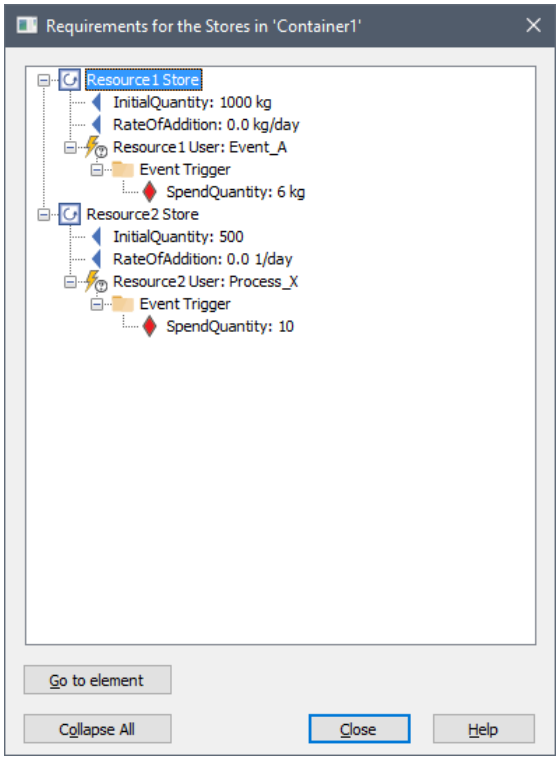
In this example, the model has 3 Resources defined. Resource1 has a Global and a Local Store; Resource2 has Local Store only; Resource3 has a Global Store only. Resource3 does not have any elements that interact with it.

Selecting an element in the tree that uses a Resource and pressing **Go to element** jumps to that element. The **Collapse All** button collapses the tree to the top level (the Resources). (The button then becomes Expand All). Pressing **Ctrl-A** also toggles between expanding and collapsing the tree.

The **Resources** tab for a Container that has Local Stores also has a **Locations** button:

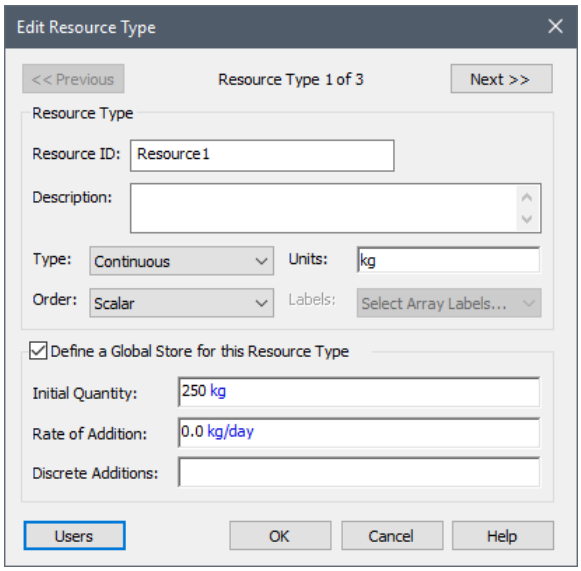


This button lists all of the Resource Stores *in the Container*, along with all of the elements that interact with them:

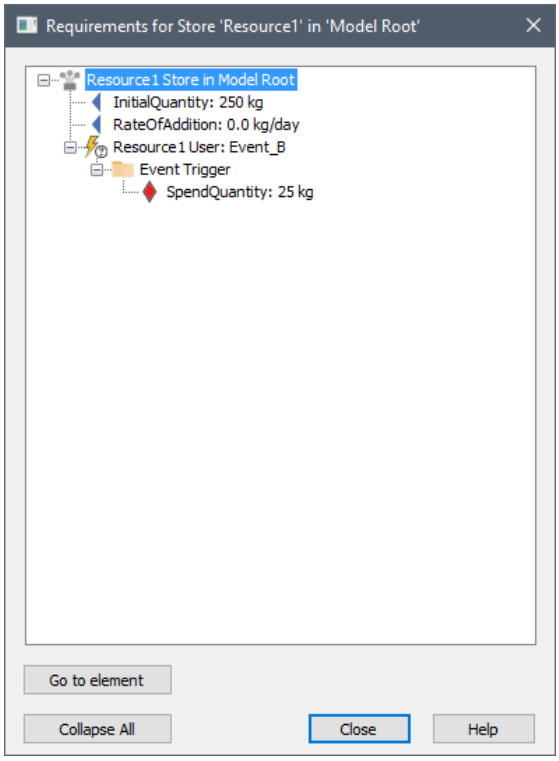


Selecting an element in the tree that uses a Resource and pressing **Go to element** jumps to that element. The **Collapse All** button collapses the tree to the top level (the Resource Stores). (The button then becomes Expand All). Pressing **Ctrl-A** also toggles between expanding and collapsing the tree.

In the dialog for defining a Resource Store (either globally or locally), there is a **Users** button:



This button lists all of the users (elements) that interact *with that particular Resource Store*:

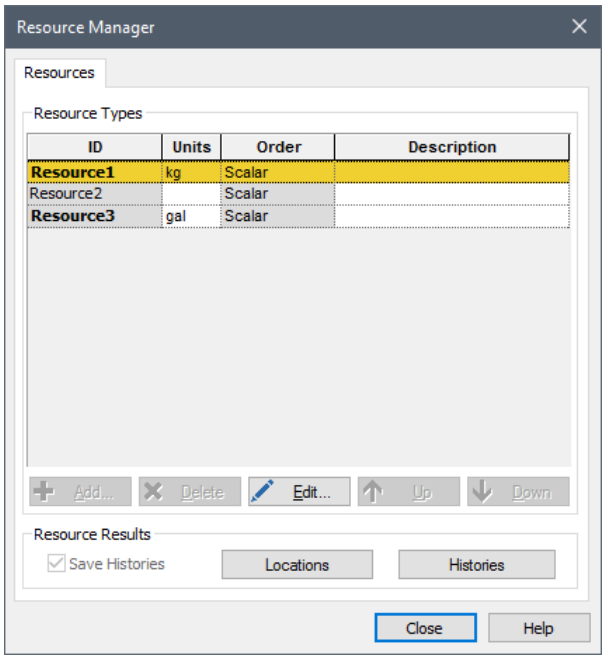


In this example, this Resource Store (Resource1) has one element that interacts with it (Event_B).

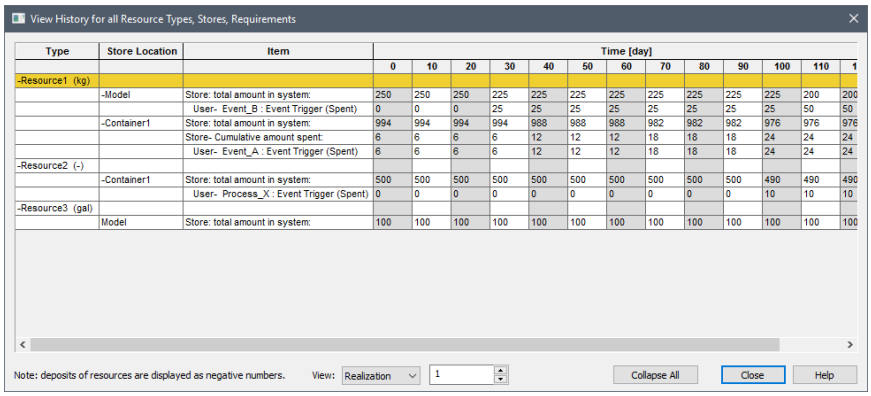
Viewing Resource Results

After you have run a model that uses Resources, you will often want to view how those Resources are being used as a function of time.

GoldSim provides several ways to do this. Within the Resources Manager (accessed via **Model | Resources…** or by pressing **F8**), or from the **Resources** tab of a Container if a Local Store has been defined, a **Histories** button is available when the model is in Result Mode:



This button provides a history (in tabular form) of all of the Resource Stores in the model, along with all of the elements that interact with them (identifying, for example, how much of each Resource Store has been spent, borrowed or deposited):

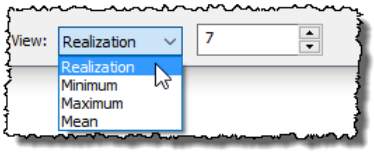


The scroll-bar allows you to scroll horizontally to view all of the time points.

The **Collapse All** button collapses the tree to the top level (the Resources). (The button then becomes **Expand All**). Pressing **Ctrl-A** also toggles between expanding and collapsing the tree.

Note: Deposits (additions) of a Resource appear as negative numbers in this table.

If you have carried out multiple realizations, additional options will be available at the bottom of the Resource Histories dialog. In particular, you must select how you want to view the Monte Carlo results:



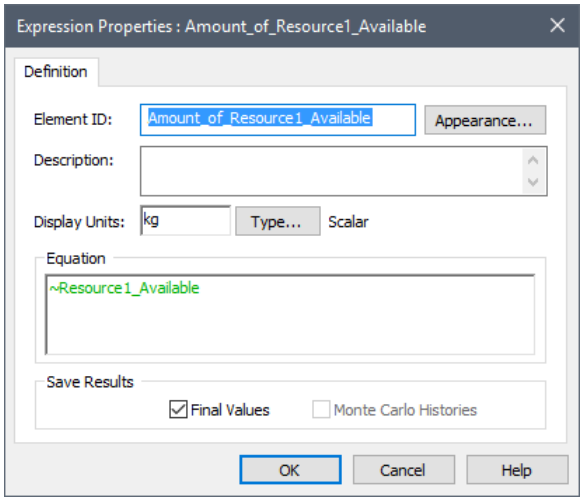
There are four choices:

- You can view a specified realization;
- You can view the minimum value at each time point;
- You can view the maximum value at each time point; or
- You can view the mean value at each time point.

Note: The **Histories** button is grayed out when the model is in Scenario Mode. That is, you cannot view these results when running and comparing scenarios.

Read more: Creating, Running and Comparing Scenarios (page 525).

You can also view time history charts of the amount of each Resource Store available by creating Expression elements that directly reference the locally-available variables for each Resource:



Read more: Referencing Resource Availability and Use in Input Expressions (page 920).

Script Elements

In some situations, you may wish to define a complex function which cannot be readily implemented using the expression editing features supplied by GoldSim. For example, calculation of an output may require very complex logic which would be cumbersome to represent using a Selector element, or it may require a numerical solution technique (e.g., iteration); or perhaps you need to construct an array using complex logic.

GoldSim provides two separate ways to deal with such situations:

- You can develop separate program modules (written in C, C++, FORTRAN or other compatible programming languages) which can then be directly coupled with the main GoldSim algorithms. These user-defined modules are referred to here as external functions, and the elements through which they are coupled to GoldSim are called External (DLL) elements.
- You can specify a sequence of statements directly within the GoldSim interface using a Script element.

Read more: External (DLL) Elements (page 1004).

Although, for some complex calculations, an External (DLL) element may be required, for many applications a Script element can be used. The key advantages of a Script over an External (DLL) is that 1) it does not require use of a separate programming language and interface; and 2) it is much more transparent (all of the "code" can be seen directly in GoldSim).

Scripts are created by inserting and editing statements or statement blocks, which may be variable definition statements, variable assignment statements, statements controlling the sequence of execution in the script (e.g., loops and if statements), or statements used for writing messages to the Run Log. The Script element sequentially evaluates the specified sequence of locally defined statements to determine its output(s).

Note: The Script element does not expect the user to learn or be familiar with a particular language. As a result, scripts are *not* created using a text editor. Rather, statements are inserted and edited within a "controlled environment" within the element's property dialog in which the user selects from a number of available statement types. The syntax is already defined for each type of statement – the user simply specifies the attributes and properties for each statement via a dialog box when the statement is inserted. Statements can subsequently be moved, deleted, and edited.

To provide a quick idea of what a script looks like, a simple example in which a script is used to define a vector is shown below:

Script

	Statement List
1	// Defines items in a vector as a function of the index
2	DO index = 1, 12, 1
3	IF (~Result[~index]<6) THEN
4	Result[~index] = ~index
5	ELSE IF (~Result[~index]<9)
6	Result[~index] = A
7	ELSE
8	Result[~index] = B
9	END IF
10	END DO

The sections below discuss the use of Script elements in detail. The Script element is powerful, and, as a result, somewhat complex. It is strongly recommended that you read through these sections carefully before attempting to build your own scripts.

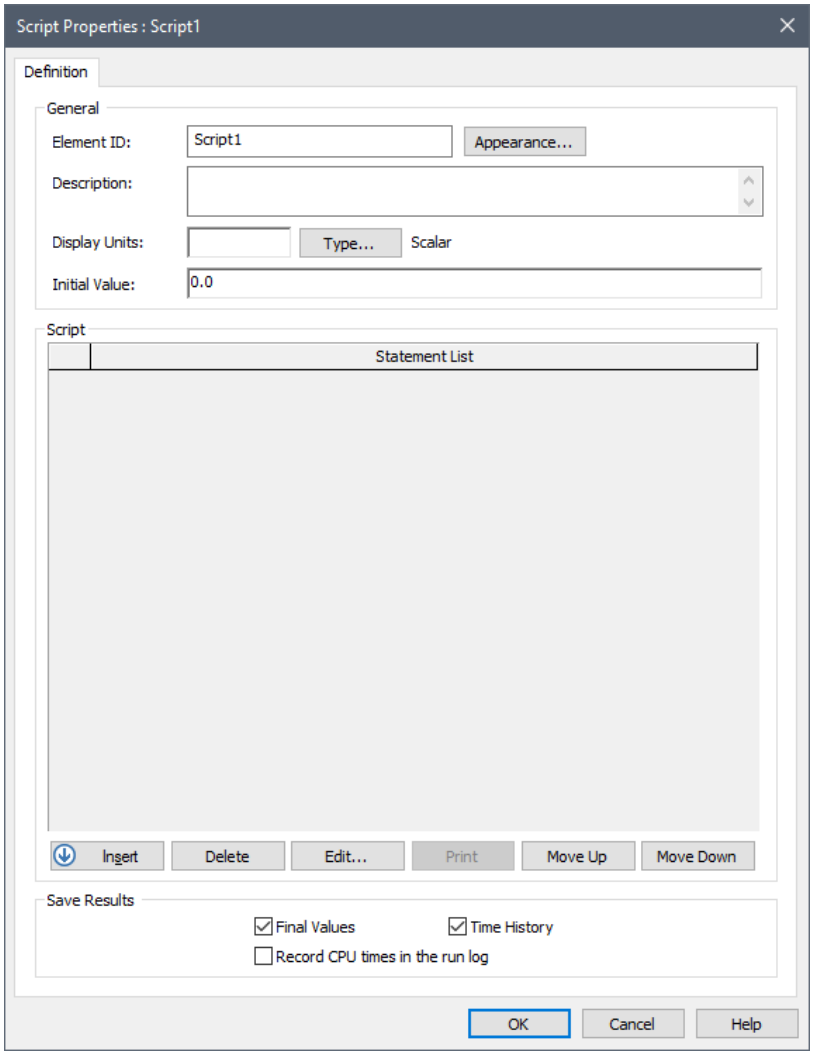
Note: In the sections that follow, the term "Script" (capitalized) refers to the element itself; the term "script" (lower case) refers to the list of statements defined by the user within the element.

Getting Started with the Script Element

The sections below help you get started with the Script element by introducing some basic concepts, and walking through the steps required to build your first script. Before you can learn the advanced Script element features, it is essential that you first understand these basic concepts.

The Script Element Dialog

The properties dialog for a Script element looks like this:



Like all elements, you first specify an **Element ID** and a **Description**.

By default, all Script elements have a single primary output. When defining a Script, therefore, the first step is to define the attributes (units, type, order) of this primary output.

The **Display Units** determine the dimensions of the output. You can specify the type and order by pressing the **Type…** button. The output can be defined as either a value or a condition, and can be specified as a scalar, a vector or a

matrix. By default, the primary output of a new Script element is a scalar, dimensionless value.

Read more: Defining and Assigning Array Variables in a Script (page 938).

Note: It is also possible to define additional outputs for the element (with their own dimensions) when defining local variables within a script.

Read more: Defining Local Script Variables (page 936).

The primary output of a Script element is a ***state variable***. A state variable provides inertia or "memory" to a system because its value is computed based on the historical value of the element's inputs (as opposed to only being a function of the current value of the element's inputs). All state variables have, by definition, an initial value. This allows the output to be computed when there are no historical inputs available (e.g., at the start of simulation).

Read more: Understanding State Variables in GoldSim (page 356); Understanding the Outputs of a Script Element (page 941).

The **Initial Value** input to the Script must have the same attributes (order and dimensions) as the primary output.

Note: The **Initial Value** must be a number or a link from a static variable (e.g., a constant Data element or a Stochastic).

Buttons at the bottom of the dialog are used to insert, delete, move and edit statements in your script. You can also print the entire script.

Read more: Editing Scripts (page 955); Printing Scripts (page 963).

If you check the **Record CPU times in the run log** box, if the element uses more than 1 CPU seconds, a message will be written to the GoldSim run log identifying the element's name, type (i.e., Script), the number of times it was updated, and the total CPU time used.

Read more: The Run Log (page 569).

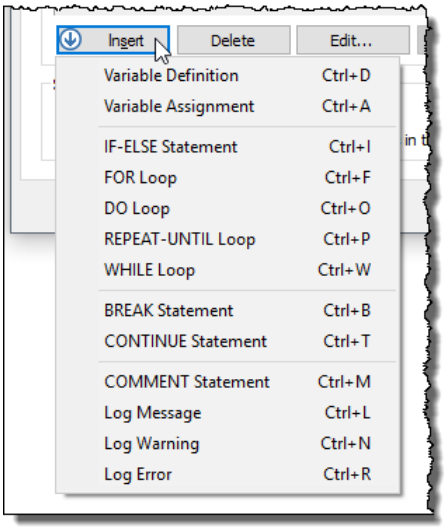
Inserting Statements into a Script

Scripts are created by inserting and editing individual statements (e.g., variable definition statements, variable assignment statements) or statement blocks (e.g., loops, if statements). The Script element sequentially evaluates the specified sequence of locally defined statements to determine its output(s).

It is important to understand that scripts are *not* created using a text editor. Rather, statements are inserted and edited within a "controlled environment" within the element's property dialog in which the user selects from a number of available statement types. The syntax is already defined for each type of statement – the user simply specifies the attributes and properties for each statement via a dialog box when the statement is inserted. Statements can subsequently be moved, deleted, and edited.

There are three ways to insert a statement into a script:

1. Select an existing statement in the script. Press the **Insert** button at the bottom of the Script element dialog. When you press this button, the following choices appear:



Left-click on one of the statement types. It will be inserted *below* the selected statement.

2. Select an existing statement in the script. Press the appropriate hot-key for the statement type (indicated in the dialog above). It will be inserted *below* the selected statement.

   Read more: Hot-keys for Quickly Creating and Editing Scripts (page 956).

3. Right-click in the statement number. This will bring up a context menu, whose first item is **Insert**. This expands to display all of the statement types shown above. Left-click on one of the statement types. It will be inserted *below* the selected statement.

Note: If you hold the **Shift** key while carrying out any of these three methods for inserting a statement, the statement will be inserted *above* the selected statement.

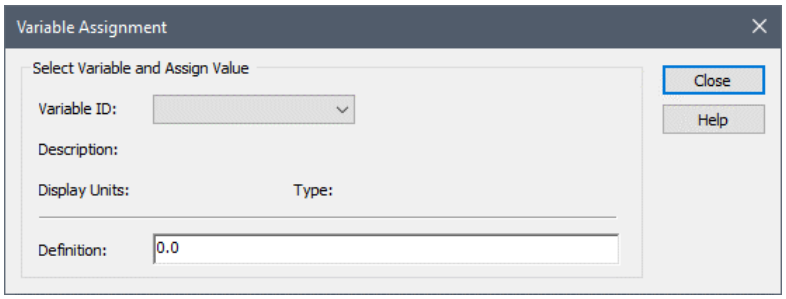
Note: When inserting statement blocks (e.g., If-Else statement, For loops), you can select multiple statements in an existing script (by left-clicking and dragging the line numbers), and GoldSim will "wrap" the statement block around the selected statements. Note, however, that this requires that the selection is a logically complete block of code (e.g., you could not select a portion of another loop).

Read more: Controlling Program Flow in the Script Element (page 942).

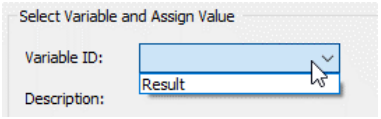
Assigning Values to Script Variables

The most fundamental of the Script element's statements is the Variable Assignment, in which you assign a value (or condition) to a variable (typically in the form of a mathematical expression).

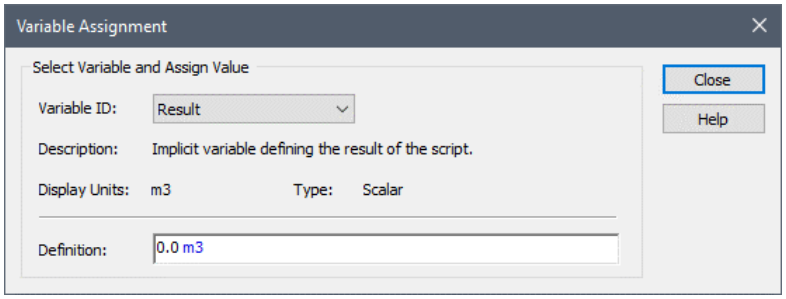
Selecting "Variable Assignment" from the Script element's **Insert** menu (or pressing **Ctrl+A** when in the Script dialog) inserts the statement in the script (below the statement that was selected when this is done), and brings up the following dialog:



It is first necessary to specify which variable is being assigned a value (the **Variable ID**). By default, in a new script, there is only one variable that exists: the primary output. Within a script, this primary output is always referenced as *Result*. Hence, for a new script, this is the only choice in the drop-list:



After selecting the **Variable ID**, GoldSim displays the attributes of the variable (in the example below, the attributes of the primary output of the Script element):



You then specify how the variable is assigned (i.e., in terms of an equation, you are defining the right-hand side of the equation). The **Definition** field is the equivalent of the **Equation** field in an Expression element; you can enter any mathematical expression using all of the functions and operators you can use in other GoldSim input fields.

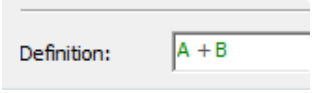
Three different kinds of variables can be referenced in this field:

1. You can reference outputs that are external to the Script element;
2. You can reference the primary output itself (i.e., *Result*); and/or
3. You can reference other local variables that you define in the script.

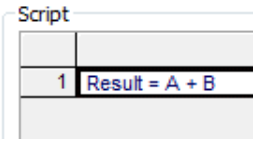
Note: If the Variable you are assigning is an array, the **Definition** portion of the dialog expands to provide some additional options for defining the array.

Read more: Defining and Assigning Array Variables in a Script (page 938).

In the example below, two outputs that are external to the Script element (A and B) are referenced:

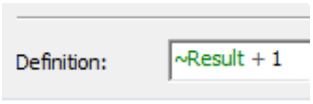


This single statement Script element (which simply adds two numbers) would then look like this:

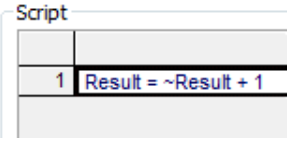


Note: Outside of the Script element, the primary output (*Result*) would be referenced by the Script element's name. It is only referenced as *Result* inside the Script element.

In the example below, the primary output itself is referenced:



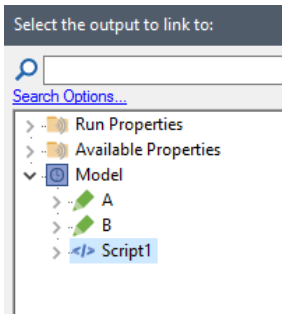
The Script element would then look like this:



In this simple Script element, every time the Script element is updated, it would increment the primary output.

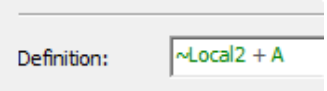
Note that when *Result* is referenced in a statement (i.e., in the right-hand side of the equation), it is referenced using the ~ operator. This is because *Result* is a locally available property. Locally available properties are only available in specific (local) parts of the model. In this case, *Result* can only be referenced inside the Script element, and has no meaning outside the Script element.

When inserting a link while assigning a statement in a script, you will note that *Result* (and any other script variables that you may have defined) are accessible only under Available Properties, and are not listed in the same manner as other outputs:

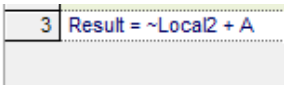


Read more: Understanding Locally Available Properties (page 874).

Finally, in the example below, *Result* is defined in terms of a (previously defined) local script variable (Local2) and an output external to the Script element (A):



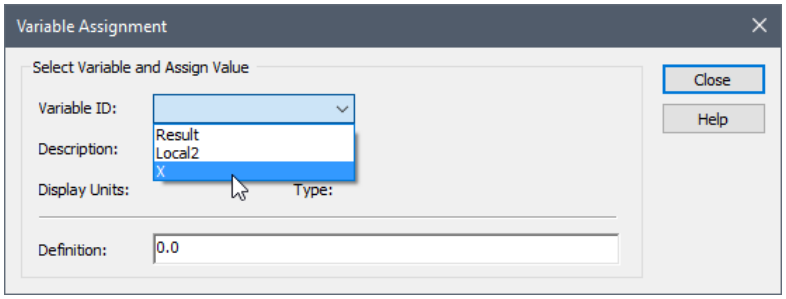
The statement in the Script element would then look like this:



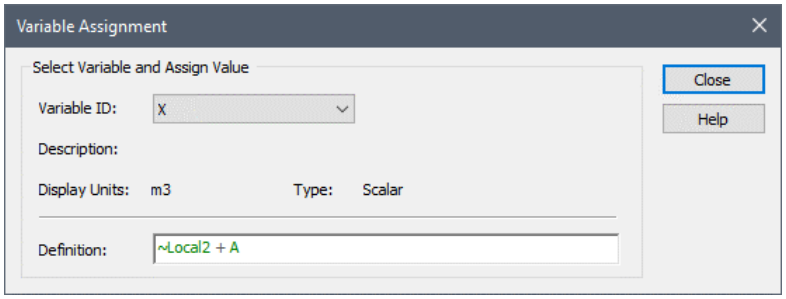
(The next section describes how local variables can be defined and added to a script).

Note that like the *Result* variable, when a local script variable is referenced in a statement, it must be referenced using the ~ operator, since it is a locally available property.

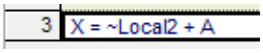
Of course, you can assign values to the local variables in your script (not just the primary output *Result*). For example, in the example below, there are two previously defined local script variables (X and Local2), and the variable X is selected as the **Variable ID** for the statement:



It is then defined in terms of another local script variable (Local2) and an output external to the Script element (A):



The statement in the Script element would then look like this:



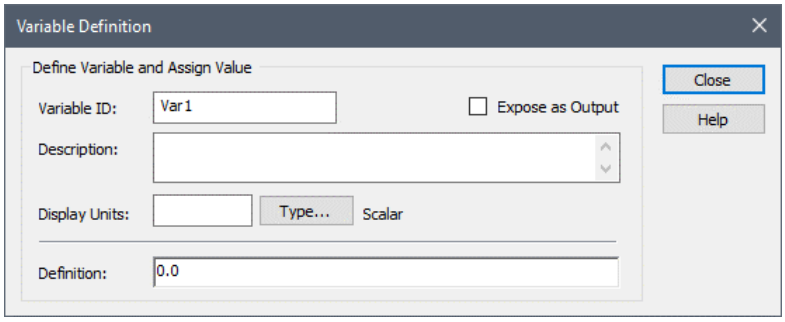
Defining Local Script Variables

Rather than just relying on the primary output (*Result*), most scripts will require local variables to do such things as hold intermediate results or act as counters for loops. Local script variables can also be specified to be additional outputs to the element (so that the Script element has outputs in addition to its primary output).

Script variables are created using a Variable Definition statement. Often a script will start out with multiple Variable Definition statements that create and initialize the local variables that are subsequently used throughout the script.

You add a local variable to a script by selecting "Variable Definition" from the Script element's **Insert** menu, or by simply pressing the hot-key (**Ctrl+D**) from

the main Script dialog. Doing so inserts the statement in the script (below the statement that was selected when this is done), and brings up the following dialog:



You must specify the **ID** of the local variable you are creating, along with its **Display Units** and **Type**. The **Display Units** determine the dimensions of the variable. You can specify the type and order by pressing the **Type…** button. The variable can be a value or a condition, and can be specified as a scalar, a vector or a matrix. By default, a local variable is a scalar, dimensionless value.

Note: If the variable you are defining is an array, the **Definition** portion of the dialog expands to provide some additional options for defining the array.

Read more: Defining and Assigning Array Variables in a Script (page 938).

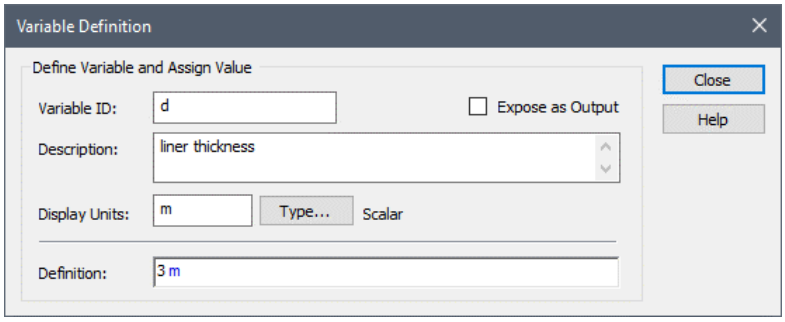
The **Description** is displayed in tool-tips when viewing the script, and is also displayed when modifying the value of the variable using Variable Assignment statements.

The **Definition** field is used to assign a value to the variable. This field is identical to the **Definition** field for a Variable Assignment statement, in that it can reference:

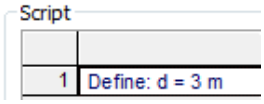
1. Outputs that are external to the Script element;
2. The primary output itself (i.e., Result); and/or
3. Other local variables that you define in the script.

Read more: Assigning Values to Script Variables (page 933).

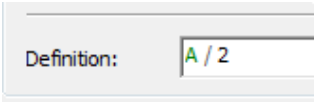
In many cases, however, the assignment in a Variable Definition statement will simply be a constant:



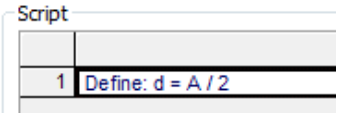
This would then look like this in the script:



Alternatively, you could define the variable and immediately define its value as an expression (as opposed to a constant):



This would then look like this in the script:

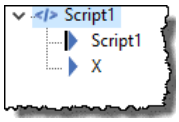


Of course, you can (and almost always will) reassign a definition to a variable later in your script (using a Variable Assignment statement).

Note: User-defined local script variables cannot reference themselves in a Variable Definition statement (e.g., X = ~X + 1 would be invalid, as there is no existing initial value of X to reference in this case). This could, however, be done in a Variable Assignment statement (since X would have been previously defined, and hence could be referenced).

When you create a local variable, you can specify that you want it to be an output for the element by checking the **Expose as Output** checkbox (which by default is cleared). This then adds an output to the Script element.

For example, if a Script element (named Script1) had two local variables (X and Y), and only X was exposed as an output, then outputs of the Script element would look like this:

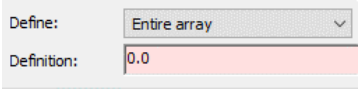


The primary output (referred to as *Result* in the script) would be referenced outside of the Script element as Script1. The secondary output X would be referenced outside of the Script element as Script1.X. The other local script variable (Y) could not be referenced outside of the Script element.

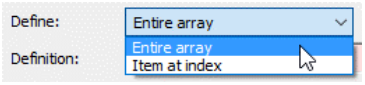
Read more: Understanding the Outputs of a Script Element (page 941).

Defining and Assigning Array Variables in a Script

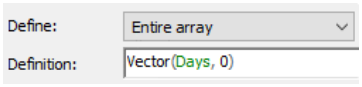
The variables in your script can be defined as arrays (vectors or matrices). When defining a local script variable that is an array in a Variable Definition statement, or assigning a value to a script variable that is an array in a Variable Assignment statement, the **Definition** portion of the dialog expands to provide some additional options for defining the array:



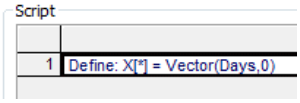
If you are defining a vector, there are two choices in this drop-list:



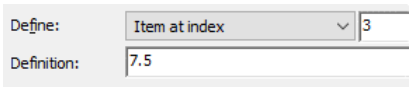
1. If you select the first one ("Entire array"), then the **Definition** field would require the field to be a vector. For example, when defining a variable (named X) that was a vector of *Days* you could enter the following to set the entire vector to zero:



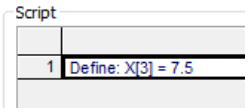
In the script, it would then look like this:



2. Alternatively, if you select "Item at index", then you must also specify the item being specified, and the **Definition** field would require the field to be a scalar. For example, you could enter the following:

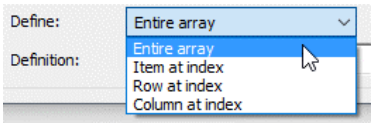


In the script, it would then look like this:

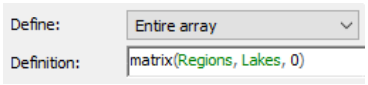


In this case, the third item of the vector would be assigned the value 7.5.

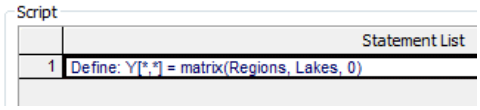
Similarly, if you are defining a matrix, there are four choices in this drop-list:



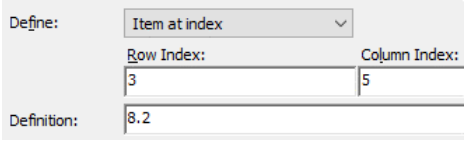
1. If you select the first one ("Entire array"), then the **Definition** field would require the field to be a matrix. For example, when defining a variable (named Y) that was a matrix of *Regions* and *Lakes* you could enter the following to set the entire matrix to 0:



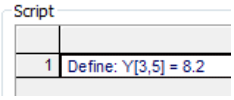
In the script, it would then look like this:



2. Alternatively, if you select "Item at index", then you must also specify the item (row and column) being specified, and the **Definition** field would require the field to be a scalar. For example, you could enter the following:

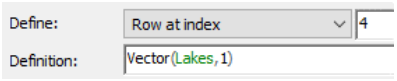


In the script, it would then look like this:

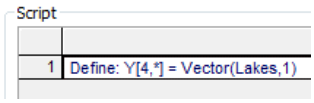


In this case, the item in the 3rd row and 5th column of the matrix would be assigned the value 8.2.

3. If you select "Row at index", then you must also specify the row being specified, and the **Definition** field would require the field to be a vector. For example, you could enter the following:

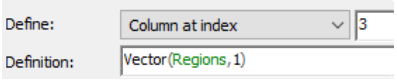


In the script, it would then look like this:

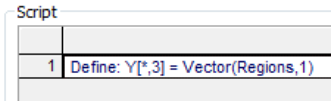


In this case, the item in the 4th row would be assigned as a vector of 1's.

4. If you select "Column at index", then you must also specify the column being specified, and the **Definition** field would require the field to be a vector. For example, you could enter the following:



In the script, it would then look like this:



In this case, the item in the 3rd column would be assigned as a vector of 1's.

Note: When you are specifying the "Item at index" (for a vector or matrix), or "Row at index" or "Column at index" (for a matrix), you do not have to enter a number. You can enter any scalar expression. GoldSim rounds the result to the nearest integer value. This allows you to define arrays by embedding Variable Assignment statements in loops (in which case these indices are often the loop counter variable).

Read more: Controlling Program Flow in the Script Element (page 942); Script Example: Manipulating a Matrix (page 965).

The discussion above applies to assigning values to arrays in both Variable Definition statements and Variable Assignment statements. That is, both types of statements are used to assign values. It is important to understand, however,

that the behavior of the two types of statements is different when assigning values to arrays.

To understand this, consider the following excerpt from a script, containing a Variable Definition statement, as well as a Variable Assignment statement (that references a previously defined variable):

```
2  // This is a Variable Definition statement
3  Define: X[2] = 4
4  // This is a Variable Assignment statement
5  Y[2] = 2
```

Both X and Y are vectors. Line 3 assigns the value 4 to the second item of vector X. Line 5 assigns the value 2 to the second item of vector Y. The question is: since these statements only partially assign values to the vector (i.e., they only assign the second item), how do the statements affect the other items in the vector (that are not explicitly referenced)? The difference is as follows:

- For a *Variable Definition* statement, if it does not assign all the items of the array, the remaining unassigned items are automatically assigned a value of 0 (for value data types) or false (for condition data types).
- For a *Variable Assignment* statement, a partial assignment of a vector or matrix has no effect on the items of the vector or matrix that were not targets of assignment. That is, since all items of the array must have been previously assigned when the variable was defined (and hence already have a value), any items of the array that are not explicitly assigned are unaffected.

Understanding the Outputs of a Script Element

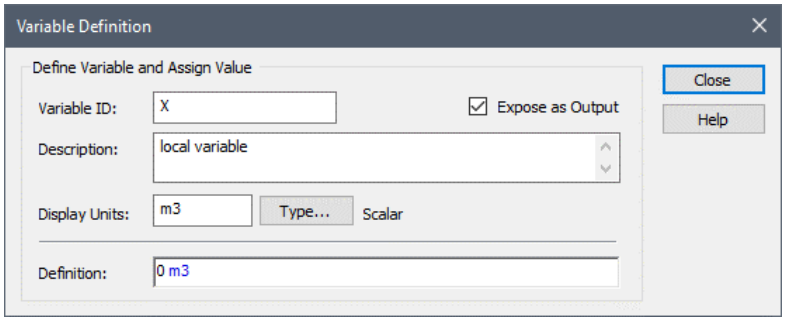
By default, a Script element has a single primary output. The attributes of this output are defined in the main Script dialog.

Read more: The Script Element Dialog (page 931).

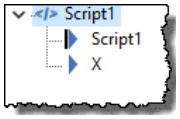
It is also possible to define additional outputs for the element (with attributes and dimensions) when defining local variables within a script.

Read more: Defining Local Script Variables (page 936).

When you create a local variable, you can specify that you want it to be an output for the element by checking the **Expose as Output** checkbox (which by default is cleared):



For example, if a Script element (named Script1) had two local variables (X and Y), and only X was exposed as an output, then outputs of the Script element would look like this:



The primary output (referred to as *Result* in the script) would be referenced outside of the Script element as Script1. The secondary output X would be referenced outside of the Script element as Script1.X. The other local script variable (Y) could not be referenced outside of the Script element.

As is the case for other GoldSim elements, you can check the checkboxes at the bottom of a Script element dialog to save "Final Values" and/or "Time Histories" of all the exposed outputs (including the primary output).

There is an important difference in the behavior of the primary output and any other exposed outputs. The primary output of a Script element is a ***state variable***. A state variable provides inertia or "memory" to a system because its value is computed based on the historical value of the element's inputs (as opposed to only being a function of the current value of the element's inputs). All state variables have, by definition, an initial value. This allows the output to be computed when there are no historical inputs available (e.g., at the start of simulation).

Read more: Understanding State Variables in GoldSim (page 356).

This has an important implication for how the variables can be used in a script. In particular, the value of the primary output is "remembered" between updates of the element. As a result, in a script you could create a Variable Assignment such as "Result = ~Result + 1" as the very first statement. The expression would use the *previous value* of the Result when it was evaluated. This is not possible for any of the other script variables, since they require a Variable Definition statement which initializes the variable every time the Script element is updated.

Note: User-defined local script variables cannot reference themselves in a Variable Definition statement (e.g., X = ~X + 1 would be invalid, as there is no existing initial value of X to reference in this case).

If you would like additional outputs of the Script element to be able to "remember" their previous update (and hence behave like state variables with initial conditions), you can do so by referencing the Script output in a Previous Value element outside of the Script element (and then referencing the Previous Value inside the script).

Read more: Referencing an Output's Previous Value (page 1030); Script Example: Referencing a Previous Value Element in a Script (page 966).

Controlling Program Flow in the Script Element

A scripting language is not complete without statements controlling the flow of execution. To this end, the Script element provides a number of statements for controlling programming flow, including if-else statements that support branching of statement execution, and various looping statements to support item-by-item array assignment and iterative calculations.

In particular, the program flow statements provided by the Script element consist of the following:

- If-Else statements;
- For loops;
- Do loops;
- Repeat-Until loops;
- While loops; and

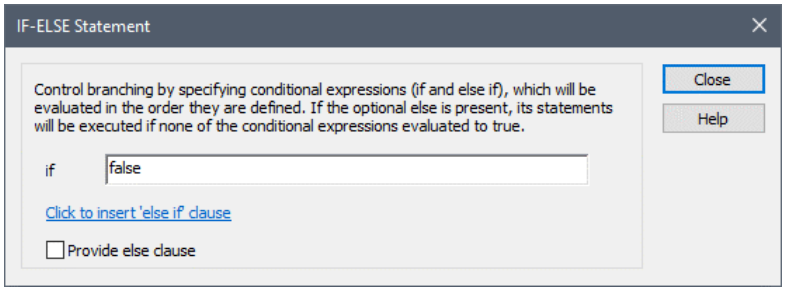
- Break and Continue statements.

These are discussed in the sections below.

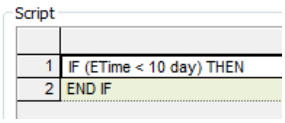
If-Else Statements in Scripts

If-Else statement blocks are used to test conditions that control branching of statement execution within a script. Else-if and Else instructions within the statement block provide a significant amount of control and flexibility.

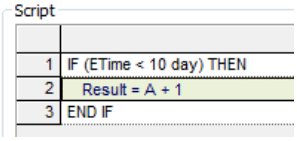
An If-Else statement block can be inserted by selecting "IF-ELSE Statement" from the Script element's **Insert** menu (or pressing **Ctrl+I** when in the Script dialog). The block is inserted below the statement that was selected when this is done. The following dialog will be displayed:



The condition defaults to False. You must enter a statement which evaluates to True or False (e.g., "Etime < 10 day"). After doing so, the script will look like this:



Obviously, such a statement block serves no function unless it contains some statements inside the block. To insert a statement inside the block, you would select the first part of the If-Else block (in this case, line 1), and insert a statement. In the example below, a Variable Assignment statement has been inserted:



In this case, when the Script element was updated, if Etime was less than 10 days, Result would be set to A + 1 (A is an output external to the Script element).

You can also move existing statements that are above or below the If-Else block into the block by using the buttons at the bottom of the Script dialog.

Read more: Moving Statements in Scripts (page 957).

Note: If multiple statements are selected (by left-clicking and dragging the line numbers) when the If-Else statement is first inserted (and the selection is a logically complete block of code), GoldSim will "wrap" the selection in the initial If statement.

In many cases, an If-Else block will have multiple branches. The simplest such case is one in which the original If condition results in one branch if it is True,

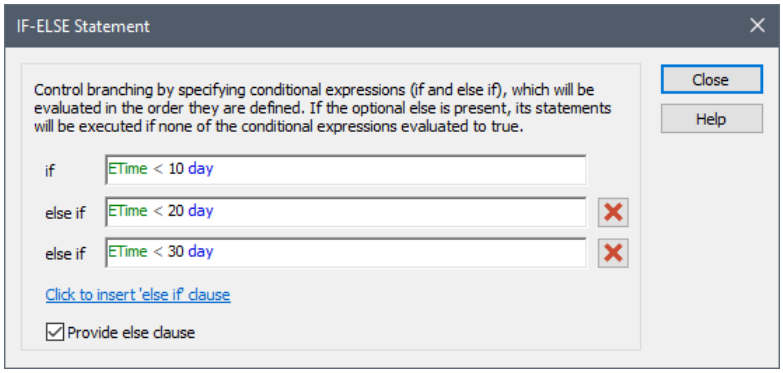
and a separate branch if it is False. This can be implemented by checking **the Provide else clause** box in the If-Else dialog. In the example below, an *else clause* (and a corresponding Variable Assignment) has been added:

Script

```
1  IF (ETime < 10 day) THEN
2    Result = A + 1
3  ELSE
4    Result = A + 2
5  END IF
```

(The Variable Assignment statement could be added to the *else clause* by selecting the ELSE statement (line 3 in this case) and inserting the new statement, or moving it from elsewhere in the script.)

If you need more complex branching, up to four *else if clauses* can be inserted by clicking the **Click to insert "else if" clause** hyperlink on the If-Else dialog. In the example below, two clauses are inserted:



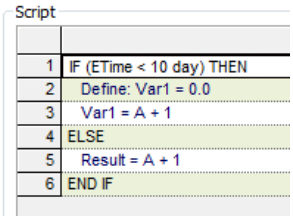
After inserting corresponding Variable Assignments for each clause, the script would look like this:

Script

```
1  IF (ETime < 10 day) THEN
2    Result = A + 1
3  ELSE IF (ETime < 20 day)
4    Result = B
5  ELSE IF (ETime < 30 day)
6    Result = C
7  ELSE
8    Result = A + 2
9  END IF
```

Note: Within an If-Else statement block, *if* and *else if* conditions are evaluated sequentially. As soon as a True statement is found, the statements corresponding to that clause are implemented, and the remaining clauses are skipped. Hence, if two clauses have conditions that evaluate to True, only the statements associated with the first one are implemented.

One key property of If-Else statement blocks that must be understood is that each clause creates local scopes for any variables that are defined within them. For example, consider the following script:



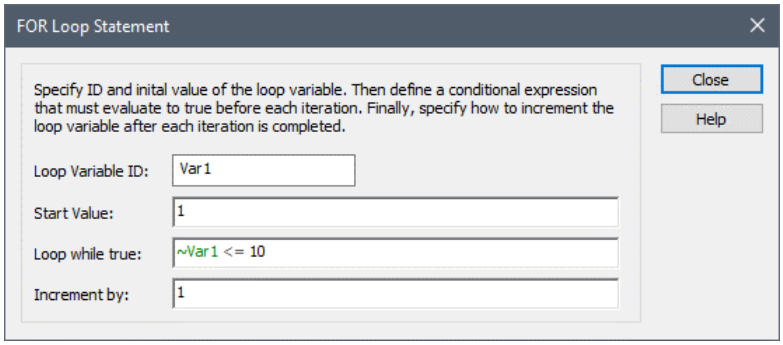
In this example, the local script variable Var1 is created in the first clause. This variable is local to that clause. That is, it cannot be referenced outside of that clause (without redefining it). If you wanted to reference it throughout the entire If-Else block, you would need to define it prior to the If-Else block.

Read more: Understanding Variable Scope in a Script (page 954).

For Loops in Scripts

For loops are one of four different types of loops provided in the Script element. They are used to loop through a set of statements. Common applications are defining and manipulating arrays, and doing an iterative calculation. For loops will be familiar to C/C++ programmers (although you certainly do not need to be familiar with these languages to use them). They require an initial integer value for the loop variable, a "Loop while true" condition, and an integer defining how the loop variable is incremented.

A For loop can be inserted by selecting "FOR Loop" from the Script element's **Insert** menu (or pressing **Ctrl+F** when in the Script dialog). The block is inserted below the statement that was selected when this is done. The following dialog will be displayed:



The first field is the name of the loop variable. This becomes a local variable within the loop (identical to having used a Variable Definition statement to create a variable).

Note: This cannot be the name of an existing script variable. You must define a new variable here.

The remaining three fields are expression fields (i.e., they can be defined as an expression):

Start Value. This is the initial value of the loop variable. It must be specified as a dimensionless scalar value. It is rounded to the nearest integer value.

Loop while true. This must be specified as a scalar condition. This condition is evaluated at the beginning of each loop (including the first loop). If it is True, the loop is executed. If it is false, control drops out the bottom of the loop.

Increment by. After a loop is completed, if the "Loop while true" condition is True, the loop variable is incremented by this value before returning to the top of the loop. It must be specified as a dimensionless scalar value (it can be positive or negative). It is rounded to the nearest integer value.

Note: If you do not change the default settings, the loop will be carried out 10 times.

Note: When the loop variable is referenced (either in the loop definition or any statements that are subsequently added to the contents of the loop), it is referenced using the ~ operator. This is because the loop variable, like all local script variables, is a locally available property. Locally available properties are only available in specific (local) parts of the model.

Read more: Understanding Locally Available Properties (page 874).

After defining the properties of the For loop, the script will look like this:

Script

	Statement List
1	FOR (Var1 = 1; ~Var1 <= 10; Var1 = ~Var1 + 1)
2	END FOR

Note that the first line indicates the start value, loop while true condition, and the increment.

Obviously, such a loop serves no function unless it contains some statements inside the looping block. To insert a statement inside the block, you would select the first part of the block (in this case, line 1), and insert a statement. In the example below, a Variable Assignment statement has been inserted:

Script

	Statement List
1	FOR (Var1 = 1; ~Var1 <= 10; Var1 = ~Var1 + 1)
2	Result = ~Result + 1
3	END FOR

In this case, every time the Script element was updated, Result would be incremented by 1.

You can also move existing statements that are above or below the loop into the loop by using the buttons at the bottom of the Script dialog.

Read more: Moving Statements in Scripts (page 957).

Note: If one or more statements are selected (by left-clicking and dragging the line numbers) when the For loop is first inserted (and the selection is a logically complete block of code), GoldSim will "wrap" the selection in loop.

Because the loop variable is simply a local script variable, it can also be assigned values within the loop (i.e., in addition to being incremented at the end of each loop). For example, this loop would be interrupted if A = B:

Script

	Statement List
1	FOR (Var1 = 1; ~Var1 <= 10; Var1 = ~Var1 + 1)
2	Result = ~Result + 1
3	Var1 = if(A=B, 11,~Var1)
4	END FOR

For loops can have any number of statements within them. For example, a For loop could contain other nested loops, as well as complex if, then logic. Here is an example of a For loop with a nested For loop and an If-Else block:

Script

```
1  FOR (X = 1; ~X <= 100; X = ~X + 1)
2    FOR (Y = 1; ~Y <= 20; Y = ~Y + 1)
3      IF (~X < 50) THEN
4        Result[~X,~Y] = ~Y
5      ELSE
6        Result[~X,~Y] = 2*~Y
7      END IF
8    END FOR
9  END FOR
```

Read more: If-Else Statements in Scripts (page 943).

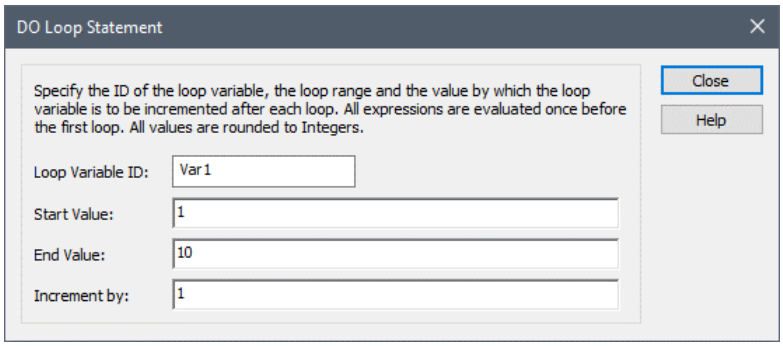
One key property of For loops that must be understood is that the loop creates a local scope for any variables that are defined within it. Hence, the loop variable (and any other variables defined in the loop) could not be referenced outside of the loop (without first redefining them).

Read more: Understanding Variable Scope in a Script (page 954).

Do Loops in Scripts

Do loops are one of four different types of loops provided in the Script element. They are used to loop through a set of statements. Common applications are defining and manipulating arrays, and doing an iterative calculation. Do loops will be familiar to FORTRAN programmers (although you do not need to be familiar with that language to use them). They require an initial integer value for the loop variable, an end value for the variable and an integer defining how the loop variable is incremented.

A Do loop can be inserted by selecting "DO Loop" from the Script element's **Insert** menu (or pressing **Ctrl+O** when in the Script dialog). The block is inserted below the statement that was selected when this is done. The following dialog will be displayed:



The first field is the name of the loop variable. This becomes a local variable within the loop (identical to having used a Variable Definition statement to create a variable).

Note: This cannot be the name of an existing script variable. You must define a new variable here.

The remaining three fields are expression fields (i.e., they can be defined as an expression):

Start Value. This is the initial value of the loop variable. It must be specified as a dimensionless scalar value. It is rounded to the nearest integer value.

End Value. This is the end value of the loop variable. It must be specified as a dimensionless scalar value. It is rounded to the nearest integer value.

Increment by. This is the increment of the loop variable. It must be specified as a dimensionless scalar value. It is rounded to the nearest integer value.

At the beginning of the first loop, the total number of loops to be carried out is computed as follows:

(**End Value** - **Start Value** + **Increment by**)/ **Increment by**

Three points should be noted here:

- If the number of loops computed above is negative, no loops are carried out;
- If **Increment by** is positive and **Start Value** > **End Value**, no loops are carried out; and
- If **Increment by** is negative and **Start Value** < **End Value**, no loops are carried out.

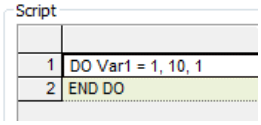
Note: Because the number of loops is computed at the beginning of the first loop, changing the Loop Variable in the middle of the loop has no impact on the number of loops carried out.

Note: If you do not change the default settings, the loop will be carried out 10 times.

Note: When the loop variable is referenced (i.e., in any statements that are subsequently added to the contents of the loop), it is referenced using the ~ operator. This is because the loop variable, like all local script variables, is a locally available property. Locally available properties are only available in "locally available" parts of the model.

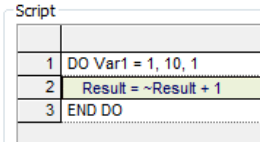
Read more: Understanding Locally Available Properties (page 874).

After defining the properties of the Do loop, the script will look like this:



Note that the first line indicates the start value, the end value, and the increment.

Obviously, such a loop serves no function unless it contains some statements inside the looping block. To insert a statement inside the block, you would select the first part of the block (in this case, line 1), and insert a statement. In the example below, a Variable Assignment statement has been inserted:



In this case, every time the Script element was updated, Result would be incremented by 10. Hence, if the model had 10 timesteps, at the end of the simulation, Result would equal 110, since the loop would be evaluated 11 times (the loop is evaluated at Etime = 0 and every subsequent timestep).

You can also move existing statements that are above or below the loop into the loop by using the buttons at the bottom of the Script dialog.

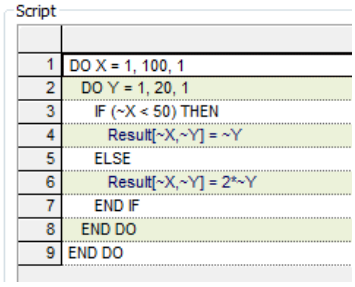
Read more: Moving Statements in Scripts (page 957).

Note: If multiple statements are selected (by left-clicking and dragging the line numbers) when the Do loop is first inserted (and the selection is a logically complete block of code), GoldSim will "wrap" the selection in the loop.

Warning: Unlike For loops, in a Do loop, the loop variable should generally *not* be assigned values within the loop. If it is, it will have no effect on the number of loops since the original increment logic is restored at the bottom of each loop.

Read more: For Loops in Scripts (page 945).

Do loops can have any number of statements within them. For example, a Do loop could contain other nested loops, as well as complex if, then logic. Here is an example of a Do loop with a nested Do loop and an If-Else block:



Read more: If-Else Statements in Scripts (page 943).

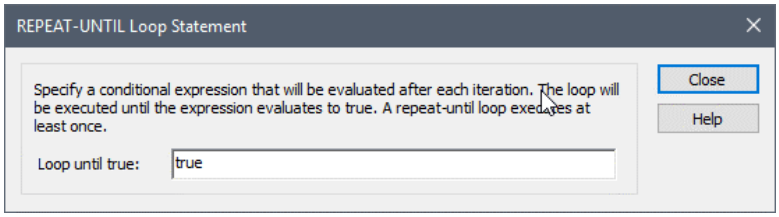
One key property of Do loops that must be understood is that the loop creates a local scope for any variables that are defined within it. Hence, the loop variable (and any other variables defined in the loop) could not be referenced outside of the loop (without first redefining them).

Read more: Understanding Variable Scope in a Script (page 954).

Repeat-Until Loops in Scripts

Repeat-Until loops are one of four different types of loops provided in the Script element. They are used to loop through a set of statements. Common applications are defining and manipulating arrays, and doing an iterative calculation. Repeat-Until loops require a single input: a condition that specifies whether the loop is to continue (which is evaluated at the bottom of the loop). As a result, a Repeat-Until loop is always evaluated at least once.

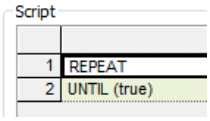
A Repeat-Until loop can be inserted by selecting "REPEAT-UNTIL Loop" from the Script element's **Insert** menu (or pressing **Ctrl+P** when in the Script dialog). The block is inserted below the statement that was selected when this is done. The following dialog will be displayed:



Loop until true must be specified as a scalar condition. This condition is evaluated at the end of each loop. If it is False, another loop is carried out. If it is True, control drops out the bottom of the loop.

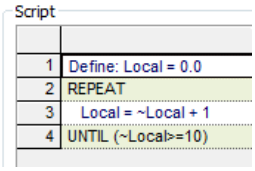
Note: If the condition is initially True (the default), one loop will be carried out.

After defining the properties of the Repeat-Until loop, the script will look like this:



Note that the last line indicates the "loop until" condition.

Obviously, such a loop serves no function unless it contains some statements inside the looping block. To insert a statement inside the block, you would select the first part of the block (in this case, line 1), and insert a statement. In the example below, a Variable Assignment statement has been inserted (and a condition has been defined):



In general, the condition for the Repeat-Until loop will involve a local variable that is also being assigned inside the loop. In this example, when control exits the loop, the variable Local would be incremented by 10.

You can also move existing statements that are above or below the loop into the loop by using the buttons at the bottom of the Script dialog.

Read more: Moving Statements in Scripts (page 957).

Note: If multiple statements are selected (by left-clicking and dragging the line numbers) when the Repeat-Until loop is first inserted (and the selection is a logically complete block of code), GoldSim will "wrap" the selection in the loop.

Repeat-Until loops can have any number of statements within them. For example, a Repeat-Until loop could contain other nested loops, as well as complex if, then logic. Here is an example of a Repeat-Until loop with a nested Repeat-Until loop and an If-Else block:

Script

```
1  Define: X = 1
2  Define: Y = 1
3  REPEAT
4    REPEAT
5      IF (~X < 50) THEN
6        Result[~X,~Y] = ~Y
7      ELSE
8        Result[~X,~Y] = 2*~Y
9      END IF
10     Y = ~Y+1
11   UNTIL (~Y >= 20)
12   X = ~X + 1
13 UNTIL (~X >= 100)
```

Read more: If-Else Statements in Scripts (page 943).

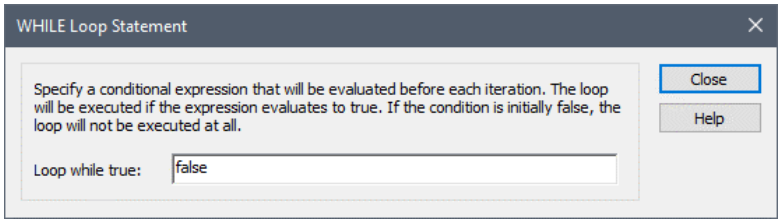
One key property of Repeat-Until loops that must be understood is that the loop creates a local scope for any variables that are defined within it. Hence any variables defined in the loop could not be referenced outside of the loop (without first redefining them).

Read more: Understanding Variable Scope in a Script (page 954).

While Loops in Scripts

While loops are one of four different types of loops provided in the Script element. They are used to loop through a set of statements. Common applications are defining and manipulating arrays, and doing an iterative calculation. While loops are a common construct in a number of programming languages. They require a single input: a condition that specifies whether the loop is to continue (the condition is evaluated at the top of the loop).

A While loop can be inserted by selecting "WHILE Loop" from the Script element's **Insert** menu (or pressing **Ctrl+W** when in the Script dialog). The block is inserted below the statement that was selected when this is done. The following dialog will be displayed:



Loop while true must be specified as a scalar condition. This condition is evaluated at the beginning of each loop. If it is True, another loop is carried out. If it is False, control drops out the bottom of the loop.

Note: If the condition is initially False (the default), no loops will be carried out at all.

After defining the properties of the While loop, the script will look like this:

Script

1	WHILE (false)
2	END WHILE

Note that the first line indicates the loop's "while" condition.

Obviously, such a loop serves no function unless it contains some statements inside the looping block. To insert a statement inside the block, you would select the first part of the block (in this case, line 1), and insert a statement. In the example below, a Variable Assignment statement has been inserted (and a condition has been defined):

Script

1	Define: Local = 0.0
2	WHILE (~Local<10)
3	Local = ~Local+1
4	END WHILE

In general, the condition for the While loop will involve a local variable that is also being assigned inside the loop. In this example, when control exits the loop, the variable Local would be incremented by 10.

You can also move existing statements that are above or below the loop into the loop by using the buttons at the bottom of the Script dialog.

Read more: Moving Statements in Scripts (page 957).

Note: If multiple statements are selected (by left-clicking and dragging the line numbers) when the While loop is first inserted (and the selection is a logically complete block of code), GoldSim will "wrap" the selection in the loop.

While loops can have any number of statements within them. For example, a While loop could contain other nested loops, as well as complex if, then logic. Here is an example of a While loop with a nested While loop and an If-Else block:

Script

1	Define: X = 1
2	Define: Y = 1
3	WHILE (~X<=100)
4	WHILE (~Y<=20)
5	IF (~X < 50) THEN
6	Result[~X,~Y] = ~Y
7	ELSE
8	Result[~X,~Y] = 2*~Y
9	END IF
10	Y = ~Y+1
11	END WHILE
12	X = ~X + 1
13	END WHILE

Read more: If-Else Statements in Scripts (page 943).

One key property of While loops that must be understood is that the loop creates a local scope for any variables that are defined within it. Hence any variables defined in the loop can not be referenced outside of the loop (without first redefining them).

Read more: Understanding Variable Scope in a Script (page 954).

Break and Continue Statements in Scripts

Break and Continue statements are used within loops (For, Do, While and Repeat-Until) to redirect script execution. These statements can only be used inside a loop. Outside of a loop, they have no meaning and will generate an error.

A Break statement can be inserted by selecting "BREAK Statement" from the Script element's **Insert** menu (or pressing **Ctrl+B** when in the Script dialog). A Continue statement can be inserted by selecting "CONTINUE Statement" from the Script element's **Insert** menu (or pressing **Ctrl+T** when in the Script dialog). There are no inputs for a Break or Continue statement; hence there is no dialog. When you insert one of these statements, they are simply added to the script.

Break statements break out of the loop. That is, they redirect execution to the statement *following* the loop in which they are contained. Hence, Break statements are usually placed within an if statement inside of a loop to conditionally exit the loop earlier than planned.

For example, in the script below, when ETime is equal to 0 (i.e., the first time the element is updated), the loop will be broken on the second time through (i.e., when n = 2). As a result, *Result* will only be incremented once.

Script

```
1  DO n = 1, 10, 1
2    IF (ETime = 0 day and ~n > 1) THEN
3      BREAK
4    END IF
5    Result = ~Result+1
6  END DO
```

Note: A Break statement within nested loops breaks the nearest enclosing loop

Continue statements transfer control to the bottom of the enclosing loop. That is, they do not break out of the loop completely, they simply skip the statements between the Continue statement and the bottom of the loop.

For example, in the script below, a vector (X) is being defined in a Do loop. In this case, the first 5 items of the vector are not assigned (they are skipped). Items 6 through 20, however, are assigned.

Script

```
1  Define: X[*] = vector(0)
2  DO n = 1, 20, 1
3    IF (~n <= 5) THEN
4      CONTINUE
5    END IF
6    X[~n] = ~n
7  END DO
```

Note: A Continue statement within nested loops transfers control to the bottom of the nearest enclosing loop.

Understanding Variable Scope in a Script

In order to effectively use Script elements in GoldSim, it is important to understand the concept of **variable scope**.

When a variable is defined in a script (either by a Variable Definition statement, or by a Do or For loop, which implicitly define loop variables), the variable persists (and hence can be referenced) from the time it is defined to the statement that closes the scope in which the variable is defined.

The scope of script variables that are 1) not inside a loop; and 2) not inside an If-Else statement consists of all lines of the script below the definition. That is, they persist until the last statement in the script.

However, script variables defined in loops or If-Else statements do not persist throughout the remainder of the script. Their scope is limited to the the loop or If-Else clause where they are defined.

To illustrate this, let's first consider a simple Do loop:

Script

```
1  DO n = 1, 10, 1
2    Define: k = 0.0
3    k = ~k+1
4  END DO
5  Result = ~k
```

Within this script, there are actually two variables that have been defined: 1) n is defined implicitly by the Do loop; and 2) k is defined explicitly by a Variable Definition statement. For both of these variables, the scope is the Do loop itself. The scope does not extend beyond the Do loop. Hence, neither n nor k can be referenced outside the loop. In the example, k is referenced outside of the loop, and this generates an error (line 5 is displayed in red, and the model will not run).

In order to reference k outside the loop, it would have to be redefined *after* the loop:

Script

```
1  DO n = 1, 10, 1
2    Define: k = 0.0
3    k = ~k+1
4  END DO
5  Define: k = 0.0
6  Result = ~k
```

In the example above, k ceased to exist after line 4, and then was redefined at line 5. Hence, the two scopes do not overlap. Note that defining k before (and within the loop) would have generated an error. That is, the following script is invalid:

Script

```
1  Define: k = 5
2  DO n = 1, 10, 1
3    Define: k = 0
4    k = ~k+1
5  END DO
6  Result = ~k
```

In this case, line 3 is displayed in red and marked as invalid. The reason for this error is that since k was defined in line 1, its scope is the entire script. Hence, when we try to define it again in line 3, an error is generated because the two scopes overlap. Defining the same variable twice within the same scope generates a redefinition error. In the previous example, there was no error because the scopes did not overlap.

This same logic also applies for the other looping constructs in GoldSim (For loops, While loops, and Repeat-Until loops).

Read more: Controlling Program Flow in the Script Element (page 942).

If-Else statement blocks also create local scopes. In this case, the scope of any variables inside an If-Else statement block is not the entire block; rather, each clause creates local scopes for any variables that are defined within them. For example, consider the following script:

Script

1	IF (ETime < 10 day) THEN
2	Define: Var1 = 0.0
3	Var1 = A + 1
4	ELSE
5	<Var1>[?] = A + 2
6	END IF

In this example, the local script variable Var1 is created in the first clause. The scope of this variable is only that clause (lines 2 and 3). Hence, it cannot be referenced outside of that clause (without redefining it). Referencing it in the second clause generates an error.

If you wanted to reference it throughout the entire If-Else block, you would need to define it prior to the If-Else block:

Script

1	Define: Var1 = 0.0
2	IF (ETime < 10 day) THEN
3	Var1 = A + 1
4	ELSE
5	Var1 = A + 2
6	END IF

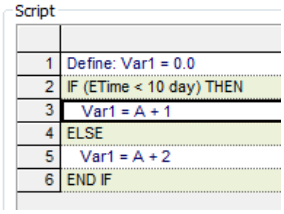
Editing Scripts

Scripts are created by inserting and editing individual statements (e.g., variable definition statements, variable assignment statements) or statement blocks (e.g., loops, if statements).

Statements are inserted and edited within a "controlled environment" within the element's property dialog in which the user selects from a number of available statement types. The syntax is already defined for each type of statement – the user simply specifies the attributes and properties for each statement via a dialog box when the statement is inserted. Statements can subsequently be moved, deleted, and edited.

Read more: Inserting Statements into a Script (page 932).

The active line of the script is outlined in black.



Line 3 (outlined in black) is the active line.

To change the active line of the script, you can use the Up and Down arrow keys, or click on a statement of the script using the mouse. Holding the **Ctrl** key down while pressing the Up or Down arrow jumps to the top or bottom of the script, respectively. Once a statement is highlighted, it can be opened for editing by double-clicking or pressing **Alt-Enter**.

A valid script statement is shown in black text. Invalid statements are shown in red text.

The sections below discuss hot-keys provided to quickly insert statements and edit scripts, as well as how to delete and move script statements.

Hot-keys for Quickly Creating and Editing Scripts

GoldSim provides a number of hot-keys for accessing common Script element functions directly from the keyboard:

Hot-key	Description
Ctrl+D	Inserts a Variable Definition statement
Ctrl+A	Inserts a Variable Assignment statement
Ctrl+I	Inserts If-Else statement block
Ctrl+F	Inserts FOR loop statement block
Ctrl+O	Inserts DO loop statement block
Ctrl+P	Inserts REPEAT-UNTIL loop statement block
Ctrl+W	Inserts WHILE loop statement block
Ctrl+M	Inserts a Comments statement
Ctrl+L	Inserts a Log Message statement
Ctrl+N	Inserts a Log Warning statement
Ctrl+R	Inserts a Log Error statement
Ctrl+Delete	Deletes selected statement(s)
Ctrl+Shift+Delete	Deletes all statements
Cursor Up	Select previous statement
Cursor Down	Select next statement
Ctrl+Cursor Up	Selects first statement
Ctrl+Cursor Down	Selects last statement
Alt+Enter	Edits active statement (opens dialog)
Ctrl+Shift+Cursor Up	Moves active statement up by one row
Ctrl+Shift+Cursor Down	Moves active statement down by one row

In addition to these, several additional hot-keys are used for debugging scripts.

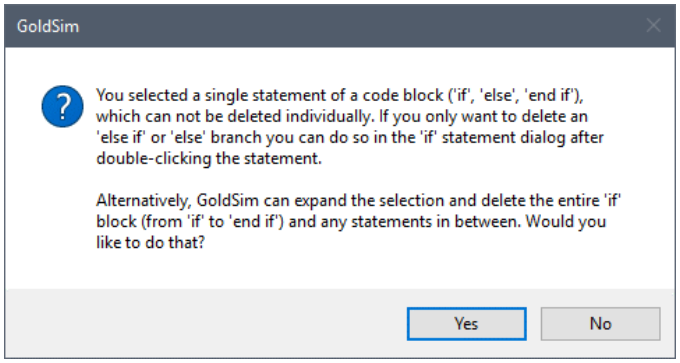
Read more: Debugging Scripts (page 959).

Note: If you use one of the statement insertion hot-keys, the statement(s) will be inserted immediately *after* the active line of the script. If you use one of the insertion hot-key combinations *while holding down the shift key*, the inserted statement(s) will appear before rather than after the active line.

Note: When inserting statement blocks (e.g., If-Else statement, For loops), you can select one or more statements in an existing script (by left-clicking and dragging the line numbers), and when you use insertion hot-keys, GoldSim will "wrap" the statement block around the selected statements. Note, however, that this requires that the selection is a logically complete block of code (e.g., you could not select a portion of another loop).

Deleting Statements from Scripts

If a single line of a script is highlighted, it can be deleted by pressing **Ctrl+Delete** or using the **Delete** button at the bottom of the Script dialog. If you try to delete a single line that is part of a loop definition or an If-Else statement block, however, you will see a message similar to this:



As can be seen, the dialog asks if you want GoldSim to automatically expand the selection to delete the entire loop or if statement (**Yes**), or cancel the deletion (**No**).

If you would like to delete a contiguous block of statements, you can select them by highlighting their line numbers (by clicking and dragging). Once you have selected them this way, you can press **Ctrl+Delete** or use the **Delete** button on the Script element. Note, however, when you are deleting multiple statements, the highlighted block of statements for deletion must be a logically complete block of statements. For example, you could not delete just a portion of a For loop or If-Else statement block.

Note: Ctrl-Shift-Delete will delete all statements in a script.

Moving Statements in Scripts

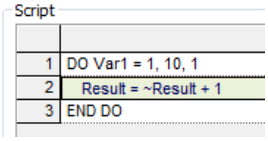
One or more statements can be moved by highlighting them and pressing **Ctrl+Shift+Up** or **Ctrl+Shift+Down**, or by using the **Move Up** or **Move Down** buttons at the bottom of the Script dialog.

There are, however, several rules that determine when GoldSim will allow a given selection to be moved. A statement that opens a scope, such as an IF statement or DO loop, cannot be moved to below the statement that closes the

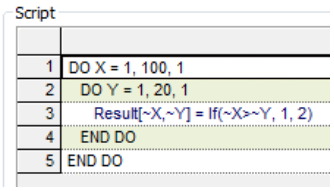
scope (e.g., the corresponding ELSE, ELSE IF, of End IF statement for an IF or the END DO for a DO loop). Similarly, a statement that closes a scope cannot be moved up to above the statement that opens a scope.

Read more: Understanding Variable Scope in a Script (page 954).

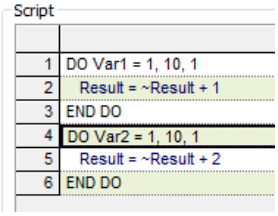
For example, in the script shown below, the line 1 could not be moved below line 3 because doing so would move a scope-opening statement below the corresponding scope-closing statement. Similarly, line 3 could not be moved above line 1.



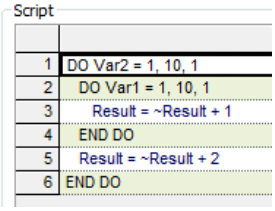
A selection of an incomplete scope, such as one that includes a DO statement without the corresponding END DO statement, cannot be moved into a higher scope or a lower nested scope, as this would create an illogical script where the scope-opening statement becomes separated from its corresponding scope-closing statement. For example, in the script shown below, line 2 cannot be moved up and line 4 cannot be moved down, but if you selected lines 2 through 4 at the same time, you would be able to move the entire Do loop statement block.



If you select an incomplete scope and attempt to move it up/down into another scope that is at the same level, the selection will be moved up/down *past* the other scope, which will have the result that the scopes will be nested. As an example of this, consider the following script:



If you try to move line 4 up, it is moved all the way to the top, resulting in nested Do loops:

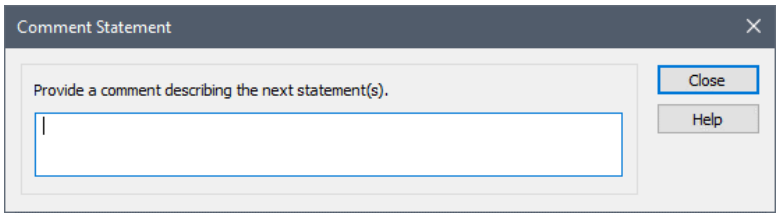


Documenting Scripts

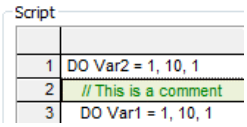
Particularly for complex scripts, it is very important that you document them internally. Comment statements provide an effective way to do this.

Comments can be inserted throughout scripts to document the statements and logic.

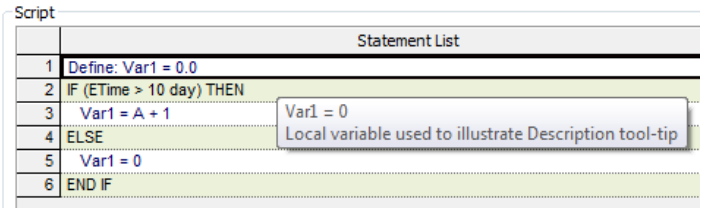
Comments can be inserted by selecting "COMMENT statement" from the Script element's **Insert** menu (or pressing **Ctrl+M** when in the Script dialog). The comment is inserted below the statement that was selected when this is done. The following dialog will be displayed:



Comments can be up to 100 characters long. They appear in the script as green text, prefaced by a double forward slash:



It should also be pointed out that the Description entered when a local variable is created in a script also serves as an excellent documentation tool. These descriptions are shown in tool-tips when you hover over a Variable Definition or Variable Assignment statement:

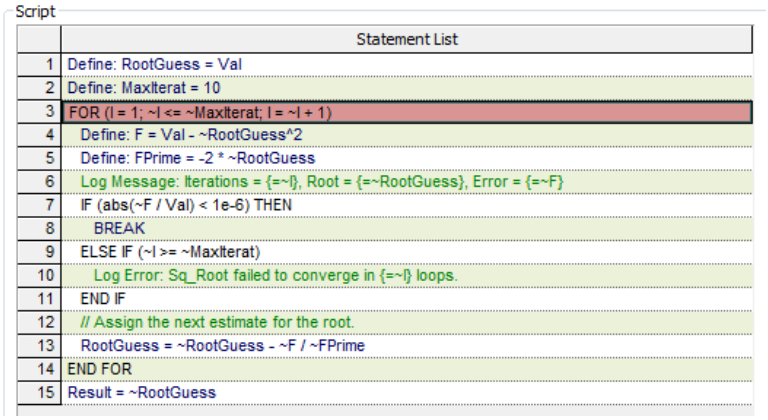


Debugging Scripts

In order to create and test scripts (particularly those with complex branching and looping), it is necessary to be able to step through the script to debug it.

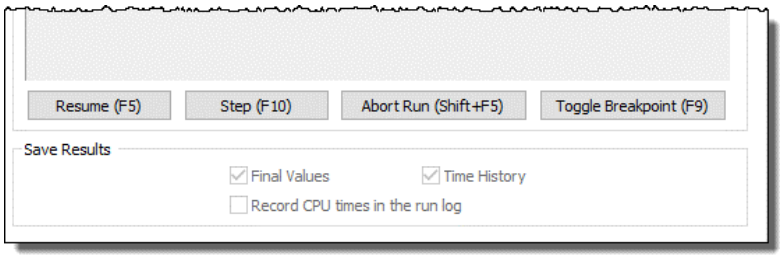
GoldSim facilitates this by allowing you to create ***breakpoints*** in your script. A breakpoint provides a mechanism for pausing a simulation in the middle of a script, and subsequently allowing you to step forward (line by line), abort the calculation, or resume the calculation.

To insert a breakpoint in a script, select (highlight) the line where you would like to insert the breakpoint and press **F9**, or right-click and select **Breakpoint**. (You can remove a breakpoint by pressing **F9**, or right-clicking and selecting **Breakpoint** again). Lines with breakpoints have a red background in the script statement list. In the example below, there is a single breakpoint inserted (at line 3):



When you run the model, at the point when a breakpoint is reached, the model will pause, and the Script element will be opened.

When a script is paused at a breakpoint, you will notice that the buttons at the bottom of the Script dialog differ from those that are displayed when the model is in Edit Mode:



The *next* line to be evaluated is outlined in black. Hence, when you first reach a breakpoint, the line where the breakpoint was inserted will be outlined in black. Note that a line that is outlined in black *has not yet been evaluated*. The calculation is actually paused immediately prior to that line.

From the paused state in a Script element you can do the following to debug the script:

- You can hover your mouse over variables in the script to see their current values. Note that if you hover over an If statement (or a While or Repeat-Until statement), it will display the statement condition (True or False). When you hover over a For or Do loop, it will display the loop counter.

  When hovering over lines to see values and debug the script, it is important to recall that a line that is outlined in black (because you have broken at that line or stepped to that line), *has not yet been evaluated*. That is, an outlined line indicates that execution is paused immediately prior to the line.

- You can press the **Resume** button or press **F5** and execution will proceed from where it is paused (until it reaches a breakpoint again).

- You can abort the model run by pressing the **Abort Run** button or pressing **Shift+F5**.

- You can turn off a breakpoint by highlighting it and pressing the **Toggle Breakpoints** button or pressing **F9**.

- You can add a new breakpoint by highlighting a line and pressing the **Toggle Breakpoints** button or pressing **F9**.
- You can press the **Step** button or press **F10** to step through execution one line at a time.

Breakpoints are not saved with the model. That is, once you close the model file, all breakpoints are intentionally removed. You will have to re-insert them if your debugging takes place over multiple GoldSim sessions.

In some cases, in order to fully understand and debug a script, you may want to print it out. You can do this from a button on the Script dialog.

Read more: Printing Scripts (page 963).

Log statements, which allow results and text to be written to the model Run Log, are also useful for debugging. These are discussed in the next section.

Logging Messages in Scripts

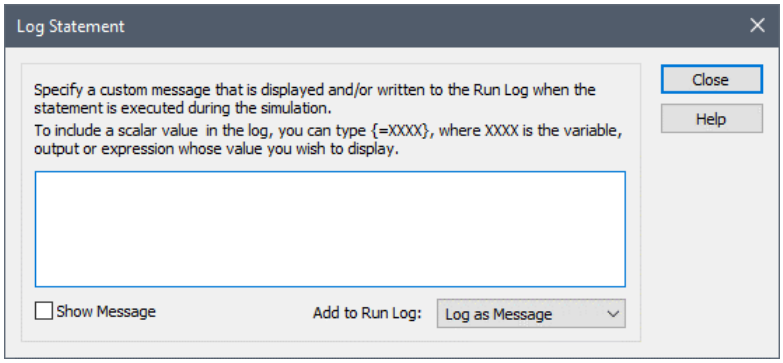
Log statements allow you to write text and computed results to the model's Run Log. This can also be useful for debugging scripts. The content can be a simple message, a warning, or a fatal error.

Read more: The Run Log (page 569).

There are three types of Log statements. All three can be inserted by selecting the appropriate type from the Script element's **Insert** menu (or pressing the appropriate hot-key when in the Script dialog):

Log Type	Hot-Key	Behavior
Message	Ctrl+L	Writes a message to the Run Log; however, no warning is displayed after the run.
Warning	Ctrl+N	Writes a message to the Run Log; a warning is displayed after the run to alert the user.
Error	Ctrl+R	Writes a message to the Run Log; treated as a fatal error (the simulation is stopped).

The Log statement is inserted below the statement that was highlighted at the time the new statement was selected for insertion. The following dialog will be displayed:

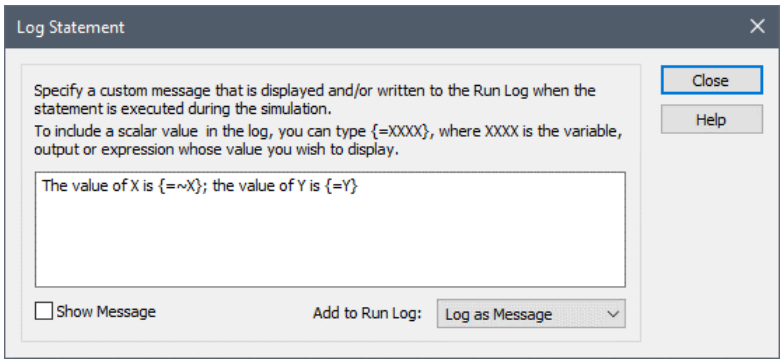


Note that at the bottom of the dialog you can modify the type of Log statement (Message, Warning or Error). If you check the **Show Message** checkbox, the message will also appear in a pop-up window during the simulation whenever the statement is executed.

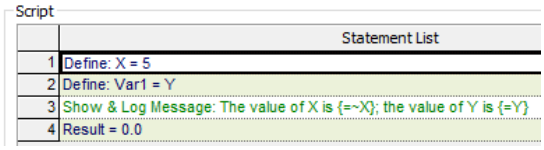
One of the most powerful features of the Log statement is that you can write the value of a variable, output or expression in the message. To include a scalar

value in the log, type {=VALUE}, where VALUE is the output, variable or expression whose value you wish to display.

For example, assume you had a script variable named X, and an external output (an output from outside the Script that was referenced inside the Script) named Y. A Log message statement like this:

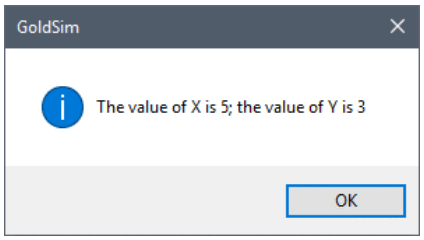


would look like this in the script:



Note: When referencing script variables in a Log statement, they must be referenced using the ~ (since they are locally available properties).

The message that would be displayed in a pop-up would look like this:

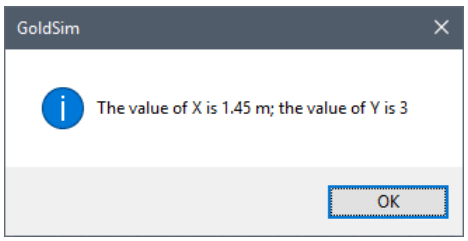


In the Run Log, it would look like this:

```
Realization 1

0 day:
\Script1: Script Message: The value of X is 5; the value of Y is 3
```

If the variables for which you are writing values have units, the units will be displayed. For example, if X was a length, this would be indicated in the message:



However, *you cannot control the units in which they are displayed*. They are always displayed in the base units for the particular dimension (e.g., meters for lengths, seconds for time).

Note: No links are created by referencing external elements in a script Log statement. Since there are no links, the causality sequence is **not** affected in any way by the existence of the expression or reference. This means that the previous (rather than current) value of an element's output could potentially be shown if the referenced element follows the Script element in the causality sequence. Usually, however, this issue will not come up, as element outputs referenced in Log statements will typically have been used elsewhere in the script (and hence would come before the Script element in the causality sequence).

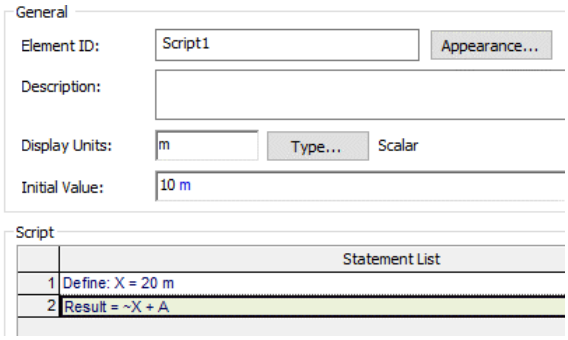
Read more: The Causality Sequence and Element Updating (page 358).

Printing Scripts

In some cases, in order to debug or modify your script, or explain it to someone else, you may want to print it out. You can do so by pressing the **Print** button on the Script dialog or by creating a text file of the Script contents using the key combination **Ctrl-Shft-Alt-S**.

When you do so, however, the printed text will not simply consist of what you would see if you were to look at the Script dialog. This is because for Variable Definition statements, there is information that is not explicitly shown in the script – the type, order and units of the variable. You must open the dialog for that statement to see this information.

Hence, when you print the script, GoldSim adds this information to the printed text. For example, consider this very simple script:



If you were to print this script, the text would look like this:

```
Script Code
-----------

Created: Oct 04, 2016 11:16:15
Element: Script1

Global Variables:
-----------------

// Implicit variable defining the result of the script.
VALUE[m] Result

Script:
-------

VALUE[m] X = 20 m
Result = ~X + A
```

Note that the text also shows the types (VALUE in this case) and units (m) for the variables, as well as descriptions. Hence, the printed script can be understood without referring back to the GoldSim model itself.

Script Examples

In order to better understand the use of Script elements, three simple example scripts are presented and briefly described in the sections below.

All three examples can be found in a file (Script.gsm) that is located in the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Script Example: Newton's Method

This simple example illustrates how the Script element can be used to carry out an iterative calculation. It can be found in a file (Script.gsm) that is located in the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu). The example uses Newton's method to calculate the square root of 101. While you're certainly not likely to need to calculate the square root of 101 by Newton's method, the model does provide a nice example of how to iterate within a script.

Newton's method is a successive approximation method for finding real roots of differentiable functions.

For a function f(X), which in this case represents the error in the approximation, which we wish to go to zero, the formula for Newton's method is:

$$X_{n+1} = X_n - \frac{f(X_n)}{f'(X_n)}$$

Where $f'(X_n)$ is the first derivative with respect to X, and X_n is the nth approximation of the root (X_0 is an initial guess for the root). Therefore, in our example of finding the square root of 101:

$f(X) = X^2 - 101$; and

$f'(X) = 2X$.

The script used for this simple example to solve for the square root of the variable Val is shown below:

Script

	Statement List
1	Define: RootGuess = Val
2	Define: MaxIterat = 10
3	FOR (I = 1; ~I <= ~MaxIterat; I = ~I + 1)
4	Define: F = ~RootGuess^2 - Val
5	Define: FPrime = 2 * ~RootGuess
6	Log Message: Iterations = {=~I}, Root = {=~RootGuess}, Error = {=~F}
7	IF (abs(~F / Val) < 1e-6) THEN
8	BREAK
9	ELSE IF (~I >= ~MaxIterat)
10	Log Error: Sq_Root failed to converge in {=~I} loops.
11	END IF
12	// Assign the next estimate for the root.
13	RootGuess = ~RootGuess - ~F / ~FPrime
14	END FOR
15	Result = ~RootGuess

The script starts out with Variable Definition statements in lines 1 and 2. Note that when script variables are referenced on the right side of equations (e.g., in line 4), a ~ symbol is required. This is because script variables are locally available properties. In line 1, the script references an element outside this Script element called Val (a constant whose square root is being sought, 101). Note that referencing another element's output does not require the ~ symbol.

Read more: Defining Local Script Variables (page 936); Assigning Values to Script Variables (page 933).

After the Variable Definition statements, a FOR loop is defined. The FOR loop starting in line 3 shows that it creates a loop variable (named "I") that is initially 1 and is incremented by 1 on each iteration, continuing while the expression "I<=MaxIterat" is true. Hence, the FOR loop executes the statements it contains until it is broken by a BREAK statement, or the loop count reaches the specified maximum number of iterations possible. In each FOR loop iteration, two more Variable Definition statements (with expressions as the assignments) compute the values for the function (F) and the derivative (FPrime). A Variable Assignment statement (line 13) then generates a new approximation of the square root at the bottom of the loop.

The IF statement block beginning at line 7 tests the approximation error in the current estimate of the square root. If it is sufficiently small, a BREAK statement is executed to terminate the FOR loop.

Read more: If-Else Statements in Scripts (page 943); Break and Continue Statements in Scripts (page 953).

If the approximation error remains high and the maximum number of iterations is reached, a LOG statement (line 10) is written to the Run Log noting that the script failed to converge. Line 6 is another LOG statement reporting the progress of the successive approximations for each iteration of the FOR loop.

Read more: Logging Messages in Scripts (page 961).

Script Example: Manipulating a Matrix

A very common application of the Script element is to construct and/or manipulate arrays. This is typically facilitated by using one of the Script element's looping constructs to assign values to rows, columns and/or individual items. The simple example described here illustrates how the Script element can be used to carry out array operations such as these. It can be found in a file (Script.gsm) that is located in the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Read more: Defining and Assigning Array Variables in a Script (page 938).

The example starts with an input matrix. In the input matrix, each column represents a variable, and each row represents an observation of the variable. The script computes the correlations among the various columns (variables) of the matrix, producing a symmetric correlation matrix (rows and columns both indexed by variable). The correlation coefficient, C_{xy}, between two columns of data (i.e., the correlation between two variables) is given by the following equation:

$$C_{xy} = \frac{\sum_{1}^{n}(x_i - m_x)(y_i - m_y)}{n s_x s_y}$$

In this equation, x and y are the variables. x_i and y_i are the i^{th} observations of variable x and y, respectively. m_x and m_y are the means of the observations for those variables (i.e., the means of all values in a particular column). s_x and s_y are the standard deviations for those observations. n is the number of observations (i.e., the number of rows).

The script used for this simple example is shown below:

Script

	Statement List
1	// Calculate standard deviations of each column
2	Define: sd[*] = sdc(Input_Matrix)
3	// Calculate the means of each column
4	Define: means[*] = meanc(Input_Matrix)
5	// Do two nested loops over the columns of the input matrix
6	DO Var2 = 1, GetColumncount(Input_Matrix), 1
7	DO Var1 = 1, GetColumnCount(Input_Matrix), 1
8	Define: temp = 0.0
9	// Do a loop up to the row count of the input matrix to sum all the squared deviations
10	DO Var3 = 1, GetRowCount(Input_Matrix), 1
11	temp = ~temp+(Input_Matrix[~Var3,~Var2]-~means[~Var2])*(Input_Matrix[~Var3,~Var1]-~me
12	END DO
13	// Finallly normalize by the product of the two column's standard deviations
14	Result[~Var1,~Var2] = ~temp/(GetRowCount(Input_Matrix)*~sd[~Var1]*~sd[~Var2])
15	END DO
16	END DO

At the top of the script (lines 2 and 4), Variable Definition statements (with expressions as the assignments) compute the means and standard deviations of each column.

Read more: Defining Local Script Variables (page 936); Assigning Values to Script Variables (page 933).

The calculation of the correlation coefficient for each column pair is then carried out using two Variable Assignment statements. The first (line 11) is in the middle of three nested DO loops. The second (line 14) is at the bottom of the second nested loop.

Read more: Do Loops in Scripts (page 947).

Script Example: Referencing a Previous Value Element in a Script

By default, a Script element has a single primary output. However, it is possible to define additional outputs for the element (with their own attributes and dimensions) when defining local variables within a script.

Read more: Understanding the Outputs of a Script Element (page 941).

There is an important difference in the behavior of the primary output and any other exposed outputs. The primary output of a Script element is a ***state variable***. A state variable provides inertia or "memory" to a system because its value is computed based on the historical value of the element's inputs (as

opposed to only being a function of the current value of the element's inputs). All state variables have, by definition, an initial value. This allows the output to be computed when there are no historical inputs available (e.g., at the start of a simulation).

Read more: Understanding State Variables in GoldSim (page 356).

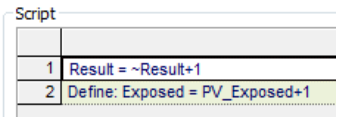
This has an important implication for how the variables can be used in a script. In particular, the value of the primary output is "remembered" between updates of the element. As a result, in a script you could create a Variable Assignment such as "Result = ~Result + 1" as the very first statement. The expression would use the *previous value* of the Result when it was evaluated. This is not possible for any of the other script variables, since they require a Variable Definition statement which initializes the variable every time the Script element is updated.

If you would like additional outputs of the Script element to be able to "remember" their previous update (and hence behave like state variables with initial conditions), you can do so by referencing the Script element's output in a Previous Value element outside of the Script element (and then referencing the Previous Value inside the script.

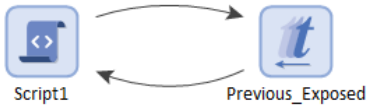
Read more: Referencing an Output's Previous Value (page 1030).

This very simple example illustrates how the Script element can be used in conjunction with a Previous Value element. It can be found in a file (Script.gsm) that is located in the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

The script simply updates the primary output (*Result*) and a secondary variable (*Exposed*) every time the Script element is updated (in this case, every timestep). In order for the defined variable (*Exposed*) to be "remembered" between timesteps, it is stored in a Previous Value element, and it is that element that is referenced by the script):

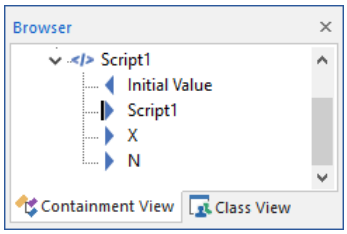


As can be seen, the script references the Previous Value element in a loop:



Browser View of a Script Element

The browser view of a Script element is shown below:



In this example, two script variables have been added as exposed outputs (N and X). By default, the Script element would only have a single output (the primary output, having the same name as the element). The Script element only has a single input – the Initial Value.

Note: Element inputs and outputs are only shown in the browser if you choose to **Show element subitems** (accessed via the browser context menu by right-clicking in the browser).

Read more: Using the Browser (page 106).

Using Conditional Containers

One of the advanced features in GoldSim is to make Containers conditional. Conditionality allows you to make a Container and all of its contents inactive until specific events occur and/or specific conditions are met.

Elements in an inactive container are "dormant". That is, they are not updated or recalculated each timestep, and while they are inactive their output values never change. When other specific events occur and/or conditions are met, the Container (and its contents) can become active (and hence carry out their normal calculations). A conditional Container can activate and deactivate multiple times during a simulation.

Conditionality is a very powerful feature, and can be used to

- temporarily "turn off" certain parts of your model (e.g., during a testing phase);
- simulate processes or features which themselves only exist or are active during certain parts of your simulation; and
- simulate projects.

As an example, suppose that you wished to model a facility (e.g., a chemical plant) which had a contingency plan for repairs following some event (e.g., an accident). This contingency plan could be represented within a conditional Container, and the Container could then be activated when the event occurred. The Container representing the contingency plan would operate (accumulating costs and other consequences) until repairs were completed, and then deactivate (until another event occurred).

A simple example which illustrates the use of conditional Containers (ConditionalContainer.gsm) can be found in the Containers subfolder of the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu). The folder also includes a more complex example of the use of conditional Containers to simulate projects (ProjectSimulation.gsm).

Behavior of Elements in Conditional Containers

Before discussing how conditional Containers can be activated and deactivated, it is useful to first explain how elements behave when they are within a conditional Container.

Elements within conditional Containers behave as follows:

- Before a Container is activated for the first time in a realization, any elements it contains behave as follows:
  - Data elements and Expressions that are static (i.e., have constant inputs or are functions of elements with constant inputs) are computed at the beginning of each realization.
  - Static Stochastic elements (Stochastics whose inputs are constant, and have no triggers) are sampled at the beginning of each realization.

  - Conditional Containers have no effect on most Time Series elements, which always output their results. Time Series elements that are set to *record*, however, cannot be placed inside a Conditional Container that can be deactivated.
  - Outputs with clearly defined non-zero initial values (i.e., Integrators, Reservoirs, Material and Information Delays, Previous Value elements, Status elements, and Milestones) take on their initial values at the beginning of each realization.
  - All other outputs are set to zero.

- Once a Container is activated, all the elements that it contains output their normal (computed) output.
- After a Container is deactivated, any elements it contains behave as follows:
  - Most outputs that are continuous (as opposed to discrete) continue to transmit their last active value.
  - The exception to this are outputs that represent material flows (e.g., the output of a Material Delay; the Overflow Rate from a Reservoir). These outflows are set to zero.

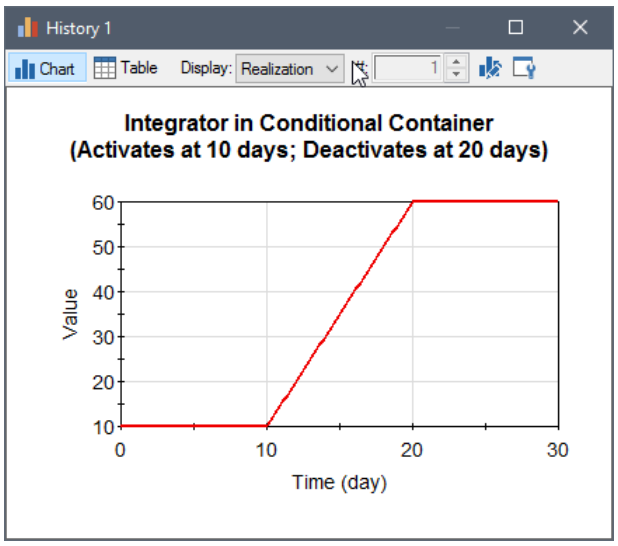
Note: When a Container is triggered to deactivate, all elements inside the Container are updated before the Container deactivates.

- While a Container is inactive,
  - All incoming material flows (e.g., Rates of Addition to Reservoirs, Flows into Material Delays) or discrete changes of material are ignored and discarded. Warning messages are written to the Run Log whenever material flows from active elements (outside the conditional Container) to inactive elements are discarded.
  - Any other discrete signals sent to inactive elements are ignored and discarded. Warning messages are written to the Run Log when discrete additions or withdrawals of material flows to inactive elements are discarded.
  - Any timed events or events triggered using an On Event trigger are ignored and discarded.
  - Any discrete or continuous signals or flows that are in transit within Delays are "frozen" (the conveyor is stopped).
  - If an inactive Container is activated at exactly the same time as some child elements are triggered, the triggers to the children are not ignored (they are applied immediately upon activation of the Container).

Warning: On Changed, On True and On False events are triggered whenever the element determines that the argument to the event has changed, become true, or become false, respectively. If the element is in a conditional Container, it does not evaluate these arguments while it is inactive, and therefore some On Changed, On True and On False events that occur while the Container is inactive can be "delayed" until the element activates (rather than ignored). For example, if an On True trigger is defined as "Etime > 15 days", and the element is inactive until 20 days, the event will actually be triggered at 20 days (since, from the element's viewpoint, this is first time that it is able to determine that the condition has become true).

As a simple example of the behavior of an element inside a conditional Container, consider an Integrator with an Initial Value of 10, and a Rate of Change of 5 per day. Assume that the Integrator was within a conditional Container that was initially inactive, was activated at 10 days, and deactivated at 20 days.

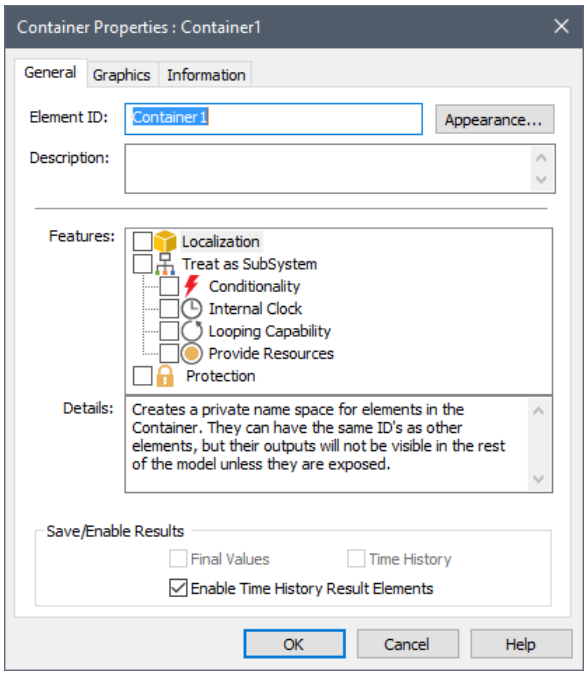
In this case, the output of the Integrator would behave as shown below:



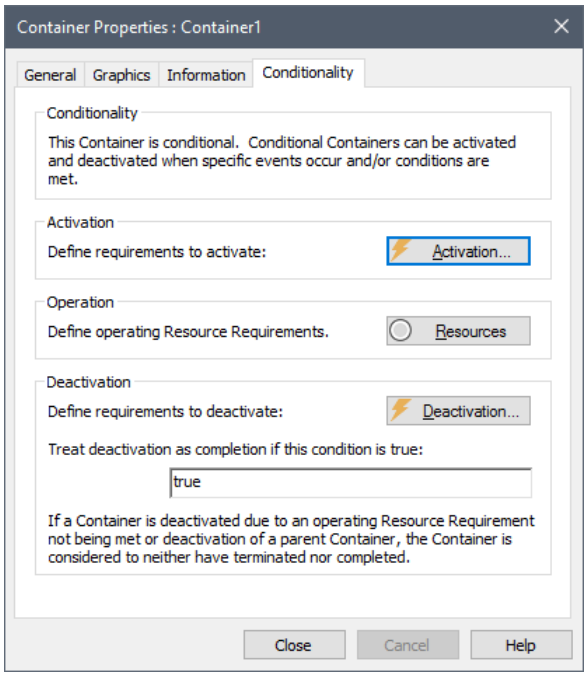
The Integrator starts at 10. It remains at 10 until the Integrator activates at 10 days. Between 10 and 20 days, the output increases linearly (to 60), and after 20 days, the output stays constant at 60.

Enabling and Disabling Conditionality

Double-clicking on any Container brings up the Container's property dialog:



Containers can be made conditional by selecting the **Conditionality** feature in the Container dialog. When you do so, a **Conditionality** tab is added to the Container dialog:



You can turn off conditionality by selecting the **Conditionality** feature in the Container dialog to clear the box. When you do so, the **Conditionality** tab is removed.

Conditional Containers are represented in the graphics pane as follows (it is red instead of yellow):

Warning: When you make a Container conditional, the **Treat as SubSystem** feature is also automatically selected (and cannot be deselected unless you first turn off **Conditionality**). That is, a Conditional Container, by definition, is treated as a SubSystem. Because a Conditional Container is treated as a SubSystem, this puts certain limitations on how Conditional Containers can be used.

Read more: Treating a Container as a SubSystem (page 140).

Outputs of a Conditional Container

When you enable conditionality for a Container, seven outputs are added to the Container. While a regular Container (i.e., one which is not conditional) has no outputs of its own, the seven outputs of a conditional Container are properties of the Container itself.

Four of the outputs are values or conditions:

Activity_Status: This is a condition which is True when the Container is active.

Completion_Status: This is a condition which is True when the Container has deactivated and the Container is considered to have been *completed*. A conditional Container is considered to have completed if, at the time it deactivates, the expression in the field named **On deactivation, output Completion event if this condition is true** evaluates to True. If a Container reactivates after completing, the Completion_Status is reset to False.

Read more: Deactivating a Container (page 974).

Num_Activations: This is the cumulative number of times that the Container has been activated.

Duration: This represents the duration that the Container has been Active.

If you wish to reference any of these outputs *outside* of the Container, you must do so by referencing the Container name as a prefix (e.g., Container1.Duration).

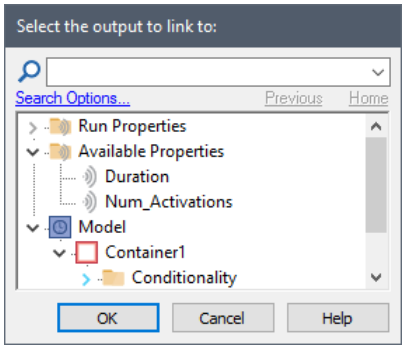
You cannot reference the **Activity_Status** or the **Completion_Status** of a Container inside a Container (GoldSim will say that this will create a recursive system). There is, in fact, no reason to do so, since if an element in the Container is being updated, the Container must be active (so that the Activity_Status must be True and the Completion_Status must be False).

In some cases, you may want to reference the **Duration** and/or **Num_Activations** outputs inside the Container or when defining Deactivation triggers for the Container. GoldSim does support this. However, you cannot do so by using the Container name (i.e., Container1.Duration). Instead, you must reference these two variables using the prefix "~" (e.g., ~Duration and ~Num_Activations). As indicated by the way they are referenced, these two outputs are examples of locally available properties.

Read more: Understanding Locally Available Properties (page 874).

If you access the Insert Link dialog *inside* a conditional Container (by right-clicking inside an input field of an element within the Container or within the Deactivate trigger dialog for the Container), these two outputs appear in an

Available Properties folder (displaying all of the locally available properties that can be accessed from that location):



Conditional Containers also have three additional outputs which are events:

Activation_Event: This is an event that is output when the Container is activated. If a Container is already active when an Activation trigger is received, it *will not* output another Activation_Event at that time.

Read more: Activating a Container (page 973).

Completion_Event: This is an event which is output when the Container has deactivated and the Container is considered to have been *completed*. A conditional Container is considered to have completed if, at the time it deactivates, the expression in the field named **On deactivation, output Completion event if this condition is true** evaluates to True.

Read more: Deactivating a Container (page 974).

Termination_Event: This is an event which is output when the Container has deactivated and the Container is considered *not* to have been *completed*. A conditional Container is considered to have *not completed* if, at the time it deactivates, the expression in the field named **On deactivation, output Completion event if this condition is true** evaluates to False.

Activating a Container

You control when a conditional Container activates via the **Activation…** button on the **Conditionality** tab, which provides access to a standard Trigger dialog.

Read more: Understanding Event Triggering (page 369).

By default, the Activation is set to "Never". This means that the Container will never activate.

Note: You can tell if an activation trigger has been defined from the appearance of the **Trigger…** button. If a trigger is defined, the rectangle next to the lightning bolt is bright green; otherwise it is dark green. And like all **Trigger…** buttons, it displays a tool-tip. If there is no trigger defined, the tool-tip will display "Never activates".

You can explicitly control when a conditional Container activates by defining one or more triggers (e.g., "Activate when Time > 10 days").

Whenever a conditional Container is activated, an Activation_Event output is released.

Read more: Outputs of a Conditional Container (page 972).

Note: You can record all activation and deactivation times in the model's Run Log. This logging can be activated via the **General** tab of the Options dialog (accessed via **Model|Options** from the main menu).

Read more: The General Tab of the Options Dialog (page 466).

If you wish the Container to activate when its parent Container activates, set the Activation trigger to **Auto Activate**. Note that if a conditional Container is set to **Auto Activate** and it is not within a conditional Container, it activates when the Model (root) Container activates (i.e., at the start of the realization).

Several important points should be noted regarding activation of Containers:

- Even if the Container is activated via a trigger, it can only activate if its parent Container is active. If its parent Container is inactive, activation triggers will be ignored (and discarded).
- A Container can be activated multiple times during a realization. Of course, in order for a Container to be reactivated, it must first be deactivated. Activation triggers that occur while the Container is active are ignored (they are not "stored" or saved).
- If an inactive Container is activated at exactly the same time as some child elements are triggered, the triggers to the children are not ignored (they are applied immediately upon activation of the Container).

One common use of conditional Containers is to use the activation of a Container to simultaneously trigger multiple elements within the Container.

For example, if you wished to trigger a number of Discrete Change elements and/or resample a number of Stochastics, you could do so by placing them inside a conditional Container *and* specifying (in their Trigger dialogs) that they are automatically triggered (**Auto Resample** for Stochastics and **Auto Trigger** for Discrete Changes). When the Container was triggered to activate, the Stochastics would automatically be resampled, and the Discrete Changes would automatically be triggered.

Note: You cannot reference the locally available properties Duration or Num_Activations in an Activation trigger. Arguments to an Activation trigger must come from outside of the Container.

Deactivating a Container

Once a Container is activated, it can be deactivated via the **Deactivation…** button on the **Conditionality** tab, which provides access to a standard Trigger dialog.

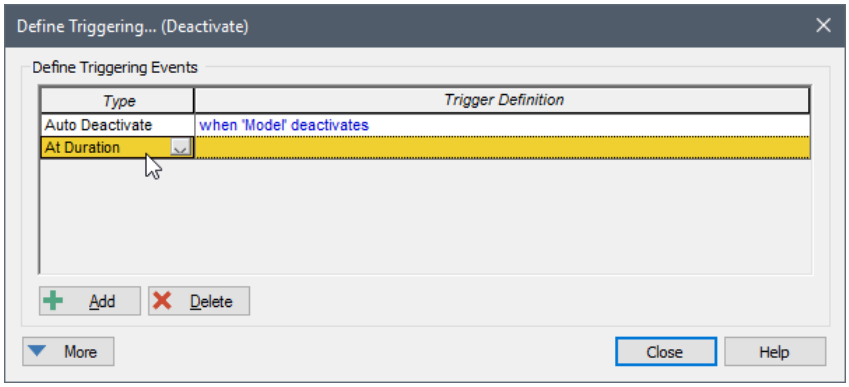
Read more: Understanding Event Triggering (page 369).

You can explicitly control when a conditional Container deactivates by defining one or more triggers.

By default, the Deactivation is set to **Auto Deactivate**. This means that the Container will deactivate when its parent Container deactivates. Note that if a conditional Container is not within a conditional Container, it deactivates when the Model (root) Container deactivates (i.e., at the end of the realization).

Note: You can tell if a deactivation trigger has been defined from the appearance of the **Trigger…** button. If a trigger is defined, the rectangle next to the lightning bolt is bright green; otherwise it is dark green. And like all **Trigger…** buttons, it displays a tool-tip. If there is no trigger defined, the tool-tip will display "Automatically deactivates when *parent* deactivates", where parent is the name of the parent Container.

One special trigger type is provided within the Deactivation trigger dialog:



The **At Duration** trigger deactivates the Container when the Duration output exceeds the specified Trigger Definition (which must represent a length of time). The Duration output represents the amount of time that the Container has been active. Hence, this provides a convenient mechanism to deactivate a Container once it has been active for a specified amount of time. The Trigger Definition input in this case would typically be defined by an element inside the Container.

Read more: Outputs of a Conditional Container (page 972).

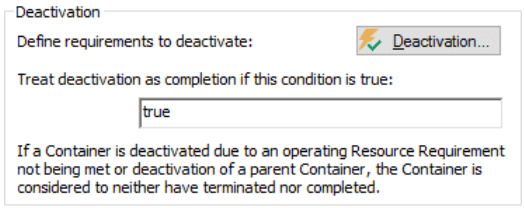
Note: You can record all activation and deactivation times in the model's Run Log. This logging can be activated via the **General** tab of the Options dialog (accessed via **Model|Options** from the main menu).

Read more: The General Tab of the Options Dialog (page 466).

Several points should be noted regarding deactivation of Containers:

- A Container can be deactivated multiple times during a realization. Of course, in order for a Container to be deactivated a second time, it must first be reactivated. Deactivation triggers which occur while the Container is inactive are ignored (they are not "stored" or saved).
- All conditional Containers have an Auto Deactivate trigger (that cannot be deleted). Hence, it will always immediately deactivate if its parent Container deactivates.
- A conditional Container can be activated and immediately deactivated by assigning the same trigger for Activation and Deactivation.
- When a Container is triggered to deactivate, all elements inside the Container are updated before the Container deactivates.

When a conditional Container is deactivated, one of two possible events are released, depending on the condition specified in the **Treat as completion if this condition is true** field (which defaults to True):



Completion_Event: This event is output when the Container has deactivated and the Container is considered to have been *completed*. A conditional Container is considered to have completed if, at the time it deactivates, the expression in the field named **On deactivation, output Completion event if this condition is true** evaluates to True.

Termination_Event: This event is output when the Container has deactivated and the Container is considered *not* to have been *completed*. A conditional Container is considered to have *not completed* if, at the time it deactivates, the expression in the field named **On deactivation, output Completion event if this condition is true** evaluates to False.

Note: If a Container is deactivated due to deactivation of a parent Container or due to an operating Resource Requirement not being met, neither a Completion_Event nor a Termination_Event is fired.

Read more: Specifying Resources for a Conditional Container (page 976).

Deactivating a Container and differentiating whether it has terminated or completed is particularly useful for simulating projects (i.e., when you are using the conditional Container to simulate a project or a task). In this case, you often need to track whether or not various tasks (or collections of tasks) have been successfully completed, as this may impact how subsequent tasks are carried out.

Using Auto Triggers in Conditional Containers

Most elements with triggers can be assigned an Auto Trigger. An Auto Trigger requires no user-defined Trigger Definition and its behavior is defined by its context (i.e., the type of element). Auto Triggers react to the activation or deactivation of their parent Container.

Read more: Understanding Event Triggering (page 369).

In most cases, an Auto Trigger is used in association with the activation of a conditional Container. In particular, if an element inside a conditional Container is given an Auto Trigger, it will be triggered when its parent Container activates.

In one instance, an Auto Trigger is associated with the deactivation of a Container. In particular, conditional Containers all have **Auto Deactivate** triggers (that cannot be deleted). This means that the Container will deactivate when its parent Container deactivates. Note that if a conditional Container is not within a conditional Container, it deactivates when the Model (root) Container deactivates (i.e., at the end of the realization).

Specifying Resources for a Conditional Container

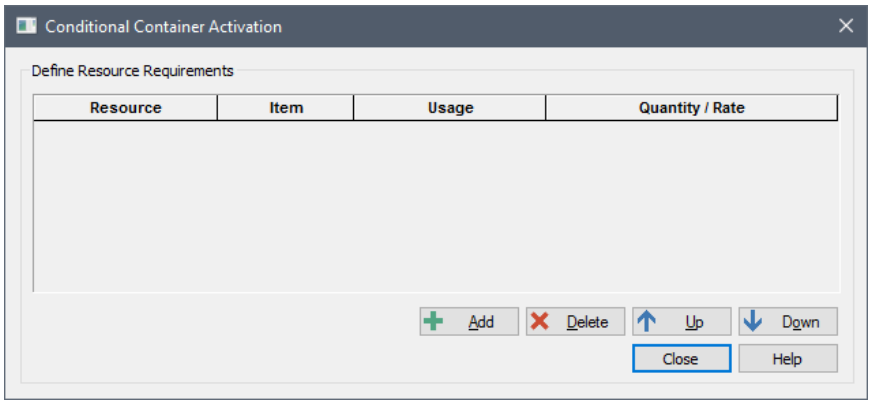
Conditional Containers can have specified Resource Requirements.

Read more: Using Resources (page 906).

There are two types of Resource Requirements that can be specified for Conditional Containers:

- Requirements to activate the Container;
- Requirements for the Container to operate.

To define a Resource Requirement for activating a Conditional Container, press the **Resources…** button in the **Activation…** trigger dialog for the element. The following dialog will be displayed:



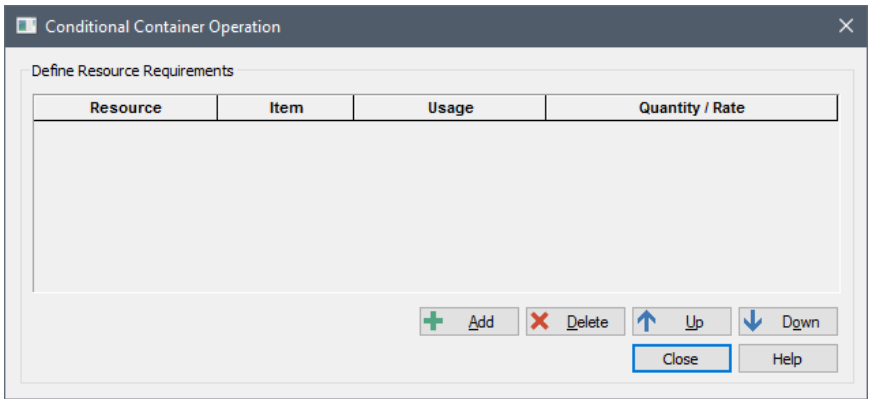
You can add a Resource Requirement by pressing the **Add** button.

Read more: Interacting with Resources (page 916).

A Conditional Container Activation trigger interacts with the specified Resource Stores when the Container is activated, and can only have three types of interactions (specified in the **Usage** column):

- **Spend (discrete):** A discrete quantity of the Resource is required in order to activate the Container. If triggered with a Spend Requirement and the requested Resource quantity is not available, the trigger is held (it waits) until the Resource becomes available. If the Resource becomes available at a later time in the simulation, this creates a delay in the activation of the Container; if the Resource never becomes available, the Container is never activated.
- **Borrow (discrete):** A discrete quantity of the Resource is required in order to activate the Container. If triggered with a Borrow Requirement and the requested Resource quantity is not available, the trigger is held (it waits) until the Resource becomes available. If the Resource becomes available at a later time in the simulation, this creates a delay in the activation of the Container; if the Resource never becomes available, the Container is never activated. Once the Container is deactivated, the borrowed quantity is returned to the Resource Store.
- **Deposit (discrete):** A discrete quantity of the Resource is created and deposited with the Store when the Container is activated.

To define a Resource Requirement for operating a Conditional Container, press the **Resources…** button on the **Conditionality** tab of the Conditional Container (labeled "Define operating Resource Requirements"). The following dialog will be displayed:



You can add a Resource Requirement by pressing the **Add** button.

Read more: Interacting with Resources (page 916).

A Conditional Container Operation Requirement interacts with the specified Resource Stores when the Container is activated, and can only have two types of interactions (specified in the **Usage** column):

- **Spend At Rate:** A specified continuous spend rate of the Resource is required in order for the Container to remain Active. If the requested Resource is not available in sufficient quantity to maintain the requested spend rate, the Conditional Container is deactivated. If it becomes available again, the Container reactivates.

Note: If a Container is deactivated due to an operating Resource Requirement not being met, although the Activity_Status is set to False, neither a Completion_Event nor a Termination_Event is fired.

Read more: Outputs of a Conditional Container (page 972).

Note: If a Container is deactivated due to an operating Resource Requirement not being met, it will reactivate if at least one timestep's worth of the Resource requirement (i.e., a quantity equal to Spend At Rate * Timestep Length) becomes available.

- **Deposit At Rate:** While the Container is active, the specified deposit rate is added to the Store.

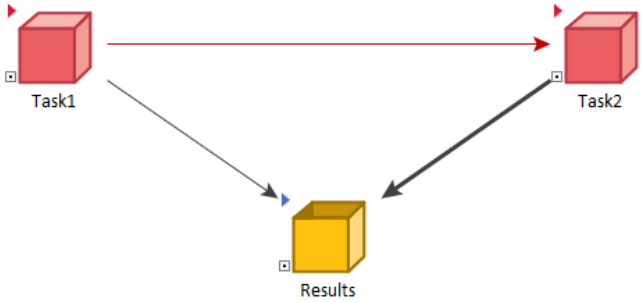
Resources are an advanced feature, and you should read the section listed below before attempting to use them.

Read more: Using Resources (page 906).

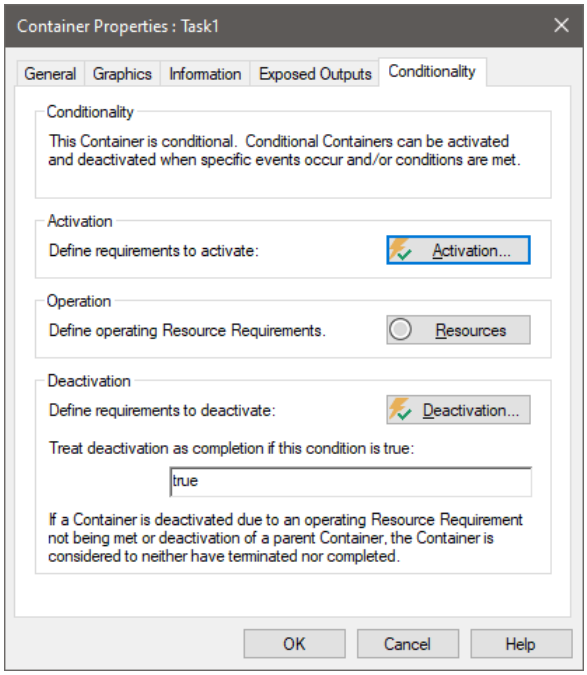
Using Conditional Containers to Simulate a Project

One of the common uses for conditional Containers is to simulate projects. In particular, a conditional Container is used to simulate a task in a project (that starts and completes), with, for example, the start or completion of one task triggering other tasks. A simple example which illustrates the use of conditional Containers to simulate projects (ProjectSimulation.gsm) can be found in the Containers subfolder of the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu). Let's explore that model briefly here.

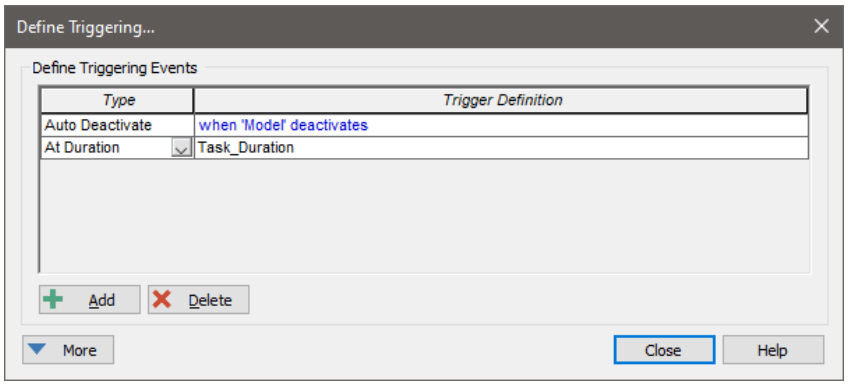
This simple project consists of two tasks:



The **Conditionality** tab for the first task looks like this:



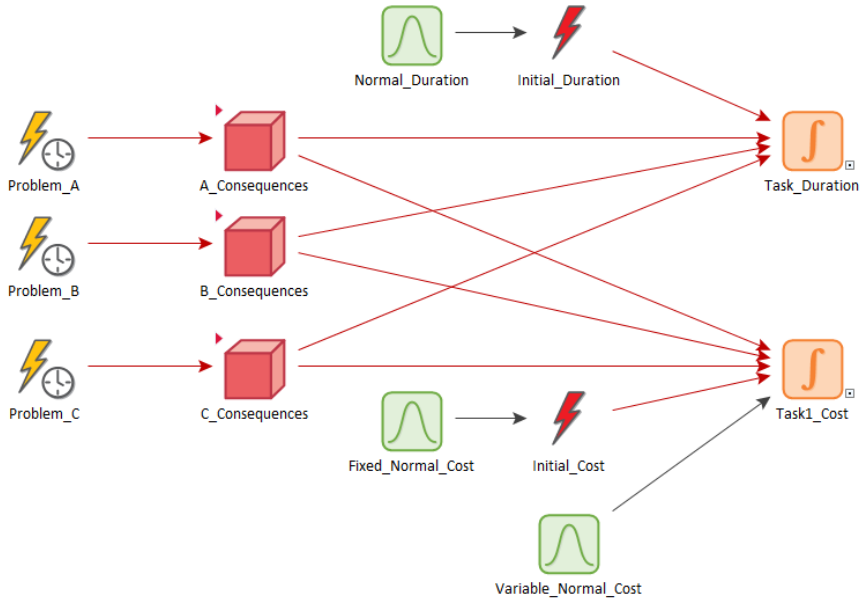
If you press the **Activation…** button you will see that the task starts immediately (when the Model activates). If you press the **Deactivation...** button you will see two different triggers:



The first simply says the task deactivates when the simulation ends. The second uses an "At Duration" trigger. GoldSim keeps track of how long the Container has been active (the Duration) and this trigger is pulled when the Duration exceeds the specified input (in this case, Task_Duration).

Read more: Deactivating a Container (page 974).

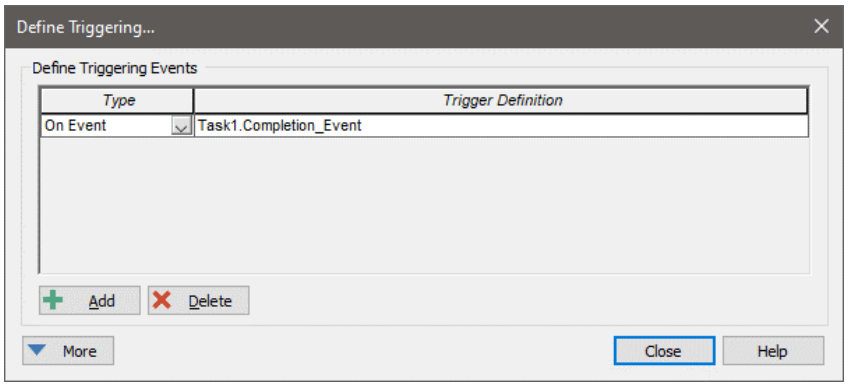
If we look inside the Task1 Container, we see that what is calculated inside is simply the Task_Duration and the Cost:



The Duration is sampled from a distribution when the task is activated. A fixed and variable cost are also sampled from distributions when the task is activated. The variable cost is accumulated while the task is active. In addition, three "problems" are defined that may occur while the task is active. If they occur, they instantaneously increment the cost and duration.

Note that on the **Conditionality** tab for Task1 is a field labeled **Treat deactivation as completion if this condition is true**. In this case, it is set to True, so that all deactivations are treated as completions. However, it is possible to deactivate a task without completing it (e.g., if the task runs out of money), and this can have important implications on the rest of the project.

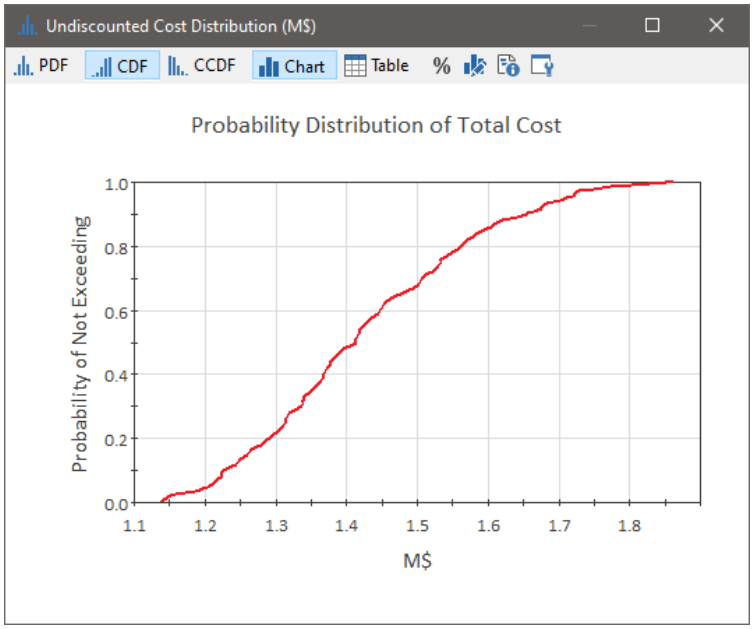
In fact, if we go to the **Conditionality** tab for Task2 and press the **Activation…** button we see the following trigger:

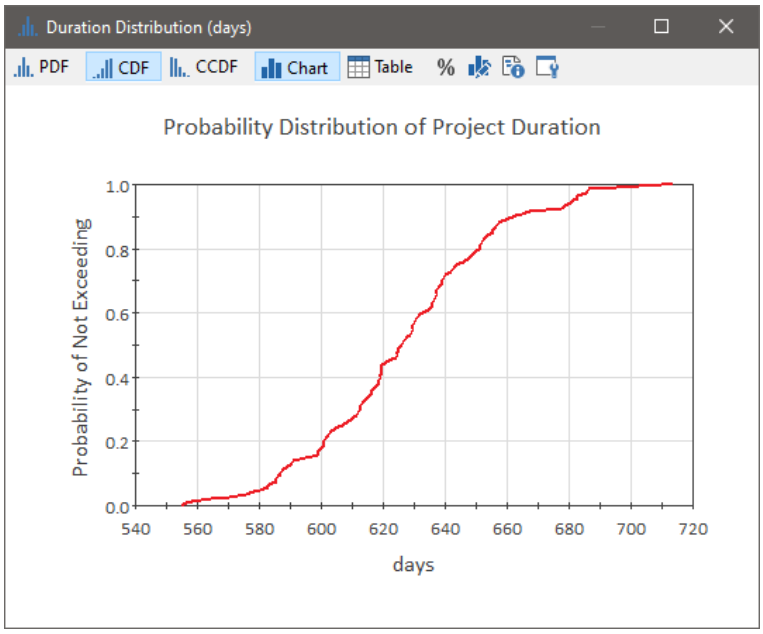


Note that Task2 starts when Task1 completes. This is why specifying whether or not a deactivation is a completion is important. If Task1 was defined in such a way that it could deactivate without completing, Task2 would not always start upon deactivation of Task1.

Task2 is defined in a similar manner to Task1 in terms of determining its duration and cost.

The Results Container displays probabilistic results for total cost and duration for the project:



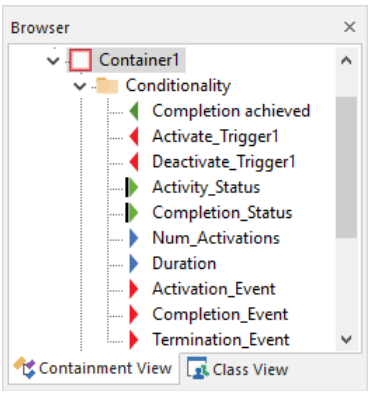


This is a very simple example of project simulation. By using the various features of conditional Containers and GoldSim's discrete event features you can represent much more complex projects. As one example, you could trigger Task2 to start 30 days after Task1 starts (or completes) by using an Event Delay.

Read more: Event Delay Elements (page 391).

Viewing a Conditional Container in the Browser

The browser view of a conditional Container is shown below:



In addition to presenting the Container's contents, a "Conditionality" folder is added to the Container's browser view. This folder contains the input triggers for activation and and other inputs, and the outputs of the Container.

Note: Element inputs and outputs are only shown in the browser if you choose to **Show element subitems** (accessed via the browser context menu by right-clicking in the browser).

Read more: Using the Browser (page 106).

Using External Application Elements

GoldSim provides three elements that can interact with external applications:

- Spreadsheet elements;
- External (DLL) elements; and
- File elements.

These are discussed below.

Spreadsheet Elements

A Spreadsheet element allows you to dynamically exchange data with a Microsoft Excel spreadsheet file. You can transmit data into specified cells in the spreadsheet, have the spreadsheet recalculate, and copy data from "result" cells back into your GoldSim model.

Alternatively, you can simply use a spreadsheet as a source of input data to GoldSim, or as a repository for output data.

Note: If you wish to import lookup tables or time history data from a spreadsheet into GoldSim, or export time history data from GoldSim to a spreadsheet, GoldSim provides specialized ways to do this using the Lookup Table, Time Series and Time History Result elements that do not require a Spreadsheet element.

Read more: Linking a Lookup Table to a Spreadsheet (page 319); Importing Data into a Time Series from a Spreadsheet (page 199); Exporting from a Time History Result Element to a Spreadsheet (page 786).

Note: GoldSim supports .xlsx, .xlsm, and .xls Excel files. However, if you have an older version of Excel (prior to Office 2007), you will need to install Microsoft's Office Compatibility Pack in order to read .xlsx and .xlsm files. Excel 2007 and later support a larger worksheet size (1,048,576 rows by 16,384 columns) than earlier versions (65,536 rows by 256 columns). If you wish to exchange data between an extended worksheet range and GoldSim, you must use Excel 2007 or newer, and the file format must be .xlsx or .xlsm. Note that GoldSim does not officially support versions of Excel prior to Excel 2003.

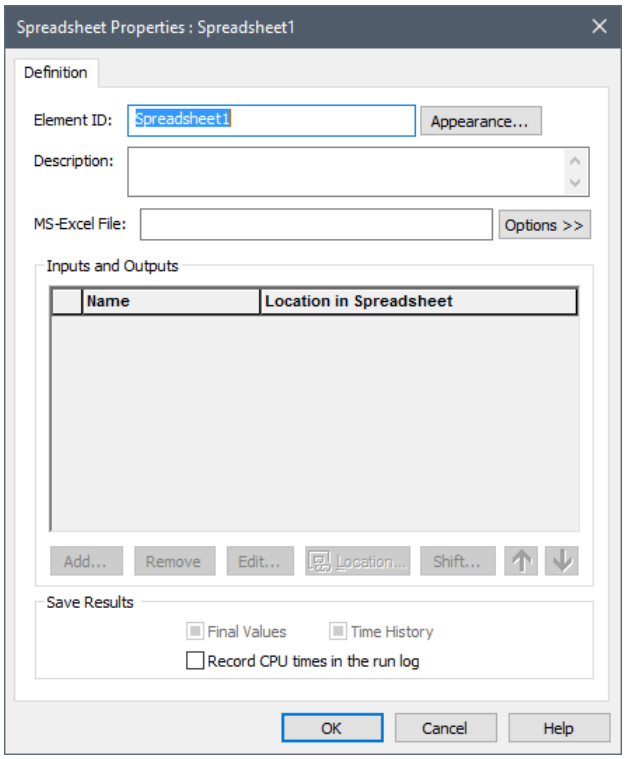
Warning: You should never try to open a spreadsheet that is linked to GoldSim while a simulation is running. In addition, prior to running a GoldSim model that is linked to a spreadsheet, all referenced spreadsheets should be closed. If you try to interact with a spreadsheet that is being used by GoldSim during a simulation, all interaction with the spreadsheet is blocked by GoldSim. However, under some circumstances this may not be possible and could lead to errors. Hence, as a general rule, you should not use Excel while a Goldsim model that references Excel is running.

Warning: You should not specify Excel files with the same filename that are in different folders, drives or network locations (e.g., using two different Spreadsheet elements). Excel is unable to open such files simultaneously, and this will cause GoldSim to fail.

An example model which uses a Spreadsheet element (Spreadsheet.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Defining the Properties of a Spreadsheet Element

The properties dialog for a Spreadsheet element looks like this:



You must first enter the name of a Microsoft Excel spreadsheet file to which you wish to link by pressing the **Options** >> button. This will provide options for either selecting an existing file, or creating (and then selecting) a new file.

Note: If you select a file in the same directory as (or a subdirectory below) your GoldSim .gsm file, GoldSim will subsequently display just a local path. If you select a file in a directory above your .gsm file, it will display the full path.

Once you have selected a file, you can subsequently use the **Options** >> button to select a different file. You can also use the **Options**>> button to open the selected file in Excel. (Note that multiple Spreadsheet elements can link to the same spreadsheet file.)

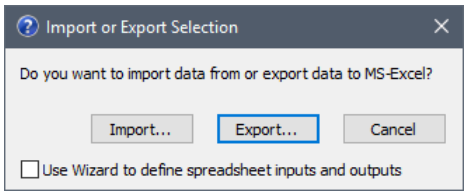
Spreadsheet elements can be used in one of three ways:

1. You can use the spreadsheet as a database and import data from the spreadsheet into GoldSim at the beginning of the simulation.
2. You can use the spreadsheet as a repository for results and export data from GoldSim to the spreadsheet throughout a simulation.
3. You can use the spreadsheet as a function by exporting data into specified cells in the spreadsheet from GoldSim, having the spreadsheet recalculate, and then import data from "result" cells in the spreadsheet back into your GoldSim model.

In all cases, you need to define either at least one input to the spreadsheet element (data that you are exporting from GoldSim to the spreadsheet), or one output from the spreadsheet (data that you are importing from the spreadsheet into GoldSim).

The dialog lists all of the inputs and outputs that you have specified (inputs are listed in the table first).

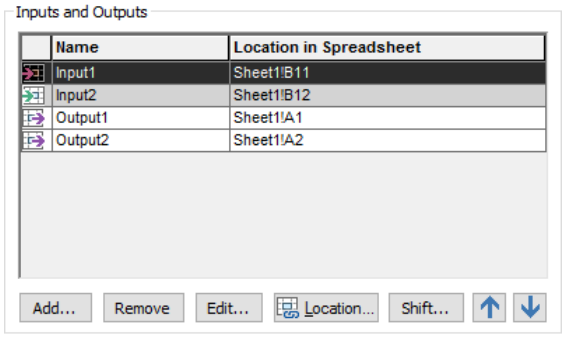
You add inputs and outputs by pressing the **Add…** button (which only becomes available after you have specified a spreadsheet file). After pressing the **Add…** button, the following dialog is displayed:



You must select whether you want to Import data from the spreadsheet (creating an output to the element) or Export data to the spreadsheet (creating an input for the element). If **Use Wizard to define spreadsheet inputs and outputs** is checked, a wizard will pop up to guide you through the process of creating an input or output. Otherwise, a dialog will appear. It is recommended that you use the wizard until you are familiar with the use of the Spreadsheet element.

Read more: Using the Spreadsheet Wizard to Define Spreadsheet Inputs (page 987); Using the Spreadsheet Wizard to Define Spreadsheet Outputs (page 994).

Once you have defined or edited an input or output, the main Spreadsheet element dialog is displayed again, listing all of the inputs and outputs that you have specified (inputs are listed in the table first):



An input or output can be edited by either selecting the row and pressing **Edit…**, or by double-clicking on the row. You can edit the spreadsheet location of any entry by selecting the row and pressing **Location…**. An input or output can be deleted by pressing the **Remove** button.

The up and down arrow buttons move the entries up and down the list (although inputs will always be listed before outputs). Note that the relative positions of the rows have no effect on how the element functions, and such repositioning is purely cosmetic.

The **Shift…** button provides access to a dialog that allows you to quickly edit the spreadsheet location of one or more inputs or outputs by shifting them by one or more sheets, rows or columns.

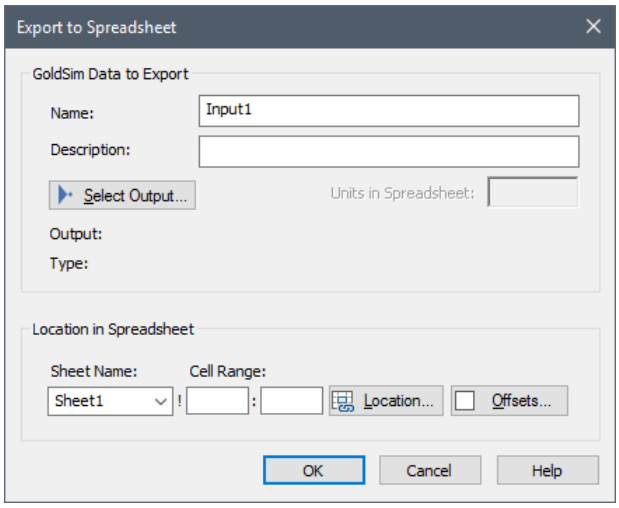
Read more: Shifting Ranges for Inputs and Outputs to a Spreadsheet Element (page 998).

If you check the **Record CPU times in the run log** box, if the element uses more than 1 CPU seconds, a message will be written to the GoldSim run log identifying the element's name, type (i.e., Spreadsheet), the number of times it was updated, and the total CPU time used.

Read more: The Run Log (page 569).

Spreadsheet Element Inputs: Exporting Data to the Spreadsheet

If you press the **Export…** button from the Import or Export Selection dialog (and the checkbox for using the wizard is cleared), or if you select an existing input in the main Spreadsheet dialog and press the **Edit…** button, the following dialog is displayed:



This dialog is used to create an input to the Spreadsheet element. An input to a Spreadsheet element is defined as an existing GoldSim output that you wish to export from GoldSim to the spreadsheet file.

You define an input as follows:

1. Select the GoldSim output that you wish to export to the spreadsheet by pressing the **Select Output…** button, which will display a browser for selecting an output. You can select a scalar, a vector or a matrix. The output can be a Value or a Condition. True Conditions will export into the spreadsheet as 1; False Conditions will export into the spreadsheet as 0.
2. The **Units in Spreadsheet** will default to the display units for the output that you selected. If the units of the data in the spreadsheet are different from this, you should change the units accordingly.
3. The **Name** of the input will default to Input*n*, where n is an integer. This name is used to label the inputs to the Spreadsheet element in the browser and the element's input interface. If you wish to, you can change this name, but it is not required. The optional **Description** appears only in this dialog and is useful for helping to document your spreadsheet link.
4. You must then select the location in the spreadsheet to which you wish to export the GoldSim data. You can do this by specifying the Sheet Name and Cell Range directly. Alternatively, you can press the **Location…** button, which opens the spreadsheet and provides a dialog allowing you to directly select the desired cell range using your mouse.

Note: The size of the range must be consistent with the dimensions of the input which you are sending to the spreadsheet. Hence, a scalar input must map to a single cell; a vector input must map to a single column or row range with the number of rows or columns matching the number of items in the vector; and a matrix input must map to a rectangular range with the number of rows and columns matching the dimensions of the matrix (e.g., a matrix with 3 rows and 6 columns would have to map to a range in the spreadsheet 3 rows long and 6 columns wide).

If required, you can control the sheet and cell range into which GoldSim exports data dynamically. For example, you could instruct GoldSim to change the location to which it exports data based on the simulation time or the realization.

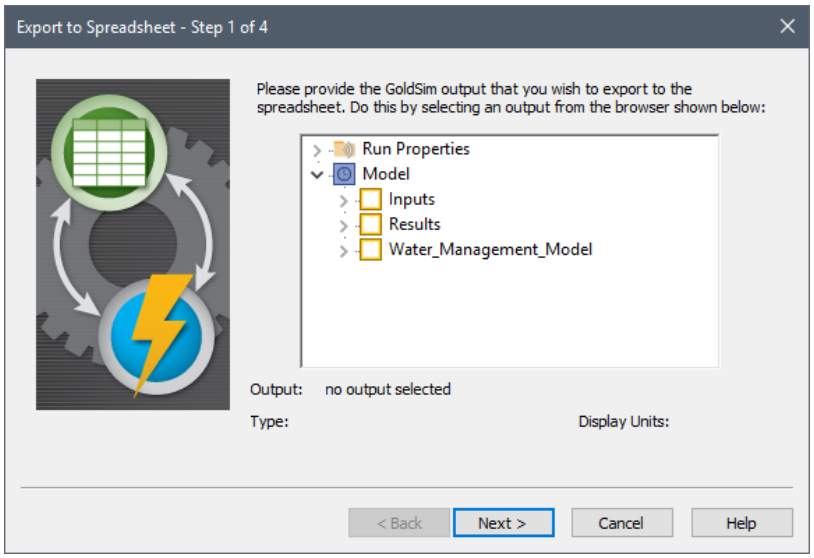
Read more: Defining Offsets for Inputs and Outputs to a Spreadsheet Element (page 996).

If you would like to edit the location of several inputs (or outputs) simultaneously by shifting them by sheet, row or column, you can do this from the main Spreadsheet element dialog using the **Shift…** button.

Read more: Shifting Ranges for Inputs and Outputs to a Spreadsheet Element (page 998).

Using the Spreadsheet Wizard to Define Spreadsheet Inputs

If you press the **Export…** button from the Import or Export Selection dialog, and the checkbox for using the wizard is checked, the Spreadsheet Wizard will be displayed:



This wizard is used to create an input to the Spreadsheet element. An input to a Spreadsheet element is defined as an existing GoldSim output that you wish to export from GoldSim to the spreadsheet file. Until you become comfortable creating inputs and outputs for Spreadsheet elements, it is recommended that you use the wizard.

The wizard has four pages:

1. On the first page you must select the GoldSim output that you wish to export to the spreadsheet. The wizard displays a browser for selecting an output. You can select a scalar, a vector or a matrix. The output can

be a Value or a Condition. True Conditions will export into the spreadsheet as 1; False Conditions will export into the spreadsheet as 0.

2. On the second page, you specify the **Name** of the input. It will default to Input*n*, where n is an integer. This name is used to label the inputs to the Spreadsheet element in the browser and the element's input interface. If you wish to, you can change this name, but it is not required. The optional **Description** appears only in the dialog for subsequently editing this Input and is useful for helping to document your spreadsheet link.
3. On the third page, you must specify the **Units in Spreadsheet.** They will default to the display units for the output that you selected. If the units of the data in the spreadsheet are different from this, you should change the units accordingly. Note that this page is skipped if the output is dimensionless or a Condition.
4. On the last page of the wizard, you select the location in the spreadsheet to which you wish to export the GoldSim data. You can do this specifying the Sheet Name and Cell Range directly. Alternatively, you can press the **Location…** button, which opens the spreadsheet and provides a dialog allowing you to directly select the desired cell range using your mouse.

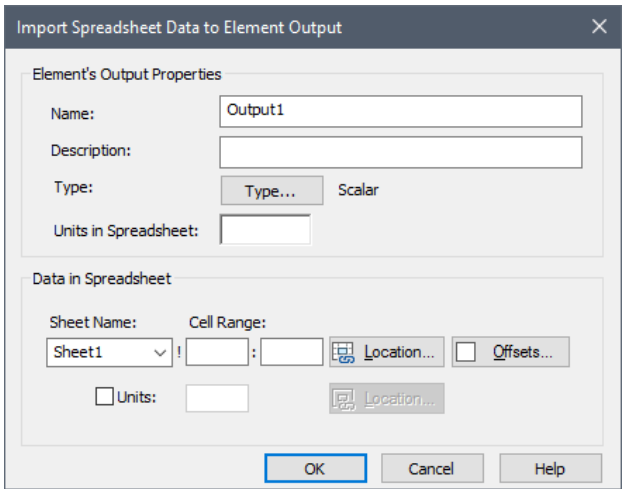
Note: The size of the range must be consistent with the dimensions of the input which you are sending to the spreadsheet. Hence, a scalar input must map to a single cell; a vector input must map to a single column or row range with the number of rows or columns matching the number of items in the vector; and a matrix input must map to a rectangular range with the number of rows and columns matching the dimensions of the matrix (e.g., a matrix with 3 rows and 6 columns would have to map to a range in the spreadsheet 3 rows long and 6 columns wide).

If required, you can control the sheet and cell range into which GoldSim exports data dynamically. For example, you could instruct GoldSim to change the location to which it exports data based on the simulation time or the realization.

Read more: Defining Offsets for Inputs and Outputs to a Spreadsheet Element (page 996).

Spreadsheet Element Outputs: Importing Data from the Spreadsheet

If you press the **Import…** button from the Import or Export Selection dialog (and the checkbox for using the wizard is cleared), or if you select an existing output in the main Spreadsheet dialog and press the **Edit…** button, the following dialog is displayed:

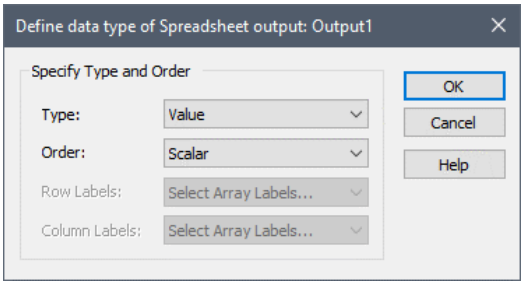


This dialog is used to create an output to the Spreadsheet element. An output to a Spreadsheet element is defined by specifying a cell range in the spreadsheet file that you wish to import from the spreadsheet into GoldSim, making the data accessible within GoldSim as an element output.

You define an output as follows:

1. The **Name** of the output will default to Output*n*, where n is an integer. You will use this name to reference the output within GoldSim (as SpreadsheetElementName.OutputName). Hence, you will likely want to change this name from its default. The optional **Description** appears only in this dialog and is useful for helping to document your spreadsheet link.

2. Press the **Type…** button to define the attributes of the output. The following dialog will be displayed:



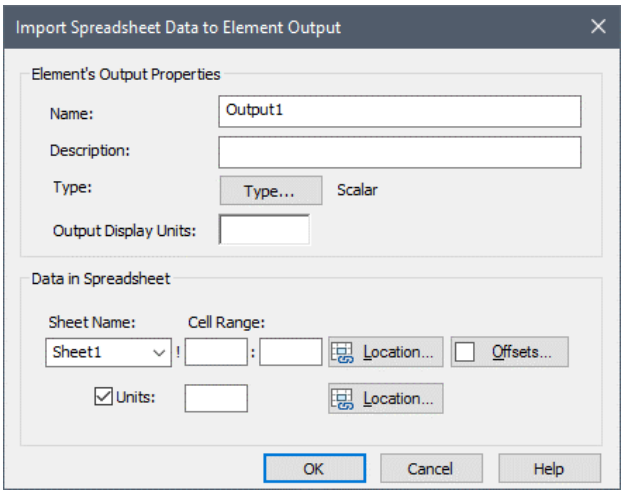
   This dialog allows you to define the Order (scalar, vector, matrix) of the output. You can also define the Type. By default, the Type is a Value (conditions are not supported and cannot be selected here). However, you can also select Probability Distribution, which allows you to import a series of input fields that define a distribution.

   Read more: Importing Stochastic Element Definitions from a Spreadsheet (page 991).

3. You must then specify the units of the date being imported from the spreadsheet. There are two ways to do this. You can simply specify in this dialog what the units are (and this is the default). In this case, the **Units in Spreadsheet** represents the units of the data in the spreadsheet. This will also become the display units for the output after it is imported into GoldSim. As discussed below, alternatively, you can also import the unit string directly from the spreadsheet.

4. You must then select the location in the spreadsheet from which you wish to import the data. You can do this by specifying the Sheet Name and Cell Range directly. Alternatively, you can press the **Location…** button, which opens the spreadsheet and provides a dialog allowing you to directly select the desired Cell Range using your mouse.

5. You can optionally choose to import the units for the data directly from the spreadsheet (rather than specifying the units directly as in step 3 above). In this case, select the **Units** checkbox in the dialog:



You must then specify the Cell containing the unit directly to the right of the **Units** checkbox (or alternatively, you can press the **Location…** button, which opens the spreadsheet and provides a dialog allowing you to directly select the desired Cell using your mouse). Note that when you check this box, the field directly below the Type button changes from **Units in Spreadsheet** to **Output Display Units**. This allows the output to have different display units than the units in the spreadsheet (although, of course, they must be of the same dimension).

Note: The size of the range specified in the spreadsheet must be consistent with Order (scalar, vector, matrix) that you defined for the output. Hence, a scalar output must map to a single cell; a vector output must map to a single column or row range with the number of rows or columns matching the number of items in the vector; and a matrix output must map to a rectangular range with the number of rows and columns matching the dimensions of the matrix (e.g., a matrix with 3 rows and 6 columns would have to map to a range in the spreadsheet 3 rows long and 6 columns wide). When importing a Probability Distribution, the range is a single cell (the first cell in the string of inputs defining the distribution)

Note: Spreadsheets cells can be defined as TRUE or FALSE. If you try to import such a cell into GoldSim, a TRUE cell will be imported as the number 1, and a FALSE cell will be imported as 0.

If required, you can control the sheet and cell range from which GoldSim imports data dynamically. For example, you could instruct GoldSim to change

the location from which it imports data based on the simulation time or the realization.

Read more: Defining Offsets for Inputs and Outputs to a Spreadsheet Element (page 996).

If you would like to edit the location of several inputs (or outputs) simultaneously by shifting them by sheet, row or column, you can do this from the main Spreadsheet element dialog using the **Shift…** button.

Read more: Shifting Ranges for Inputs and Outputs to a Spreadsheet Element (page 998).

Note: Prior to running the model, you can view any spreadsheet data that you plan to import by first selecting the **Update Spreadsheet Outputs** item in the menu displayed via the **Options>>** button for the Spreadsheet element, and then viewing the outputs of the element in tool-tips within the element's output port.

Note: If GoldSim cannot find the spreadsheet when you try to run the model, the model will still run and GoldSim will log a warning message to the Run Log. If data from the spreadsheet was previously imported (i.e., it had been run previously with the spreadsheet accessible), it will use the data that was imported previously. If data from the spreadsheet was never imported (i.e., it had never been run previously with the spreadsheet accessible), all values will default to 0.

Importing Stochastic Element Definitions from a Spreadsheet

You can use the Spreadsheet element to import a probability distribution from a spreadsheet. The distribution is defined in the spreadsheet using a number of fields that specify the type of distribution, as well as the arguments to the distribution.

Probability distributions must be specified in the spreadsheet in a very specific format. In particular, the distribution must be defined in a row of adjacent cells in the spreadsheet. The first cell is a code that defines the type of distribution. The subsequent cells (to the right of the code) define the input parameters for the distribution. The table below specifies how each type of distribution must be entered in the spreadsheet.

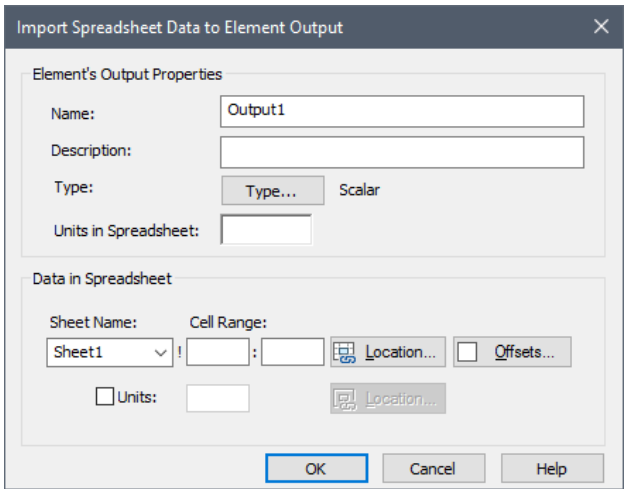
Distribution	Type Code	Distribution Parameters				
	Cell1	*Cell2*	*Cell3*	*Cell4*	*Cell5*	*Cell6*
Generalized Beta	BETAGEN	Mean	SD	Min	Max	
Beta	BETASF	Successes	Failures			
BetaPERT	BETAPERT	Min (0%) or 10%	Most Likely	Max (100%) or 90%	0 for 0/100; 1 for 10/90	
Binomial	BINOM	Batch Size	Prob			
Cumulative	CUM	# pairs	Linear = 0; Log = 1	Prob1	Val1	

Distribution	Type Code	Distribution Parameters				
	Cell1	*Cell2*	*Cell3*	*Cell4*	*Cell5*	*Cell6*
Discrete	DISCRETE	# pairs	Prob1	Val1	Prob2	Val2
Exponential	EXPON	Mean				
Extreme Probability	EXTRPROB	Min = 0; Max =1	Number samples			
Extreme Value	EXTRVAL	Min = 0; Max =1	Location	Scale		
Gamma	GAMMA	Mean	SD	(Min)	(Max)	
Log-Normal	LOGNORM	True = 0; Geom = 1	True or Geom Mean	True or Geom SD	(Min)	(Max)
Negative Binomial	NEGBINOM	Number successes	Prob of success			
Normal	NORMAL	Mean	SD	(Min)	(Max)	
Pareto	PARETO	Shape	Mode	(Max)		
Pearson Type III	PEARSON	Location	Scale	Shape		
Poisson	POISSON	Expected Value				
Sampled Results	SAMPLED	# Results	Val1	Val2	Val3	Val4
Student's t	STUDENTT	Deg of Freedom				
Triangular	TRIANG	Linear =0; Log =1	Min (0%) or 10%	Most Likely	Max (100%) or 90%	0 for 0/100; 1 for 10/90
Uniform	UNIFORM	Linear =0; Log =1	Min	Max		
Weibull	WEIBULL	Min	Slope	Mean – Min	(Max)	

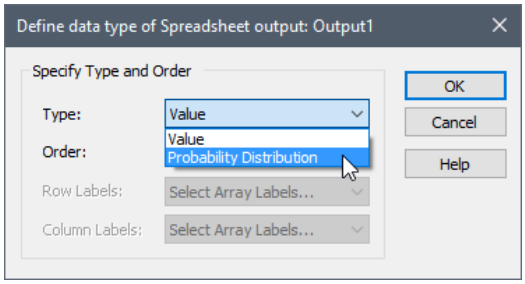
Table Notes:

- *Cumulative and Discrete can have as many Prob/Val pairs as required.*
- *Sampled Results can have as many Values as required.*
- *Parameters in parentheses are optional.*
- *If Log-Normal distribution is defined using Geometric parameters, the SD is dimensionless*
- *Shaded parameters are dimensionless; others have same dimension as the distribution*
- *There is no option to import a Boolean distribution.*

To import a distribution from a spreadsheet, you must press the **Type** button in the Import dialog:



After doing so, the following dialog will be displayed. You must select "Probability Distribution" as the Type:



The Order of a Probability Distribution must be Scalar.

When you specify the Location, you must select a single cell: that corresponding to the Type Code for the distribution. GoldSim will automatically read in the appropriate number of additional cells based on the distribution type.

Note: Prior to running the model, you can view any spreadsheet data that you plan to import by first selecting the **Update Spreadsheet Outputs** item in the menu displayed via the **Options>>** button for the Spreadsheet element, and then viewing the outputs of the element in tool-tips within the element's output port.

Note: Care must be taken when importing distributions that represent dates and temperatures. This is because dates and temperatures both have an absolute reference (i.e., 12/31/1899 for dates and absolute zero for temperatures). *Differences* between dates are expressed in units of time (e.g. days, seconds, etc) and *differences* between temperatures are expressed in 'deg' units (Cdeg, Fdeg). This can lead to errors when importing Stochastics, since GoldSim assumes a single unit for the distribution parameters, while some types of distributions would require two different types of units. For example, a Normal distribution representing a temperature would require the Mean to be specified in absolute units (e.g., C) and the Standard Deviation to be specified in difference units (e.g., Cdeg). Similarly, a Normal distribution representing a date would require the Mean to be specified in absolute units (e.g., as a date) and the Standard Deviation to be specified in difference units (e.g., days). If faced with this problem, there are several approaches for addressing this: 1) Use a distribution type where all parameters have the same units (e.g., triangular, uniform, cumulative); or 2) Specify and import the distributions as dimensionless and then apply a unit to the sampled value using an Expression element. This latter option would work for temperatures, but not dates, since a date cannot be specified with dimensionless values. It could, however, be imported as a Julian date, in which case you could use day units (or some other time unit). Alternatively, the mean date could be defined as a Data element and an imported distribution with time units could be used to model a 'lag' (positive or negative) from the fixed date. An Expression element could be used to add the sampled lag value to the fixed (mean) date.

Read more: Dealing with Temperature Units (page 92).

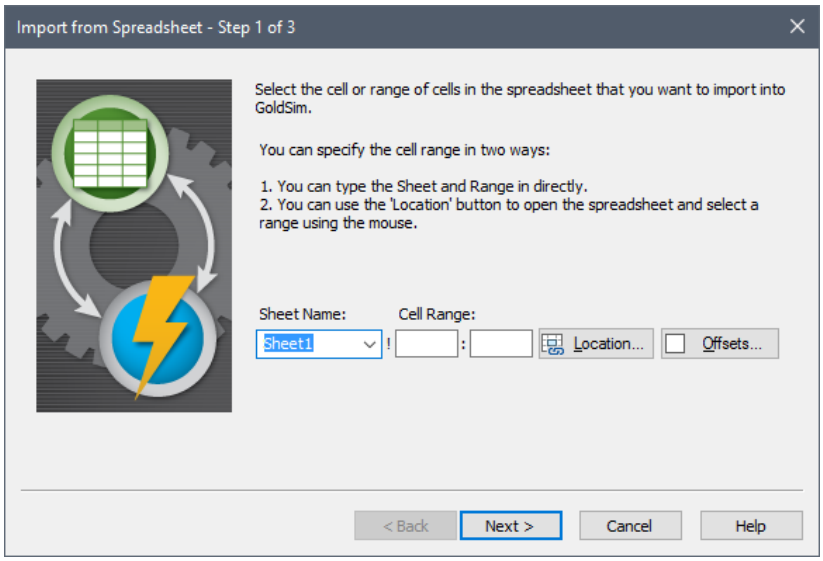
When a distribution is imported in this way, the output type on the spreadsheet element is not a value; rather, it is a complex output referred to as a Distribution output. Distribution outputs are complex outputs that represent all the statistical information necessary to define a probability distribution and only be used in several specialized locations.

To import this information into a Stochastic element, you must then use this Distribution output as the definition for a Stochastic element specified as an Externally-Defined distribution.

Read more: Externally-Defined Distribution (page 172).

Using the Spreadsheet Wizard to Define Spreadsheet Outputs

If you press the **Import…** button from the Import or Export Selection dialog, and the checkbox for using the wizard is checked, the Spreadsheet Wizard will be displayed:



This wizard is used to create an output to the Spreadsheet element. An output to a Spreadsheet element is defined by specifying a cell range in the spreadsheet file that you wish to import from the spreadsheet into GoldSim, making the data accessible within GoldSim as an element output. Until you become comfortable creating inputs and outputs for Spreadsheet elements, it is recommended that you use the wizard.

The wizard has three pages:

1. On the first page of the wizard, you select the location in the spreadsheet from which you wish to import the data. You can do this specifying the Sheet Name and Cell Range directly. Alternatively, you can press the **Location…** button, which opens the spreadsheet and provides a dialog allowing you to directly select the desired cell range using your mouse.

Note: You cannot use the wizard to import a probability distribution from a spreadsheet. To do this, you must define the Import manually.

Read more: Importing Stochastic Element Definitions from a Spreadsheet (page 991).

2. On the second page, you must specify the **Units in Spreadsheet**. These represent the units of the data in the spreadsheet. This will also become the display units for the output after it is imported into GoldSim. If the range you have selected in Step 1 is more than a single cell (indicating that the data will be imported into GoldSim in the form of a vector or matrix), you will be prompted for the Array Labels for the vector or matrix.

Note: You cannot use the wizard to import the units for the data from a spreadsheet. To do this, you must define the Import manually.

Read more: Spreadsheet Element Outputs: Importing Data from the Spreadsheet (page 988).

3. On the last page of the wizard, you specify the **Name** of the output. It will default to Output*n*, where n is an integer. You will use this name to reference the output within GoldSim (as SpreadsheetElementName.OutputName). Hence, you will likely want to change this name from its default.

Note: If you specify a spreadsheet range that is more than one cell, the size of the range specified in Step 1 must be consistent with the size of the Array Label set(s) specified in Step 2. Hence, a vector output must map to a single column or row range with the number of rows or columns matching the number of items in the vector; and a matrix output must map to a rectangular range with the number of rows and columns matching the dimensions of the matrix (e.g., a matrix with 3 rows and 6 columns would have to map to a range in the spreadsheet 3 rows long and 6 columns wide).

If required, you can control the sheet and cell range into which GoldSim exports data dynamically. For example, you could instruct GoldSim to change the location to which it exports data based on the simulation time or the realization.

Read more: Defining Offsets for Inputs and Outputs to a Spreadsheet Element (page 996).

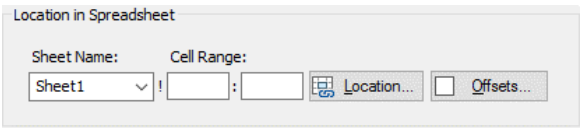
Note: Prior to running the model, you can view any spreadsheet data that you plan to import by first selecting the **Update Spreadsheet Outputs** item in the menu displayed via the **Options>>** button for the Spreadsheet element, and then viewing the outputs of the element in tool-tips within the element's output port.

Defining Offsets for Inputs and Outputs to a Spreadsheet Element

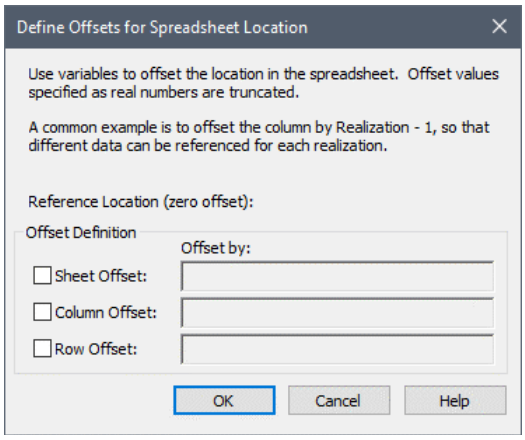
In some cases, you may want to specify the location in the spreadsheet file to which you are linking in terms of an offset from a defined location, in which the offset is defined by model variables (such as Time or Realization).

For example, you could instruct GoldSim to change the location to which it exports data based on the realization number, with results from each realization being exported to a different column in the spreadsheet file.

You do this by selecting the **Offset…** button when you are selecting a spreadsheet location while defining inputs or outputs to a Spreadsheet file:

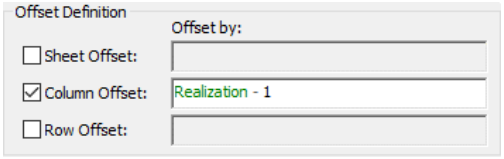


When you press this button, the following dialog is displayed:



You select whether you want to offset by Sheet, Column, and/or Row by clicking the appropriate checkboxes. For example, if you were exporting a scalar GoldSim output to the spreadsheet file, and wanted to export the value to Sheet1!A1 for realization 1, Sheet1!B1 for realization 2, and so on, you would simply do the following:

1. Specify Sheet1!A1 for the Location in Spreadsheet
2. Define the Column offset as follows:



In this case, the offset would be 0 for Realization 1 (and hence the value would be exported to Sheet1!A1), it would be 1 for Realization 2 (and hence the value would be exported to Sheet1!B1), and so on.

Note: The offsets can be any expression with links to other GoldSim outputs, but should be specified as dimensionless, integer values. GoldSim will not accept expressions in these fields that have dimensions. Offsets defined as real numbers are truncated.

Note: If as a result of an offset, you try to access a cell that is invalid (e.g., if you specify a negative offset from the first column), GoldSim will display a fatal error message at runtime.

If you wish to use a particular unit of time to define an offset, you must *cast* the output to a dimensionless number. For example, Time|day| will represent the number of days (which could be fractional, and hence will be truncated). Note that Run Properties like Day and Year are, by definition, dimensionless.

Read more: Unit Casting (page 93); Understanding and Referencing Run Properties (page 505).

When you close the Offset dialog and have a defined offset, this is indicated in the Spreadsheet Location (**Offset…** is checked) and in the list of inputs and outputs (any offset ranges are indicated as such).

Warning: In order to properly use offsets, you must have a good understanding of the conditions and settings that control when GoldSim exchanges data with the spreadsheet file.

Read more: Controlling When GoldSim Exchanges Data with the Spreadsheet File (page 1000).

An example model which includes an illustration of the use of offsets for a Spreadsheet element (Spreadsheet.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

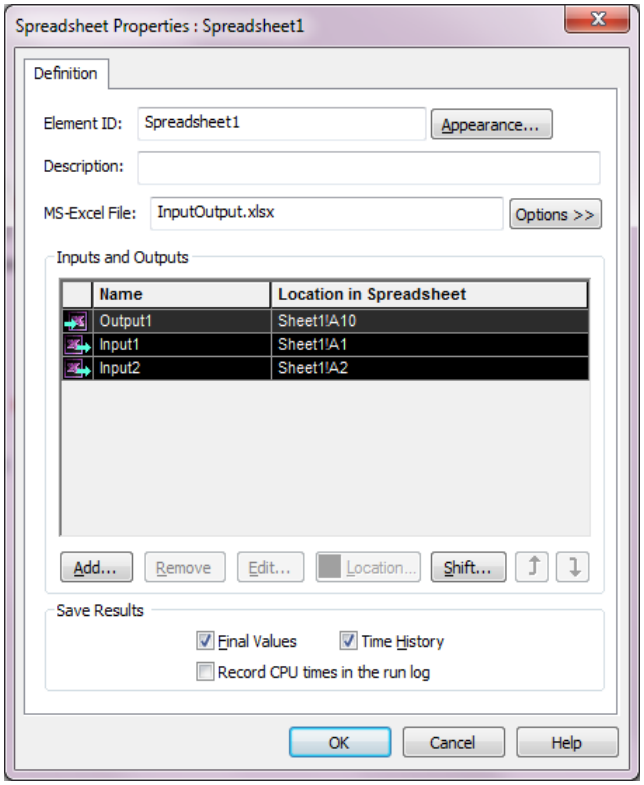
Shifting Ranges for Inputs and Outputs to a Spreadsheet Element

In some cases, you may want to edit the location of several inputs (or outputs) simultaneously by shifting them by sheet, row or column.

This could happen, for example, if you have multiple Spreadsheet elements linked to a single spreadsheet with multiple sheets. You may want each Spreadsheet element to link to a different sheet of the file, but otherwise, you would like all of the row and columns in the links to be identical.

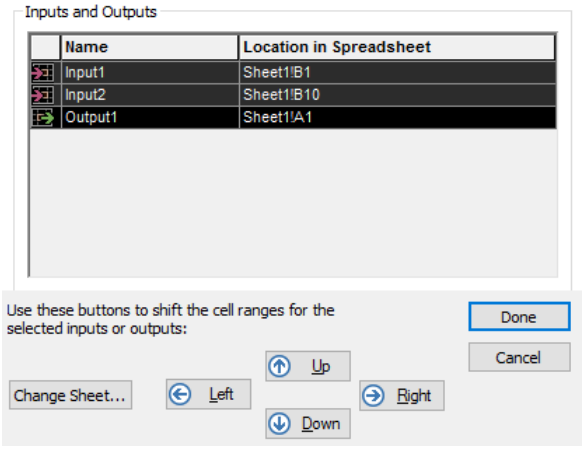
GoldSim provides a very convenient way to shift multiple inputs or outputs by sheet, row, and/or column.

You do this by selecting the items that you want to shift, and pressing the **Shift…** button from the main Spreadsheet element dialog:



Multiple contiguous rows in this dialog can be selected by holding down the **Shift** key while selecting with the mouse. Multiple rows that are not contiguous can be selected by holding down the **Ctrl** key while selecting with the mouse. All rows can be selected by placing the cursor in any row and pressing **Ctrl-A**.

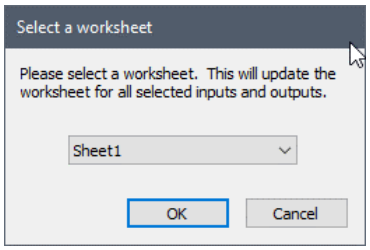
When you select items and press the **Shift…** button, the Spreadsheet element dialog expands to show the following section:



The **Up** and **Down** keys shift the selected items by row. The **Left** and **Right** buttons shift the selected items by column.

Note: If you try to shift beyond the valid range for any of the selected items (e.g., if you try to shift left and one of the items is defined as being in column A) GoldSim will not shift any of the items.

The **Change Sheet…** button displays a dialog for selecting a new sheet to apply to all selected items:



The drop-list includes all worksheets present in the Excel file. By default, no new sheet is selected. If you press OK without selecting a sheet, no changes are made. If you select a sheet and press OK, all selected items will be updated (they will point to that sheet).

Note: If you are importing both the data and the units for the data from a spreadsheet, when you shift the data, GoldSim will also shift the reference to the unit if a) you are shifting rows, and the data and the units are in the same row; b) you are shifting columns, and the data and the units are in the same column; or c) you are shifting sheets (by definition, the units are always in the same sheet as the data).

Locking onto a Spreadsheet File

GoldSim allows you to "lock onto" the spreadsheet file that is being referenced. When you lock onto a file (by selecting the **Lock onto selected file** item in the menu displayed via the **Options>>** button), the following additional information regarding the referenced file is saved with the element:

- File and path name;

- Date the file was created;
- Date the file was last modified;
- File size; and
- CRC signature.

Once you have locked onto a file, the CRC signature is displayed in a tool-tip when you hold your cursor over the filename in the dialog.

The CRC signature is an alphanumeric code that can be used to uniquely identify whether the file contents have changed. When you run a model that has locked onto a file, GoldSim compares the CRC signature of the file with the original signature that was stored. If these are not identical (indicating that the file has been changed), GoldSim displays an error message and will not run the model.

You can unlock a file by clearing the **Lock onto selected file** item. Note that if versioning is enabled, whenever a file is locked onto or unlocked, this information is logged with the version.

Read more: Tracking Model Changes (page 1099).

Note: Saving changes to a spreadsheet file and file locking are mutually exclusive. If the **Save MS-Excel file after simulation** item is selected in the **Options>>** menu when you try to lock onto a file, GoldSim will warn you that locking onto the file will automatically disable saving changes to the MS-Excel file. When you lock onto a file, the **Save MS-Excel file after simulation** item is no longer available in the **Options>>** menu.

Note: The act of opening a workbook in Excel automatically modifies the file, even if no changes are made. In order to allow spreadsheet files to be viewed without changing the CRC signature, GoldSim automatically makes the file read-only when it is locked onto. Note that if it is subsequently unlocked, it remains read only, and you will need to change this manually if you wish to edit the file.

Read more: How Spreadsheet Files are Affected by GoldSim (page 1002).

Controlling When GoldSim Exchanges Data with the Spreadsheet File

Whenever a Spreadsheet element is used in a model, GoldSim uses the following information to determine when during the simulation it should import data from or export data to the spreadsheet file:

- Is the **Recalculate in Excel during simulation** setting (accessed via the **Options>>** button) On or Off? This defaults to being On (yes) when a new Spreadsheet element is created.
- Are you importing data from the spreadsheet, exporting data to the spreadsheet, or both?
- Are offsets defined, and if so, has an offset value changed?
- If you are exporting data to the spreadsheet, have any of the GoldSim outputs being exported changed?

The following table summarizes how this information is used to determine when to exchange data with the spreadsheet file:

Type of Exchange Specified in Element	Recalculate Setting	Offsets defined	When does GoldSim exchange data with spreadsheet file?
Export only	Not available	No	Export all data at end of simulation.
	Not available	Yes	Export data from just before its offset changes.* Export all data at end of simulation.
Import only	Not available	No	Import all data at beginning of simulation.
	Not available	Yes	Import all data at beginning of simulation. Import data when its offset changes
Export and Import	Off	No	Export all data at end of simulation. Import all data at beginning of simulation.
	On	No	Export and Import all data at beginning of simulation. Export and Import all data whenever an Export variable changes. Export all data at end of simulation.
	Off	Yes	Export and Import all data at beginning of simulation. Export data from just before its offset changes.* Export all data at end of simulation. Import data when its offset changes
	On	Yes	Export and Import all data at beginning of simulation. Export and Import all data whenever an Export variable changes. Export data from just before its offset changes.* Export all data at end of simulation. Import data when its offset changes

**The value that is exported when an export offset changes is the value from the update immediately before the offset changed. Hence, if the offset was "Realization", when Realization changes from 1 to 2, GoldSim would export the value from the end of Realization 1 using an offset of 1. Similarly, if the offset was "Month", when Month changes from 1 to 2, GoldSim would export the value from the end of Month 1 using an offset of 1.*

Several points about spreadsheet recalculations are worth noting:

- Regardless of the **Recalculate in Excel during simulation** setting, by default, Excel will recalculate whenever cell values change. As pointed out below, however, GoldSim will only retrieve the updated data if **Recalculate in Excel during simulation** is selected. You can change this setting in Excel (so it does not automatically recalculate) in the Calculation tab of Excel's Options dialog.

- The **Recalculate in Excel during simulation** setting does two things: 1) it forces Excel to recalculate, and 2) it retrieves the recalculated data back into GoldSim. Hence, if the **Recalculate in Excel during simulation** setting is off, GoldSim will *not retrieve updated data* from the spreadsheet, even if some cells have changed (and Excel automatically recalculated).

Note: When you use a Spreadsheet element, there may be a delay of several seconds at the start of a simulation as Excel is loaded into memory. Once it is loaded, however, the simulation should progress rapidly.

Note: If you are only importing data from a spreadsheet *and* you have not specified any dynamic offsets *and* you have already imported the data previously, if GoldSim cannot find the spreadsheet when you try to run the model it will use the data that was imported previously and will log a warning message to the Run Log.

Warning: You should never try to open a spreadsheet that is linked to GoldSim while a simulation is running. In addition, prior to running a GoldSim model that is linked to a spreadsheet, all referenced spreadsheets should be closed. If you try to interact with a spreadsheet that is being used by GoldSim during a simulation, all interaction with the spreadsheet is blocked by GoldSim.

If you are importing data from a spreadsheet, you can tell GoldSim to import the data while in Edit Mode by selecting **Update Spreadsheet Outputs** via the **Options>>** menu button. When you do this, GoldSim will import the data currently existing in the spreadsheet. If the information being imported is impacted by data that is being exported to the spreadsheet (and that data can be computed in Edit Mode), GoldSim will export the data to the spreadsheet, trigger a recalculation, and import the data from the spreadsheet to GoldSim, where it can be viewed as an output of the spreadsheet element.

How Spreadsheet Files are Affected By GoldSim

By default, GoldSim's interactions with the Excel spreadsheet only affect a copy of the spreadsheet temporarily stored in memory, and do not affect the data permanently stored in your spreadsheet file. That is, following your simulation, the spreadsheet file will be unchanged (even if during the simulation GoldSim has sent data to cells in the spreadsheet).

In some cases, however, you may want to save the changes you make to a spreadsheet (i.e., when GoldSim exports data to the spreadsheet). To do so, select the **Save MS-Excel file after simulation** item in the **Options>>** menu (which by default is cleared).

Note: Saving the changes you make to a spreadsheet (from the **Options**>> menu) is not possible when carrying out a distributed processing simulation (using the Distributed Processing Module). This is because each Slave uses a private copy of the original spreadsheet. The Distributed Processing Module is discussed in detail in the **GoldSim Distributed Processing Module User's Guide**.

Note: Unless you use offsets that vary with time or realization, if you access the spreadsheet multiple times (at multiple timesteps or for multiple realizations), only the changes made to the spreadsheet the final time you access it will be saved (all the previous modifications will be overwritten each time that you access it).

Read more: Defining Offsets for Inputs and Outputs to a Spreadsheet Element (page 996).

Note: Saving changes to a spreadsheet file and file locking are mutually exclusive. If the **Save MS-Excel file after simulation** item is selected in the **Options**>> menu when you try to lock onto a file, GoldSim will warn you that locking onto the file will automatically disable saving changes to the MS-Excel file. When you lock onto a file, the **Save MS-Excel file after simulation** item is no longer available in the **Options**>> menu.

Read more: Locking onto a Spreadsheet File (page 999).

Warning: You should always close any spreadsheets that are referenced by GoldSim prior to running your GoldSim model. In fact, in most cases, GoldSim will warn you if it tries to interact with (in particular, write to) a spreadsheet that is already open.

Exchanging Date Information with a Spreadsheet

In some cases, you may wish to exchange date or time information with a spreadsheet. For example, you may wish to send the current date in the GoldSim simulation to a cell formatted as a date in a spreadsheet, or retrieve a date from a spreadsheet into GoldSim. In order to do so, you must understand how Microsoft Excel (and GoldSim) deal with dates.

Within Excel, a date is stored internally as the number of days (which can be fractional) since December 31, 1899 00:00:00. Hence, if you were to export the number 4.25 into a spreadsheet cell formatted as a date, it would be interpreted as January 4, 1900 at 6:00:00 AM. However, Excel mistakenly adds an extra day into its calendar that did not actually exist (February 29, 1900). As a result, the *effective* Julian date reference for all times after March 1, 1900 in Excel is actually December 30, 1899 00:00:00.

Within GoldSim, the Run Property DateTime represents the elapsed time since the reference date December 30, 1899 00:00:00. Hence, for all dates after March 1, 1900, Excel and GoldSim have the same effective Julian date reference.

Given this information, the following rules should be followed for exchanging date information between GoldSim and a spreadsheet:

- When exporting a date/time from GoldSim to a spreadsheet cell, you should select Days for the **Units in Spreadsheet**. If the spreadsheet cell is formatted as a date, it will display as a date; otherwise, it will display the number of days from December 30, 1899 00:00:00 to the specified date that was exported.
- When importing a date from a spreadsheet cell (i.e., a cell formatted in the spreadsheet as a date), you should select Date or Datetime for the **Units in Spreadsheet**. Within GoldSim, the output from the Spreadsheet element would then be stored as the number of days from December 30, 1899 00:00:00 to the particular date that was imported from the spreadsheet. If running a Calendar Time simulation, the output would be displayed as a date when viewing it (e.g., using a tool-tip) in GoldSim.

Read more: Referencing Dates in Expressions (page 135); Setting the Basic Time Options (page 471).

Saving Spreadsheet Element Outputs

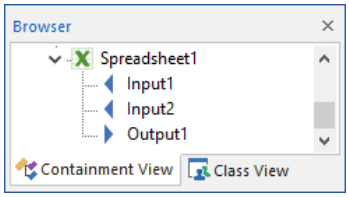
You can save results for a Spreadsheet element by clicking **Final Values** and/or **Time Histories**. Checking one of these causes all output arguments to be saved.

If the element has multiple outputs, and you wish to save only one or two of these as results, you can use the context menu of the output in the browser (accessed via a right-click on an output) to turn on or off a particular output. In this case, the checkbox in the dialog would then become a box instead of a check (indicating that only some of the results will be saved). Note that in order to see outputs in the browser you must first ensure that **Show element subitems** is selected by right-clicking anywhere in the browser.

Note: A Spreadsheet element does not have a primary output.

Viewing a Spreadsheet Element in the Browser

The browser view of a Spreadsheet element is shown below:



As can be seen, the browser view shows an item for each specified input to the spreadsheet, and an item for each specified output.

Note: Element inputs and outputs are only shown in the browser if you choose to **Show element subitems** (accessed via the browser context menu by right-clicking in the browser).

Read more: Using the Browser (page 106).

External (DLL) Elements

In some situations, you may wish to define a complex function which can not be readily implemented using the expression editing features supplied by GoldSim. For example, calculation of an output may require very complex logic which

would be cumbersome to represent using a Selector element, or it may require a numerical solution technique (e.g., iteration).

GoldSim provides two separate ways to deal with such situations:

- You can develop separate program modules (written in C, C++, FORTRAN or other compatible programming languages) which can then be directly coupled with the main GoldSim algorithms. These user-defined modules are referred to here as external functions, and the elements through which they are coupled to GoldSim are called External (DLL) elements.
- You can specify a sequence of statements directly within the GoldSim interface using a Script element.

Read more: Script Elements (page 929).

In general, using Script elements is preferred, as this approach has the key advantages that 1) it does not require use of a separate programming language and interface; and 2) it is much more transparent (all of the "code" can be seen directly in GoldSim). However, in some cases (e.g., linking complex existing programs directly into GoldSim), Script elements cannot be used and External (DLL) elements are the only option.

The modules are linked into GoldSim as DLLs (Dynamic Link Libraries) at run time. Integrating these external modules into GoldSim requires that you develop a "wrapper" (or "shell") around your existing function, and compile it into a DLL. In most cases, this will require only a limited number of programming modifications. GoldSim supports both 32-bit and 64-bit DLLs.

An example model which uses an External (DLL) element (External.gsm) can be found in the General Examples/External folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu). This folder also includes the corresponding DLL, as well as the source code (in C++ and Fortran) for the example.

Implementing the External Module

The steps involved in creating and using an External element are as follows:

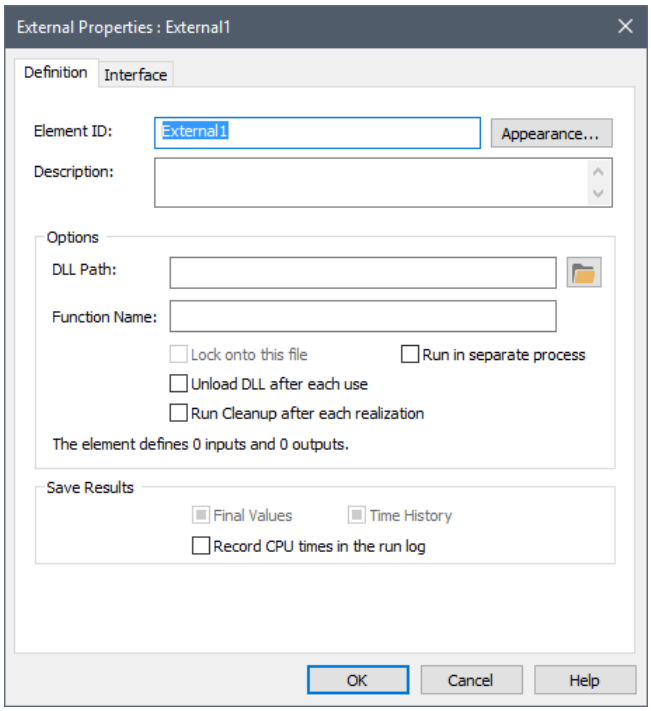
1. Code the external function to be used by the External element in your model;
2. Compile the external function into a DLL (multiple functions can be included in the same DLL);
3. Create an External element within GoldSim and specify the DLL and the specific function within the DLL to be used;
4. Specify the input and output arguments that are to be sent to and received from the function.

The details of the first two steps are discussed in Appendix C. The remaining two steps are discussed below.

Read more: Appendix C: Implementing External (DLL) Elements (page 1171).

Defining the External Element

The editing dialog for an External element is shown below:



In order to use an External element, you must first specify the **DLL Path** and **Function Name** within the DLL that the element will utilize:

DLL Path: This is the name of the dynamic link library containing the external function. You can press the Browse button (the folder to the right of the **DLL Path** field) to search for the file. In general, you should specify the full path to the DLL. (If you specify just the filename, it will look for the DLL only in the working directory containing the GoldSim model file). Note that a single DLL can contain multiple external functions.

Note: If the DLL references any external files and it is run in a separate process, it will look for those files in the folder where the DLL resides. If it is not run in a separate process, it will look for the files in the folder where the model file resides.

Function Name: This is the specific name of the external function in the DLL. This name is case-sensitive and must exactly match the name of the function in the source code for the external function.

There are also several options that control how the DLL is called by GoldSim:

Unload DLL after each use: If this box is checked, GoldSim will unload the DLL (and continue the simulation). This is useful when running very large model files (in which the DLL only needs to be called infrequently). If the DLL is subsequently called again, GoldSim will automatically reload it.

Run Cleanup after each realization: If this box is checked, GoldSim will call the DLL with a cleanup instruction (99) at the end of each realization.

Read more: Appendix C: Implementing External (DLL) Elements (page 1171).

Lock onto this file: If this box is checked, GoldSim regards various properties of the file to determine whether the file contents have changed.

Read more: Locking onto a DLL File (page 1010).

Run in separate process: If this box is checked, GoldSim executes the DLL outside of the GoldSim process space. This can be useful for DLLs that have large memory requirements.

Read more: Running the DLL in a Separate Process (page 1011).

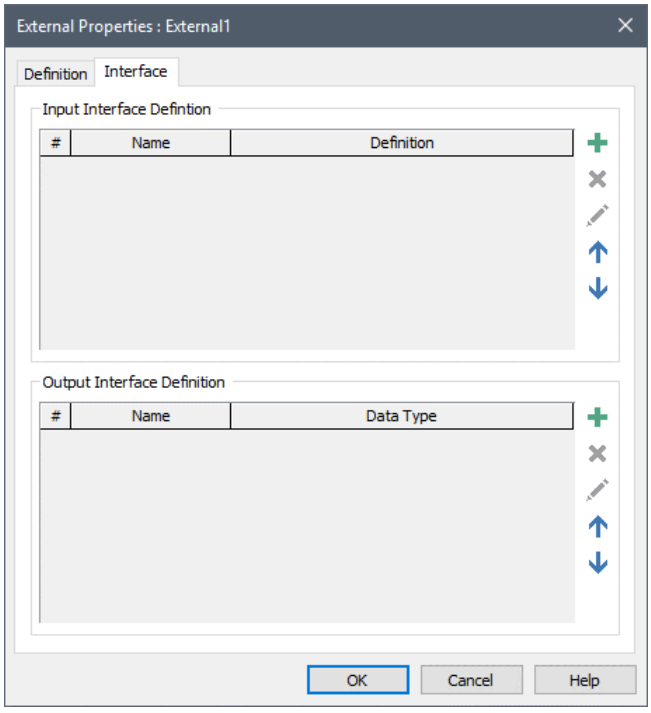
Note: You can use GoldSim's File element to automatically copy the DLL file from some location (typically on a network) to your machine. Because GoldSim records this action in the Run Log, it can provide an "audit trail" to ensure that the proper version of an external file (such as a DLL) was used in a particular simulation.

Read more: File Elements (page 1015).

If you check the **Record CPU times in the run log** box, if the element uses more than 1 CPU seconds, a message will be written to the GoldSim run log identifying the element's name, type (i.e., External), the number of times it was updated, and the total CPU time used.

Read more: The Run Log (page 569).

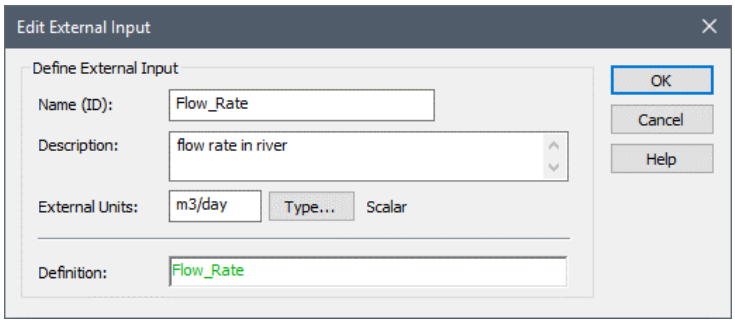
You define the input and output arguments for the External element via the **Interface** tab:



The top part of this dialog is used to define the input arguments. The bottom portion is used to define the output arguments.

Add button

In order to add an input argument, press the Add button in the Input Interface portion of the dialog. When you do this, GoldSim displays the Insert Link dialog, allowing you to select an existing output to add to the interface). After selecting a output, the following dialog is displayed:



The **Definition** displays the output that was selected. The **Name (ID)** defaults to the output name. The **Name (ID)** will appear on the input interface for the External element (accessed via the input port). The **Description** is optional and simply provides additional information regarding the input argument (it defaults to the element description for the output that was selected).

Before sending the input to the DLL, GoldSim converts the value to the **External Units** (the units themselves are not sent to the DLL, just the value). The **External Units** and **Type…** (e.g., value/condition, scalar/vector/matrix) for the input argument are automatically determined by the output that was selected and linked to. Moreover, the **External Units** themselves default to the Display Units for the linked output. Of course, the DLL may require that the value be sent to it assuming different units. Hence, you can edit the **External Units** specified (but, of course, these must have dimensions consistent with the **Definition**).

Note: If you send an output whose **Type** is a Condition to an external function, GoldSim will automatically convert it to either a 0 (for False) or 1 (for True) prior to sending the argument to the DLL.

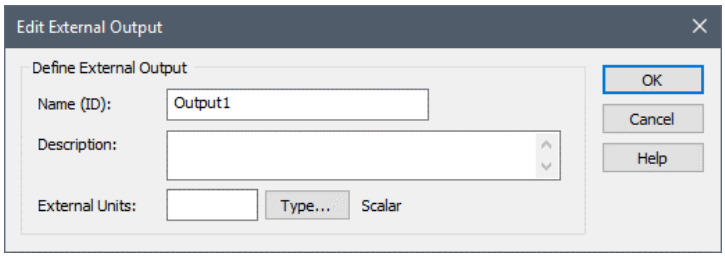
Note: If you pressed **Cancel** (rather than selecting an output) when adding the input argument, the **Definition** (and hence **External Units** and **Type**) will be blank. You could enter any expression into the **Definition** field (including constants). The **External Units** and **Type** would need to be specified in a manner that was consistent with the **Definition**.

Note: In addition to reading in Values or Conditions, an External function can also read in (and subsequently output) a Time Series Definition.

Read more: Using an External Element to Read and/or Output Time Series (page 1013).

Add button

In order to add an output argument, press the Add button in the Output Interface portion of the dialog. When you do this, GoldSim displays the following dialog:

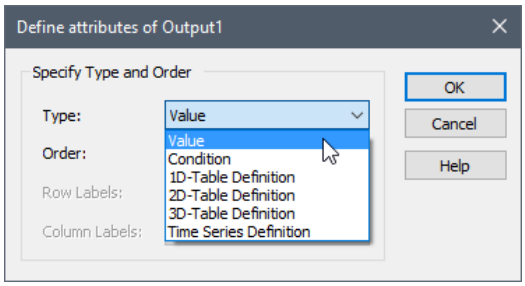


The **Name (ID)** is the name by which the output variable can be referenced in the model. For example, if the name of the External element was X, and the name of the output was Y, the output could be referenced as X.Y. This ID has the same restrictions as an element ID.

The **Description** is an optional description of the output. The **External Units** represent the units in which the External function returns the value. The specified units also become the display units for the output. The **Type...** button is used to access a dialog for specifying the data type (e.g., value/condition, scalar/vector/matrix).

Note: If you add an output whose **Type** is a Condition to the output interface, GoldSim will treat any non-zero number as True, and zero as False.

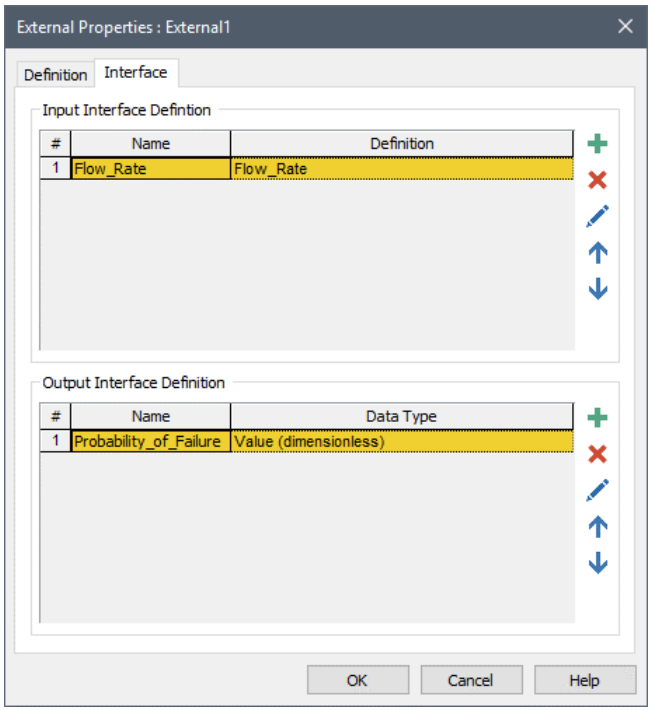
In addition to defining the output as a Value or a Condition, the output can also represent either a Lookup Table or a Time Series:



Read more: Using an External Element to Define Lookup Tables (page 1011); Using an External Element to Read and/or Output Time Series (page 1013).

There is no limit to the number of input and output arguments that can be added.

After adding the input and output arguments, the Interface tab displays them as follows:



The input arguments and output arguments are transferred between GoldSim and the external function in exactly the order in which they are listed on the **Interface** tab.

Buttons for deleting, editing and moving the input and output arguments up and down in the list are available directly below the Add buttons.

Locking onto a DLL File

GoldSim allows you to "lock onto" the DLL file that is being referenced. When you lock onto a file (by checking the **Lock onto this file** option in the External element dialog), the following additional information regarding the referenced file is saved with the element:

- File and path name;
- Date the file was created;
- Date the file was last modified;
- File size; and
- CRC signature.

Once you have locked onto a file, this information is displayed in a tool-tip when you hold your cursor over the filename in the dialog.

The CRC signature is an alphanumeric code that can be used to uniquely identify whether the file contents have changed. When you run a model that has locked onto a file, GoldSim compares the CRC signature of the file with the original signature that was stored. If these are not identical (indicating that the file has been changed), GoldSim displays an error message and will not run the model.

You can unlock a file by clearing the **Lock onto this file** checkbox. Note that if versioning is enabled, whenever a file is locked onto or unlocked, this information is logged with the version.

Read more: Tracking Model Changes (page 1099).

Running the DLL in a Separate Process

By default, GoldSim loads DLLs used by External elements into the GoldSim process space. GoldSim and the all external DLLs therefore share the application's address space, which is usually limited to 2 GB on Windows operating systems. In some case, a single DLL itself may have large memory requirements (e.g., if it loaded large sets of data from files or databases), or it could statically or dynamically allocate large blocks of memory. If the combined memory requirements of GoldSim (the executable), the GoldSim model (including all model properties, buffers and result values) and all DLLs exceeds 2 GB, GoldSim will be unable to carry out the simulation. The user will be forced to preserve memory by saving fewer histories or time steps, or by turning off saving of results for certain elements.

To circumvent this limitation, GoldSim provides a feature that allows external DLLs to be executed outside of the GoldSim process space. If **Run in separate process** is checked, GoldSim does not load the DLL into its process space. Instead, it launches a separate small DLL server with its own private process space. The DLL server works like a middleman who dispatches information between GoldSim and the external DLL. Each DLL that runs in a separate process has its own DLL server. Therefore each DLL has access to a private 2 GB process space, which is not shared with any other DLL or application.

Note: If the DLL references any external files and it is run in a separate process, it will look for those files in the folder where the DLL resides. If it is not run in a separate process, it will look for the files in the folder where the model file resides.

Note: 64-bit DLLs *must* be run in a separate process.

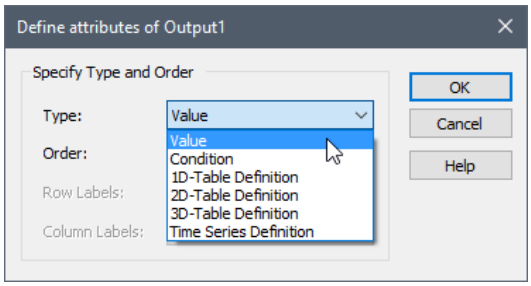
Using an External Element to Define Lookup Tables

In some cases, you may wish an external program to directly generate a look-up table that you can use to dynamically define a Lookup Table element.

Read more: Using Lookup Table Elements (page 307).

To facilitate this, GoldSim allows you to define the table using an External element. The entire table then becomes an output of the External element, which can subsequently be linked to a Lookup Table element.

In order to specify that an output of the External element is a table, you must indicate that the Data Type of the output is a 1D, 2D, or 3D Table Definition (when you define the **Type…** for an output argument):

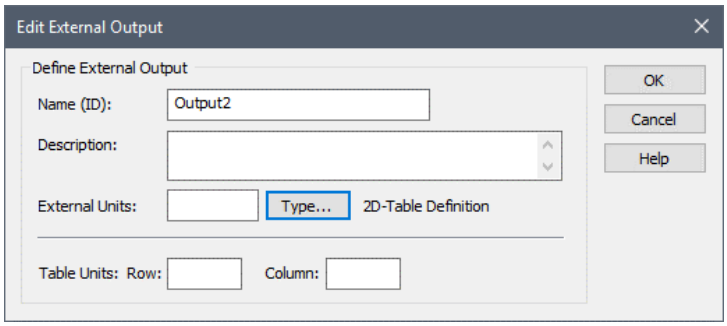


As seen above, in addition to defining an output of an External element as a Value or a Condition, you can also define an output whose data type is a 1D, 2D, or 3D Table Definition. These three special data types can only be produced

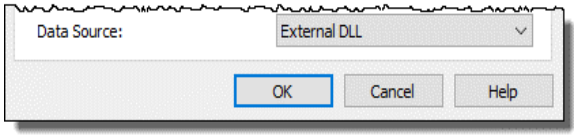
by an External element and outputs of these types can only be used in special locations within GoldSim (i.e., an input defining a Table element's data).

Since the table itself is being defined by an external function (and will subsequently be linked to a Lookup Table element), it is necessary to specify the units for the numbers representing the table that are being passed into GoldSim by the external function.

As a result, when you add an output argument and define it as a Lookup Table, the dialog for defining the output differs depending on whether the data type is a 1D, 2D, or 3D Table Definition. In all cases, the **External Units** represent the units for the independent variable. For a 1D Table Definition, you must also define the units for a single independent (**Row**) variable. For a 2D Table Definition, you must define the units for the two independent (**Row** and **Column**) variables. For a 3D Table Definition, you must define the units for the three independent (**Row**, **Column** and **Layer**) variables. Here is an example of what the output argument dialog looks like for a 2D Table Definition:



You link a Lookup Table to an external function by selecting "External DLL" from the **Data Source** field at the bottom of the Lookup Table dialog:



When you do so, a new tab (**External DLL**) is added to the dialog. You use this tab to specify the name of the External element output that defines the table.

Note: In order to link a 1D, 2D, or 3D Table Definition output from an External element to a Table element, the dimensions of the External Units specified in the dialog for the output must be consistent with the Result Units and the independent variable units specified when defining the Lookup Table element.

Note: After you have defined a Lookup Table element externally and run the model (so that the DLL has loaded the table into the Lookup Table element), you can view the table definition created by the external function by pressing **View Data…**. In addition, if you have run the model and you subsequently "uncouple" the External element from the Lookup Table element (by selecting "None" from the **Data Source** drop-list in the Lookup Table dialog), the data in the table will become accessible (by pressing **Edit Table…**).

The specific format in which an external function passes table definitions to GoldSim is discussed in Appendix C.

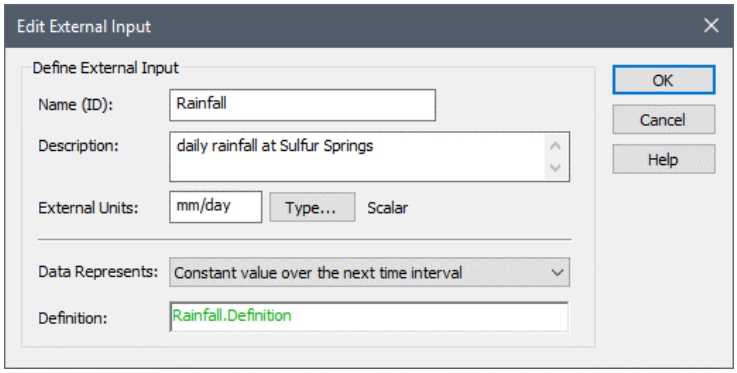
Using an External Element to Read and/or Output Time Series

In some cases, you may wish an external program to directly read, manipulate, and/or generate a Time Series Definition. A Time Series Definition output produced by such an external function can be used to dynamically define a Time Series element.

Read more: Referencing a Time Series Definition Output (page 230).

To facilitate this, GoldSim allows you to input and/or output a Time Series Definition using an External element.

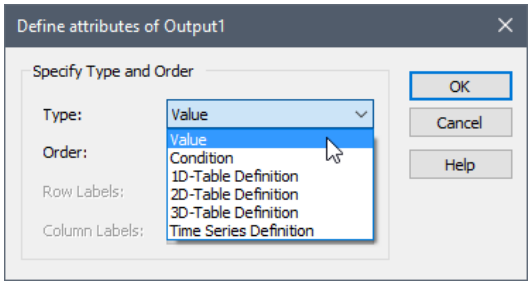
In order to specify that an *input* argument of the External element is a Time Series Definition, you must select a Time Series Definition output when you select the output to link to. After doing so, the input argument dialog will look like this:



Note that in addition to listing the **Definition** and **External Units**, it is also necessary to specify what the time series **Data Represents**. The **External Units** and **Data Represents** field must be consistent with the actual Time Series Definition that is referenced (and automatically default to the correct values when the link is created).

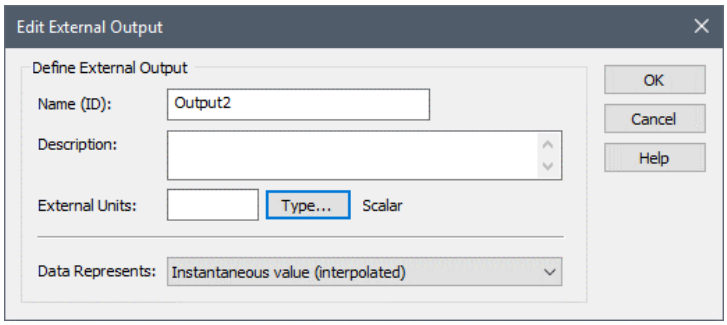
Read more: Specifying What the Input to a Time Series Represents (page 195).

In order to specify that an *output* argument of the External element is a Time Series Definition, you must indicate that the Data Type of the output is a Time Series Definition (when you define the **Type…** for an output argument):



As seen above, in addition to defining an output of an External element as a Value, Condition or Table, you can also define an output whose data type is a Time Series Definition. Time History Definition outputs are complex outputs that represent all the information necessary to define a time series.

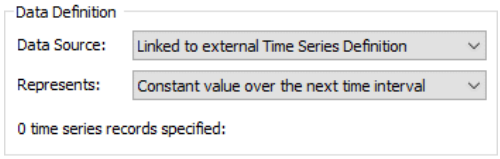
If you select Time Series Definition, the following dialog is displayed for specifying the attributes of the output:



Note that in addition to defining the **External Units**, you must also specify what the time series **Data Represents**.

Read more: Specifying What the Input to a Time Series Represents (page 195).

You link a Time Series Definition produced by an External element to a Time Series element by selecting "Linked to external Time Series Definition" from the **Data Source** field in the Data Definition section of the Time Series element dialog:



When you do so, a new tab (**Linked**) is added to the dialog. You use this tab to specify the name of the External element output that defines the time series.

Note: If using an External element to output a Time Series Definition, the DLL can only be called at etime = 0. Because a Time Series must be defined at the beginning of the simulation, if you try to redefine the time series in the middle of the simulation, GoldSim will issue a Fatal Error.

The specific format in which an external function reads and outputs Time Series Definitions is discussed in Appendix C.

When is the External Element Called?

The external function is called at the following times:

- At the beginning of the simulation (Etime = 0);
- Every GoldSim timestep (if one of the inputs to the element has changed); and
- At any internal step in which an Event is triggered (if one of the inputs to the element has changed).

Read more: How GoldSim Inserts Events into a Simulation (page 431).

It is likely that you may want to treat each of these calls in a different way. For example, you may wish the external function to ignore the call at the beginning of the simulation, or you may want it to carry out some special initialization routines at that time.

You may also want to treat a call in the middle of a timestep (due to an Event) differently from a call at the end of a timestep.

In order to communicate this kind of information to the external function, you would need to send Etime (the current elapsed time) and perhaps Timestep_Length (the length of the current timestep) to the external function as optional input arguments. (Both of these are Run Properties).

Read more: Understanding and Referencing Run Properties (page 505).

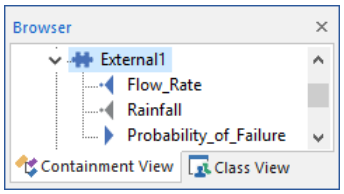
Saving External Element Outputs

You can save results for an External element by clicking Final Values and/or Time Histories. Checking one of these causes all output arguments to be saved. If the element has multiple outputs, and you wish to save only one or two of these as results, you can use the context menu of the output (accessed via a right-click) in the browser to turn a particular output on or off. In this case, the checkbox in the dialog will become gray (indicating that some of the results will be saved). The display units for these outputs are defined when the output is created.

Note: An External element does not have a primary output.

Viewing an External Element in the Browser

The browser view of an External element is shown below:



Note: Element inputs and outputs are only shown in the browser if you choose to **Show element subitems** (accessed via the browser context menu by right-clicking in the browser).

The browser view shows an item for each specified input argument, and an item for each specified output argument. The names of the inputs and outputs are determined by the **Name (ID)** specified when you added the argument to the interface.

File Elements

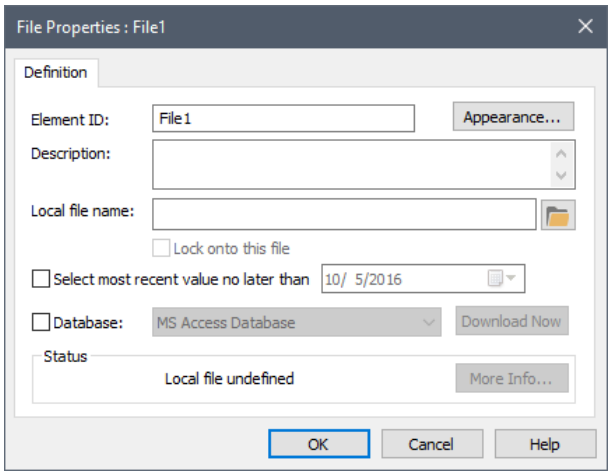
The File element is a support element in GoldSim. It has no inputs or outputs and carries out no calculations. Its purpose is to simply control copies of auxiliary files that may be required by External elements and Spreadsheet elements.

File elements have two uses:

- To ensure that all necessary support files are passed to Slaves when using the GoldSim Distributed Processing Module; and
- To ensure that support files which are stored on a network are accessed for use in a simulation, and to provide an "audit trail" of the file transfer.

In the latter case, the File Element utilizes a specifically formatted database to identify a "source" file, typically on a network, and then copy the target file onto the local computer. This file is then available for access by GoldSim elements.

The dialog for a File element looks like this:



Using File Elements to Support Distributed Processing

The most common use of a File element is to ensure all necessary support files are passed to Slaves when using the GoldSim Distributed Processing Module.

The Distributed Processing Module allows you to use multiple computers connected over a network to share the computational burden of a Monte Carlo simulation. This is accomplished by having a Master (server) GoldSim executable connect to multiple Slave (client) GoldSim executables.

The first step in such a simulation is for the Master to transfer the necessary files (the model files and any support files) to the Slaves.

If the model uses any External or Spreadsheet elements, the Master automatically transfers the DLLs and spreadsheet file, respectively, to the Slaves. If, however, these elements reference any other files (e.g., if the DLL reads in a separate data file the first time it is called), GoldSim has no way of knowing this, and could not send the required files to the Slaves.

The File element can be used to overcome this problem. Any file referenced by a File element is automatically sent to Slaves in a distributed processing simulation.

Hence, when using the Distributed Processing Module with external function elements that reference other files, a File element should be created for each file.

The file name should be entered in the **Local file name** field of the File element, and the **Database** checkbox should be cleared. If no path is provided, the file should be placed in the same directory as the model file, and if the file cannot be found locally, the Status area displays "Local file missing", and the simulation is not allowed to proceed.

Note: The Distributed Processing Module is discussed in detail in the **GoldSim Distributed Processing Module User's Guide**.

Using File Elements to Access a File on a Network

A File element can be used to ensure that support files which are stored on a network are accessed for use in a simulation, and to provide an "audit trail" of the file transfer.

When used in this way, the **Element ID** for the File element is used as a key to access a record in a specifically formatted database referred to as an Extended GoldSim database. This record provides a network path-name for the source file, and also provides an integrity-checking code for the file (to ensure that the file was copied with no errors).

Read more: Downloading from an Extended GoldSim Database (page 1114).

To use a File element in this way, the **Database** box must be checked, and you must enter the data source name associated with an Extended GoldSim database. Before using GoldSim's database features you must first define all available databases on your computer using Control Panel's 32-bit ODBC Data Sources option. This allows you to define a name for each data source, and link it to a specific database file.

Read more: Adding Data Sources to Your Computer (page 1109).

When the **Download Now** button is pressed, or when a global database download is carried out, GoldSim locates the source file and makes a copy of it. The **Local file name** input field defines the local destination for the copy of the source file. If the local file already exists, it is automatically overwritten.

After copying, the CRC signature of the downloaded file is compared to that of the file entered in the database to ensure the integrity of the data transfer. (The CRC signature is an alphanumeric code that can be used to uniquely identify whether the file's contents have changed.) If the codes are different, the download is treated as having failed.

As is the case for other Extended GoldSim database records, you can optionally **Select most recent value no later than**, in which case GoldSim will interrogate the database for the most current version of the source file dated on or prior to that date. If this field is left blank, GoldSim will use the default effective date, as specified in the GS_Parameter table. Details in the format of the Extended GoldSim database are provided in Appendix E.

Locking onto a File

GoldSim allows you to "lock onto" the file that is being referenced by a file element. When you lock onto a file (by checking the **Lock onto this file** option in the File element dialog), the following additional information regarding the referenced file is saved with the element:

- File and path name;
- Date the file was created;
- Date the file was last modified;
- File size; and
- CRC signature.

Once you have locked onto a file, this information is displayed in a tool-tip when you hold your cursor over the filename in the dialog.

The CRC signature is an alphanumeric code that can be used to uniquely identify whether the file contents have changed. When you run a model that has locked onto a file, GoldSim compares the CRC signature of the file with the original signature that was stored. If these are not identical (indicating that the file has been changed), GoldSim displays an error message and will not run the model.

You can unlock a file by clearing the **Lock onto this file** checkbox. Note that if versioning is enabled, whenever a file is locked onto or unlocked, this information is logged with the version.

Read more: Tracking Model Changes (page 1099).

Localizing Containers

In most models, element names are forced to be unique. In some cases, however, you may want to have more than one element with the same name. This requirement usually arises when you have a number of similar subsystems in your model.

For example, suppose that you have developed a subsystem (within a Container) that calculates the balance in a bank account as a function of the previous balance, interest rate, deposits and withdrawals. Each of these items would be represented by its own element in the Container. After creating these elements, you decide you would like to track ten other accounts.

In such a case, it would be convenient to create ten copies of the Container (one for each of the other ten accounts). If GoldSim allowed you to just make copies of the bank account Container, however, there would be confusion when you referred to an element by name (e.g., in an expression), since GoldSim would have no way of knowing which copy of the element you were referring to.

GoldSim's solution to this problem is to allow you to localize portions of your model, such that any element names in the local region are hidden from elements outside of that region. A local region is referred to as a ***scope*** in GoldSim. Elements with the same name cannot exist within the same scope. Elements can, however, have the same name if they are located in different scopes. You change the scope of an element by localizing the Container in which it is located. Unless you specifically "expose" an element, the contents of a local Container can only be "seen" and hence referenced by other elements inside the Container.

The example model LocalizedContainer.gsm in the General Examples/Containers folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains an example of the use of Localized Containers.

Localizing a Container

All Containers in a model are either global or local. By default, new Containers that you insert into a model are global. You can localize a Container in two ways:

- By selecting **Localize** from the context menu for the element in the graphics pane or a browser (accessed via a right-click); or
- By selecting the **Localization** checkbox on the properties dialog for a Container.

You can recognize a localized container in four ways:

- The triangle in the upper left hand corner of the Container's symbol in the graphics pane is red (instead of blue).
- The icon for the Container in the browsers is a closed box (rather than an open box).
- The default symbol for the Container in the graphics pane is a closed box (rather than an open box):

- The tool-tip for a localized container will display "Localized".

In addition, the properties dialog for the Container will indicate that it is localized.

If a Container is localized, then *internally* it is like a new model: all of the elements within it must have unique names. The elements within the localized Container, however, can share a name with elements outside of the Container.

Note: Like global Containers, localized Containers can be nested, so that a localized Container (referred to here as the parent) can itself contain a localized Container (referred to here as the child). In such a case, the scope of the parent localized Container does not extend into the child localized Container. Hence, an element ID within the child could be the same as one in some other location within the parent.

Read more: Nesting Localized Containers (page 1022).

In addition to manually localizing a Container, GoldSim will also automatically localize Containers under some circumstances. In particular, whenever you paste a Container from one portion of your model (or one model) to another, GoldSim will automatically localize it if the names of elements inside the pasted Container conflict with those at the location where it is being pasted. (When it does this, it will warn you with a message.)

Referencing the Contents of a Localized Container

By design, the contents of a localized Container can only be "seen" (and hence referenced) by other elements inside the Container. Therefore, if you place an element called A in a localized Container called C, and then try to reference A in an expression (outside of C), GoldSim will report that it cannot find A (since it is "hidden" within the scope of the localized Container).

Eventually, however, you will need to pull information out of the localized Container to another portion of your model. GoldSim allows you to propagate outputs outside of localized Containers by *exposing* them as if they were outputs of the localized Container itself. Once an output is exposed, it is referenced in expressions by using the form ContainerID.OutputID.

For example, suppose you had a localized Container L, containing an Expression element named X. Assume further that another element named X existed outside of Container L. If you exposed X on the localized Container L, then you could access it from other Containers (outside of L) by referencing it as L.X in expressions.

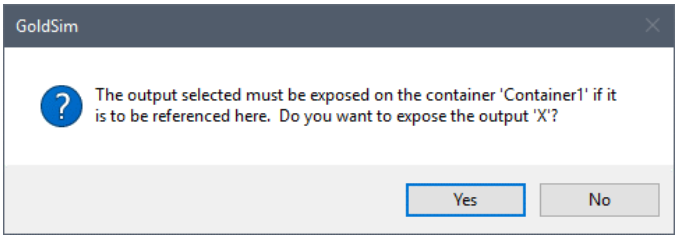
There would be no confusion with the other element named X in the model, since you would be referring to the X within Container L as L.X (not simply X). Within Container L, however, you could access X in the normal way, by entering X directly in expressions.

Exposing an Output on a Localized Container

An output can be exposed on a localized Container in four ways:

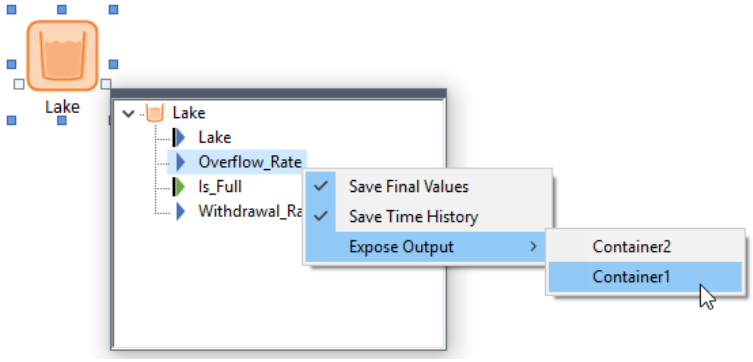
1. Whenever you localize a Container, any outputs which are already referenced outside of the Container are automatically exposed.
2. If you use the Link Cursor to create a link from an output within a localized Container to a location outside of the Container, the output is automatically exposed.
3. If you use the Insert Link dialog (accessed by selecting **Insert Link…** from the context menu of an input field) to create a link from an output within a localized Container to a location outside of the Container, you

will be prompted with a message asking if you want to expose the output:



If you select **Yes**, the output is exposed.

4. You can manually expose an output on a Container using the context menu for the output (accessed by left-clicking on the output port and then right-clicking on the output in the output interface).



The dialog lists all localized Containers containing the element (i.e., if the element is contained within nested localized Containers, all of the localized Containers are shown). The output can be exposed on any (or all) of the localized Containers in which it resides by clicking on the Container name. If the output is already exposed on a particular Container, a check will appear next to the Container name.

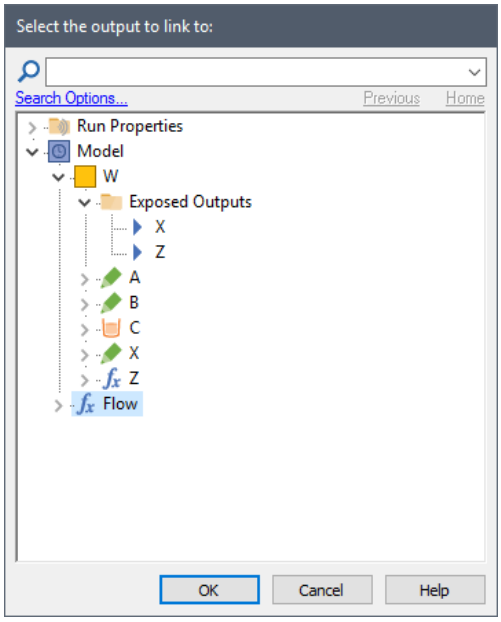
Once an output is exposed, it remains exposed even if the element to which it was originally linked is deleted. The only way to unexpose an output is to access the context menu for the output, and under the Expose Output option, clear the check mark (by clicking on it) for the Container.

Note: Because moving an element is implemented as a cut and paste operation, and this operation effectively deletes and then recreates the links, if the move involves localized Containers, situations can arise where GoldSim will not be able to recreate all of the links. This can occur, for example, if you move an element into a localized Container such that elements referencing its outputs can no longer see them, or if you move an element outside a localized Container that references an output inside that Container. In such cases, you will have to expose the outputs (and press F9) in order to recreate the links.

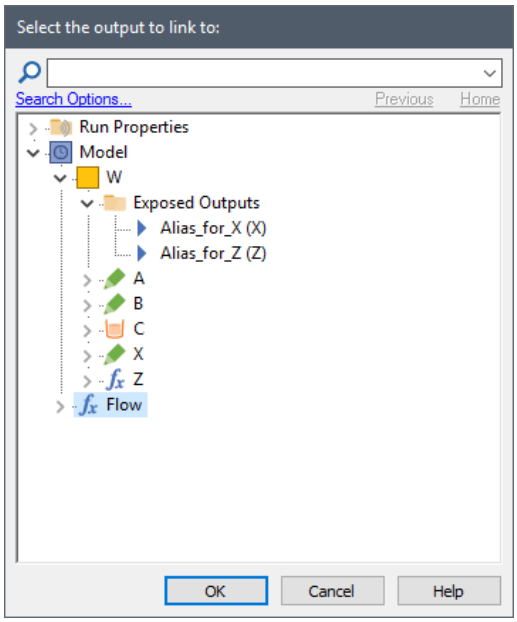
Read more: Moving Elements Between Containers (page 103).

Once an output is exposed on a Container, it is displayed within an *Exposed Outputs* folder within the Insert Link dialog (accessed by right-clicking in an input field and selecting **Insert Link…**. For example, suppose that the variable

X was exposed on the Container W. If you selected **Insert Link…** from an input field outside of the Container, you could select X from the Exposed Outputs folder:



Note that if the exposed output has a defined alias, this is shown first, followed by the element name in parentheses:



Read more: Defining an Alias for an Exposed Output (page 1023).

Similarly, when typing output names into an input field, GoldSim's link suggestion feature makes allows you to easily enter exposed outputs. In particular, if you wish to link to an exposed output of a localized Container, you can do so by typing a period after the name of the Container in the input field. The suggestion box will then list any exposed outputs that exist for that Container.

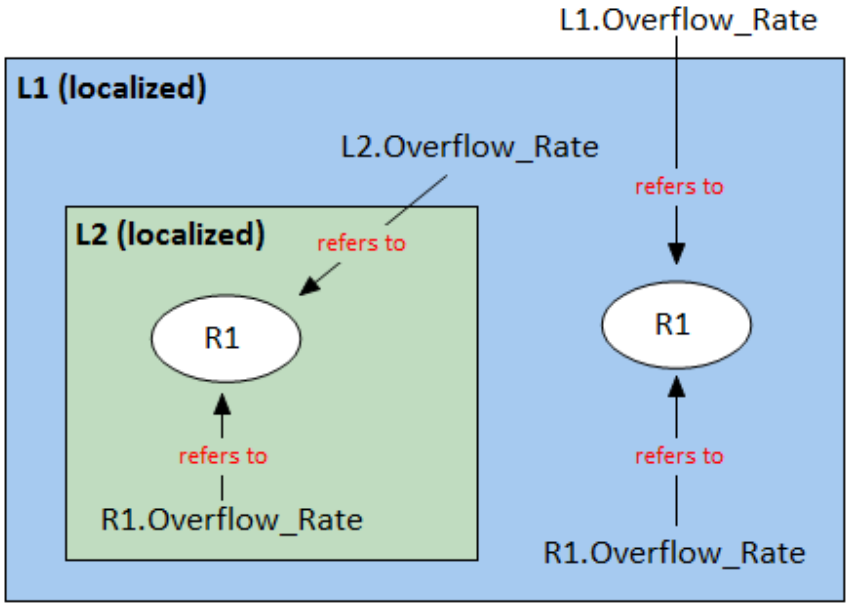
Read more: Displaying Link Suggestions in Input Fields (page 84).

Nesting Localized Containers

Localized Containers can be nested, so that a localized Container (referred to here as the parent) can itself contain a localized Container (referred to here as the child). In such a case, the scope of the parent localized Container does not extend into the child localized Container.

To illustrate this, consider the following example. Suppose you had a localized Container L1, containing a second localized Container L2. A Reservoir element named R1, with an output (among others) called Overflow_Rate, exists in L2. Because this Reservoir is within a localized Container, a second Reservoir element with the same name could exist in L1.

If the Overflow_Rate for the Reservoir in L2 was exposed on L2, and the Overflow_Rate for the Reservoir in L1 was exposed on L1, these outputs would be referenced as shown schematically below:



As indicated in the diagram,

- The Overflow_Rate for the Reservoir within L2 would be referenced as:
  - R1.Overflow_Rate from within L2; and
  - L2.Overflow_Rate from within L1 (but outside of L2).
- The Overflow_Rate for the Reservoir within L1 would be referenced as:
  - R1.Overflow_Rate from within L1 (but outside of L2); and
  - L1.Overflow_Rate outside of L1.

Hence, if you were to reference R1.Overflow rate from an expression within L1, it would link to a different element than if you were to do the same from an expression within L2.

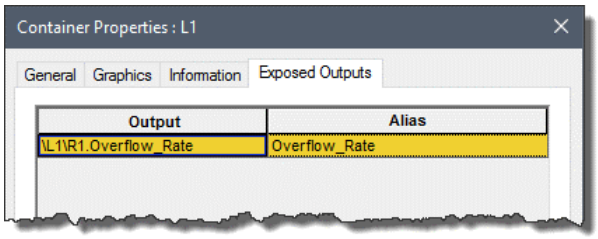
Note: In the example shown above, it is not possible to reference the Overflow_Rate for the Reservoir within L1 from within L2. In order to do so, you would need to first rename one of the two Reservoir elements.

Read more: Search Logic for Linking to an Output Present in Multiple Scopes (page 1024).

Defining an Alias for an Exposed Output

There are some situations where referencing an exposed output of a localized container might be ambiguous. In particular, suppose you exposed the Overflow_Rate from the Reservoir in L2 on Container L1. How would you then reference this output from outside of L1? L1.Overflow_Rate is already used (it refers to the output from the Reservoir in L1). The same problem would occur if you added another Reservoir element with a different name (e.g., R2) to L1 and exposed the Overflow_Rate on L1. Again, L1.Overflow_Rate is already used and is not available.

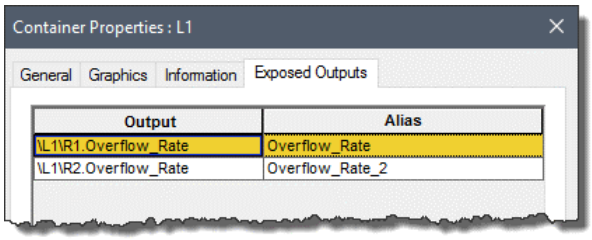
GoldSim solves this potential conflict by defining an alias for each exposed output. Whenever at least one output is exposed on a Container, an **Exposed Outputs** tab is added to the Container's property dialog:



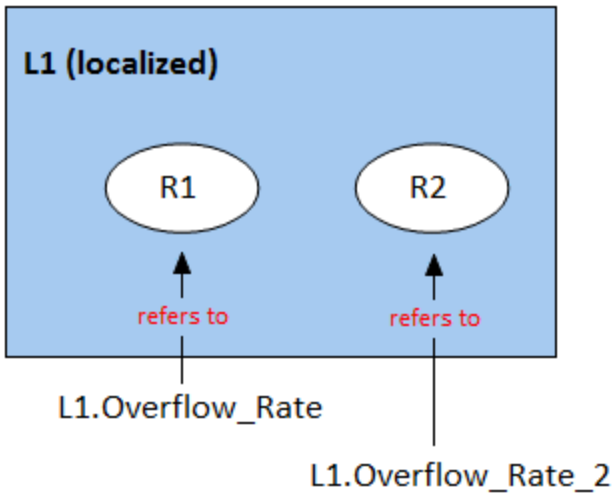
If you hold the cursor over the Output field, a tool-tip showing the full path to the output is displayed.

The first column on this tab lists the full path of the output (which uniquely identifies it). The second column contains an ***alias***. By default, the alias is the output name. When you reference an exposed output outside of a localized Container, it is not actually referenced as ContainerID.OutputID. Rather, it is referenced as ContainerID.Alias.

If you expose an additional output which has the same output name, GoldSim automatically appends a number to the alias.



In the example above, if you exposed the Overflow_Rate from Reservoir R2 on Container L1 *after* exposing the Overflow_Rate from Reservoir R1 on L1, then outside of L1, R2.Overflow_Rate would be referenced as L1.Overflow_Rate_2:



Note: The aliases automatically created by GoldSim for outputs with the same name depend on the order in which the outputs are exposed. The alias of the first output with a particular name that is exposed is always the output name. GoldSim then adds numbers (beginning with 2) to each additional output with the same name that is exposed on the Container.

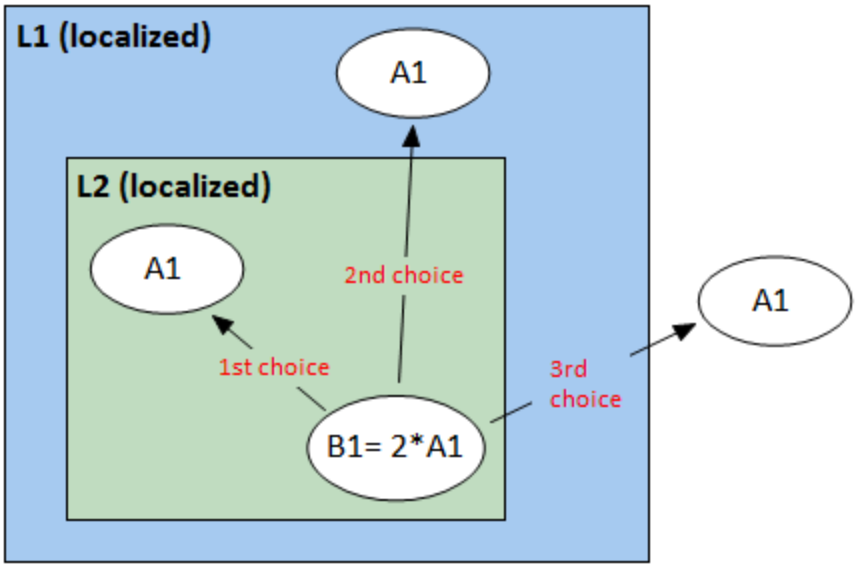
Although GoldSim automatically creates aliases, you can manually edit an alias if you wish (by clicking on it in the dialog). The same rules that apply for element names apply for aliases: Aliases can only include letters, numbers, and the underscore ("_") character. They cannot include spaces and must begin with a letter. Furthermore, for a given Container, no two exposed output aliases can be the same.

Search Logic for Linking to an Output Present in Multiple Scopes

Although the outputs of an element in a localized Container can be referenced outside of the Container only if the output is exposed on that Container, the inputs to the element can come from any location in the model. That is, a localized Container is analogous to a two-way mirrored glass: you cannot look into the Container, but you can look out of it.

In cases where multiple outputs with the same name exist in a model, however, it is important to clearly identify the search logic used by GoldSim to link to outputs.

Consider the following example. Localized container L2 is contained within localized Container L1. Both L1 and L2 contain an element (with a primary output) named A1. A third element named A1 also exists outside of L1. Within L2, you create an Expression element (named B1), and specify its definition as 2*A1. Which of the three A1 elements does GoldSim create a link to?



The schematic above illustrates the search logic GoldSim would use to create the link. It would first look within its own scope (the local scope of B1). If it finds A1 there, it creates the link. If it does not find A1 in its local scope, it moves one level up in the scope hierarchy (in this case within L1) and looks for it there. If it finds A1 there, it creates the link. If it does not find A1 at that level, it continues to search upward through the various scopes that it has access to until it finds an A1, or exhausts the search (and fails to complete the link).

Warning: In the example shown above, if A1 exists in L2, it is impossible to access the outputs of the other A1 elements in the model from within L2. That is, B1 will always try to link to the "nearest" A1, and there is no way for B1 to reference one of the other A1 elements in the model. Even if you use the Link Cursor or the Insert Link dialog to explicitly link to one of these other elements, GoldSim will ignore this and link to the "nearest" A1. It will try to do this even if the output of the nearest A1 is incompatible with input requirements (and one of the other A1 has a compatible output). If you needed to access one of the other elements, you would need to change its name (to something that did not exist inside L2).

Globalizing a Container

You can convert a localized Container to a normal (global) Container in two ways:

- By selecting **Globalize** from the context menu for the element in the graphics pane or a browser (accessed via a right-click); or
- By clearing the **Localization** checkbox on the Container's property dialog.

When you do this, GoldSim first checks to ensure that none of the elements in the Container will conflict with (i.e., have the same name as) other elements in the scope into which the Container's contents will be placed when it was globalized. If it finds a conflict, it will not globalize the Container, and will issue a warning message. You will not be able to globalize the Container until all of the conflicts are eliminated (i.e., until all conflicting elements are renamed).

Cloning Elements

In some situations, you may wish to have elements in your model that always have identical definitions. You could accomplish this by copying an element to various locations in your model, but if you ever needed to change the definition of the element, you would need to make the change to all the copies, and this could be time-consuming and error-prone.

GoldSim addresses this issue by allowing you to create multiple ***clones*** of an element. When you create clones of an element, all of the clones behave identically: if you change one of the inputs to a clone, the same input is automatically changed for all of the other clones.

Clones are often used in conjunction with localized Containers. For example, suppose that you wished to model the salmon populations in each of ten streams. To do this, you might create ten parallel (adjacent) localized Containers, each of which represented a different stream. Although the inputs differ, let's assume that the basic algorithm used to compute the salmon population as a function of time was the same for each of the ten streams.

One way to build this model would be to create the elements representing the algorithm and copy them to each of the ten Containers. If, however, you were expecting to frequently change and modify the algorithm (e.g., as more data became available), it would become cumbersome (and error-prone) to edit the elements in all ten Containers whenever you wanted to make a change.

Clones provide an easier way to build and maintain such a model: You would simply create ten sets of *clones* (rather than *copies*) of the elements defining the algorithm and place them in each of the ten localized Containers. Then if you wanted to modify the algorithm, you would need only to change the elements in one of the Containers and the corresponding clones of those elements would automatically be changed in all of the others.

Note that use of clones does not imply that all clones produce the same output result; it only implies that they have the same definition. For example, a cloned Expression element might have the definition 2*A. All clones of the element would indeed have the same definition, but if the clones were each located in a different localized Container, then A in one Container could have a different value than A in another Container (i.e., each localized Container could have its own element A). As a result, the output of the Expression would be different in each Container.

Creating Clones

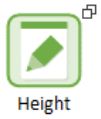
You create clones of an element by right-clicking on the element you wish to clone in the graphics pane or a browser to access its context menu, and selecting **Clone Element**.

When you do so, you will then be presented with a dialog containing all of the Containers in your model. Using this dialog, you must then select the Container into which you wish to place the clone.

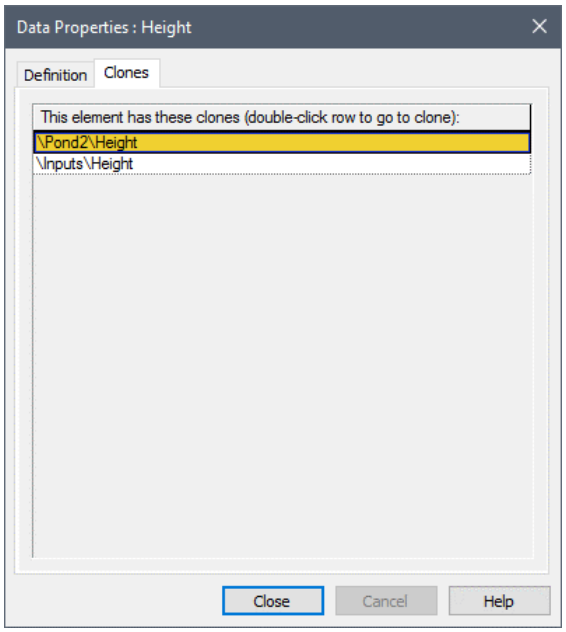
If you select a Container in the same scope as the element you are cloning (or an existing clone of the element), GoldSim will ensure that the names of none of the clones conflict by adding a number to the end of the new clone. If you select a Container in a different scope, the cloned element will have the same name as the element being cloned.

All clones are "equal". That is, the original element is no different than the clone which was created from it. Both are clones, and if you change an input to one, the same input in the other is automatically changed accordingly.

You can always recognize a clone in the graphics pane, because a small symbol (two overlapping boxes) will be present in the upper right-hand corner of the image:



In addition, within the the properties dialog of a cloned element, you will notice an additional tab, labeled **Clones**.



The **Clones** tab lists all of the clones of the element. There is no limit on the number of clones of an element that can be created.

Double-clicking on a row in this dialog jumps directly to that clone.

Moving and Copying Clones

When you move a cloned element (by right-clicking and selecting Move To…), the element remains a clone after it is moved.

However, if you copy and paste a cloned element, the pasted element is not a clone.

Element Properties that are Not Cloned

If you change an input for one clone, it is automatically changed for the other clones. This is the case for standard inputs, as well as other properties, such as checkboxes.

There are, however, several exceptions to this rule:

- Names (element IDs) are never cloned. Each clone can have a unique name.
- Descriptions are never cloned. Each clone can have a unique description.
- Save flags (i.e., Save Final Values and Save Time Histories) are never cloned. You must separately select whether you wish to save results for each clone.

- The graphical properties of an element (e.g., size, color, and symbol used in graphics pane) are not cloned. Each clone can have a different appearance.
- The random seed of Stochastic elements is not cloned. Therefore, cloned Stochastic elements have different seeds (and hence will have different sampled values).
- A number of elements (e.g., Reservoirs) provide an input field that only accepts Discrete Changes. These fields are followed by a button that allows you to more easily add multiple Discrete Changes. If an element is cloned, this button is disabled (such that the only way to add multiple Discrete Changes is by separating them in the input field using a semi-colon).

Elements that Cannot be Cloned

Six element types cannot be cloned:

- Result elements (including Decision Analysis elements);
- Script elements;
- SubModels;
- CellNet Generators;
- File Elements; and
- Dashboards.

In addition, if a Data element is defined to provide Scenario Data, it cannot be cloned.

Read more: Scenario Data: Defining Inputs for Different Scenarios (page 527).

No option is provided to clone these elements. Moreover, if they are present in a Container that you want to clone, you will not be able to clone the Container. You also cannot insert any of these elements into a previously cloned Container.

Read more: Cloning Containers (page 1028).

Freeing a Clone (Decloning)

In some situations, you may want to "declone" or "free a clone" (i.e., change it to a "normal" element). You can do this by right-clicking on the clone you wish to declone in the graphics pane or a browser to access its context menu, and selecting **Free Clone**.

In either case, the element will be changed into a "normal" element: it will no longer be a clone (and the Clone tab will no longer appear in the properties dialog for the element).

Note that if the element was one of only two clones before it was freed, the other remaining clone would also be automatically freed (since it would have no other clones).

Similarly, if you delete a clone which was one of only two clones before it was deleted, the remaining clone is automatically freed.

Cloning Containers

In addition to cloning individual elements, you can also clone an entire Container. Before cloning a Container, it must first be localized. Once a Container is cloned, it cannot be globalized.

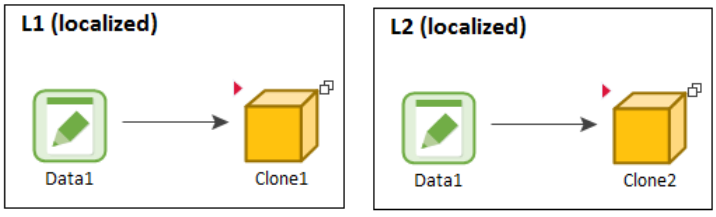
When you clone a Container, all of its contents are also automatically cloned. Any change you make to any element within one cloned Container is made to all of the clones. In particular,

- When you create, paste or delete an element in one cloned Container, it is automatically created, pasted or deleted in all of the cloned Containers.
- When you move an element between Containers inside of a cloned Container, it is automatically moved within all of the cloned Containers.
- When you move an element into a cloned Container, the element is replicated and moved into all of the cloned Containers.
- When you move an element out of a cloned Container, that copy is moved and all of the clones of the element in the other cloned Containers are deleted.

Several other points regarding cloned Containers should also be noted:

- The names of all elements within a cloned Container are also cloned. (Recall that cloned elements which are not inside a cloned Container can have different names).
- You cannot declone an element which is inside a cloned Container.
- When you declone a Container, the elements inside the formerly cloned Containers remain clones. Once the Container is decloned, however, you can individually declone elements within the Container.
- Some elements cannot be cloned (e.g., Dashboards, Scripts, SubModels, Files, Results). As a result, GoldSim prevents your from adding these to a cloned Container, and prevents a Container that contains such elements from being cloned.
- If graphic images are present inside a Container when it is cloned, these are copied to the cloned Containers. If they are subsequently edited, however, the changes are not propagated to the other cloned Containers.
- When you change the positions of elements within a cloned Container (e.g., by dragging an element from one part of the screen to another), the new position is not propagated to the other cloned Containers.

The key to using cloned Containers is to provide unique inputs to them from elements that are *outside of them* (otherwise, all of the cloned Containers would behave identically and produce exactly the same results). This can be done by placing the cloned Containers within separate localized Containers:



In the example shown above, the two cloned Containers (Clone1 and Clone2) are within two separate localized Containers (L1 and L2). Within the cloned Containers, all the equations and elements are, by definition, identical. In this example, it is assumed that within each cloned Container, an element references Data1. Since the clones are in different localized Containers, however, they each link to a *different* Data1 element.

The example model CloningContainers.gsm in the General Examples/Containers folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) contains an example of the use of cloned Containers.

Copying Containers with Clones

In general, you cannot copy a cloned element to create another cloned element. If you simply copy a clone and paste it elsewhere, the pasted element will not be a clone. The only way to clone an element is to right-click on it and select **Clone Element.**

Under one circumstance, however, you can create a clone by copying and pasting an element. In particular, you can create clones if you copy and paste a Container that contains clones.

When you copy and paste a Container that contains clones, GoldSim uses the following rules when the Container is pasted:

- If the Container contains at least two elements that are clones of each other (cloned sisters), the pasted Container will also treat those elements as clones. Note, however, that they will not be clones of the elements in the original Container. For example, if Container1 contains elements A and B that are sister clones, and Container1 is copied and pasted (and the pasted Container is named Container2), A and B inside Container2 will be clones of each other, but they will not be clones of the original A and B in Container 1. The rule here is simple: when you copy and paste a Container with clones, under no circumstances can you increase the size of a set of existing clones. You can only make a copy of a set (forming a new set of clones).
- If the Container contains only one clone (with the other clones being outside of the copied Container), the element will not be a clone in the pasted Container.

Referencing an Output's Previous Value

There are some situations in which you may want to reference the *previous* (as opposed to the *current*) value of an element's output. For example, you may want to reference the amount of money in an account (represented by a Reservoir) one day ago, as opposed to at the current time. GoldSim allows you to reference an output's previous value by using a Previous Value element.

A previous value element outputs the value of its input from the *previous update* of the model. Usually, a model is only updated every timestep, so that the previous update refers to the previous "scheduled" timestep specified in the Time Phase settings of the Simulation Settings dialog.

Read more: Setting the Basic Time Options (page 471).

In some cases, however, GoldSim actually updates the model between specified (scheduled) timesteps. In such a case, the previous value is not necessarily the previous scheduled timestep, and may return a value between the current scheduled timestep and the previous scheduled timestep.

Read more: Understanding Timestepping in GoldSim (page 473).

There are basically three instances in which a Previous Value element can be useful:

- Occasionally, you may actually want to directly reference the previous value of an output (as in the example of an account mentioned above). Generally, however, you should be careful when doing so, and in most

cases it is poor modeling practice, as it ties your model to the timestep length. For example, if you were interested in obtaining the value for an output from 3 days previous, and to do so you used a Previous Value element, you would need to take care to always use a 3 day timestep. In such a case, rather than choosing a 3 day timestep and referencing its previous value using Previous Value element, it is almost always better to use an Information Delay with a Delay Time of 3 days.

Read more: Information Delay Elements (page 335).

- In some situations, you may wish to simulate a static or dynamic process in which the variables in the loop are coupled such that they respond instantaneously to each other, and there are no time lags. In GoldSim, these are referred to as ***recursive loops***, and they are conceptually different from feedback loops. The output of a Previous Value element can be used to provide an approximation to the current value of an output so that coupled equations can be solved explicitly.

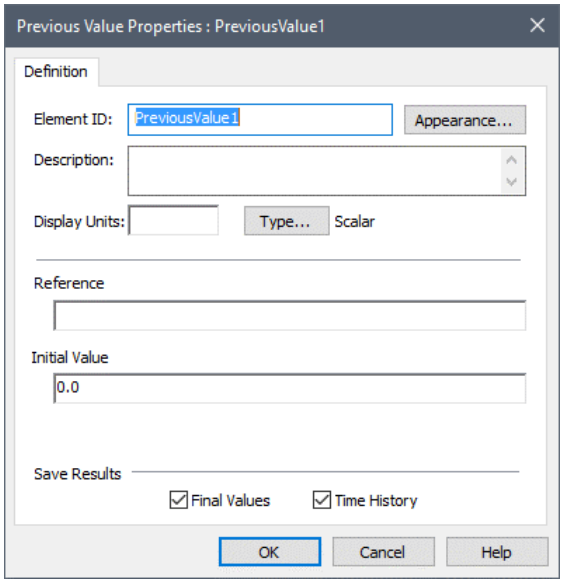
  Read more: Creating Recursive Loops Using Previous Value Elements (page 1033).

- GoldSim provides the ability to carry out looping (iterative) calculations at each update (at each point in time) within a Container. In these special Containers, a calculation is repeated until a specified number of loops is completed or a particular condition is met. In most cases, the condition will likely involve comparing the output of the looping calculation to the previous loop's output (e.g., determining if ($X_{now} - X_{prev}$) < some tolerance value). Previous Value elements can be used to facilitate such a calculation.

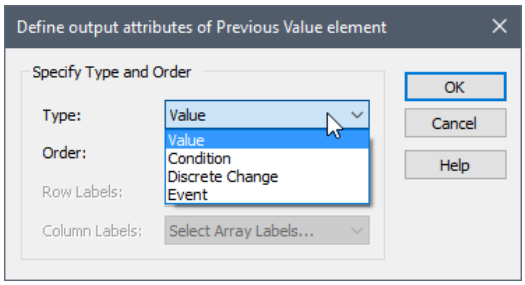
  Read more: Using Looping Containers (page 1036).

Inputs and Outputs to a Previous Value Element

The property dialog for a Previous Value element looks like this:



When defining a Previous Value element, your first step should be to specify the type of output for which you want to compute a previous value. You do this by pressing the **Type…** button, which will display the following dialog:



By default, the output of a new Previous Value element is a scalar, dimensionless value. However, a Previous Value element can accept as an input (and hence output) one of four types of outputs (as specified in the **Type** field in this dialog): Values, Conditions, Discrete Change Signals and Discrete Event Signals.

If you select Value, Condition, or Discrete Change Signal, the **Order** can also be specified as a vector or a matrix.

The **Display Units** determine the dimensions of the input to and output from the Previous Value element, and are only applicable if the output is a Value or a Discrete Change Signal (otherwise the field is grayed out).

The **Reference** is the value for which you want to compute a previous value.

Note: If the **Reference** is a Discrete Event Signal or a Discrete Change Signal, it can accept multiple discrete signals. This is indicated in the input field by separating the individual discrete signals by semi-colons (e.g., Change1; Change2; Change3).

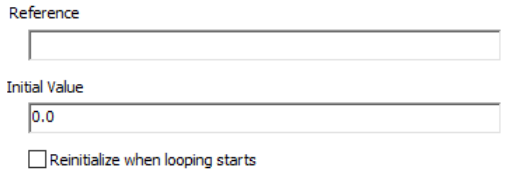
If the **Reference** is a Value or a Condition, in order to compute the output of a Previous Value element, GoldSim must know what value to use at the beginning of the simulation. This is specified within the **Initial Value** field.

Note: The **Initial Value** must be a number or a link from a static variable (e.g., a constant Data element, a Stochastic, or an Expression that is a function of constant elements).

Obviously, the **Reference** and the **Initial Value** inputs to the Previous Value element must have the same attributes (type, order and dimensions) as specified in the attributes dialogs (accessed via the **Type…** button).

Note: If you specify the output type as a Discrete Event Signal, the Reference field will also accept Discrete Change Signals. However, the information in the signal (Instruction and Value) will be lost when it is output by the Previous Value element.

If you place a Previous Value element inside a looping Container (and the Reference is a Value of a Condition), the element has an additional property (**Reinitialize when looping starts**) that controls how the Initial Value is treated between loops:



Read more: Using Looping Containers (page 1036).

A Previous Value element has two outputs:

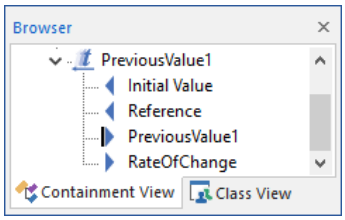
- The previous value of the Reference; and
- The rate of change of the Reference (i.e., the derivative).

The previous value is the primary output.

Note: The rate of change output is only available if the Reference is a Value.

Viewing a Previous Value Element in the Browser

The browser view of a Previous Value element is shown below:



As can be seen, the browser view shows the two inputs (Reference and Initial Value) and the two outputs (the previous value itself, which has the same name as the element, and the RateOfChange).

Note: Element inputs and outputs are only shown in the browser if you choose to **Show element subitems** (accessed via the browser context menu by right-clicking in the browser).

Creating Recursive Loops Using Previous Value Elements

In some situations, you may need to define circular logic in your model that is not necessarily dynamic. A simple simultaneous system of equations is an example of such a system. Such logic does not represent a feedback loop, in that there is no chain of "cause and effect" and no dynamics – in fact, the variables may not change with time at all. In GoldSim, these kinds of circular systems are referred to as recursive loops (and are conceptually different from feedback loops).

Read more: Evaluating Feedback Loops (page 361).

As pointed out above, a simultaneous system of equations is an example of such a system. Consider the following example:

$$B = 4 - A$$

$$A = (6 - B)/3$$

This is a circular system, because A is a function of B and B is a function of A. To compute A and B, it is necessary to solve this coupled system of equations. In this particular case, through simple substitution, you can convince yourself that the solution to these equations is A =1 and B=3.

If you encounter a system such as this in one of your models, you can handle it in one of two ways. First, you could solve the system of equations directly either prior to running the model (e.g., using substitution), or dynamically while running the model (e.g., using an External element or GoldSim's matrix functions to solve the appropriate equations).

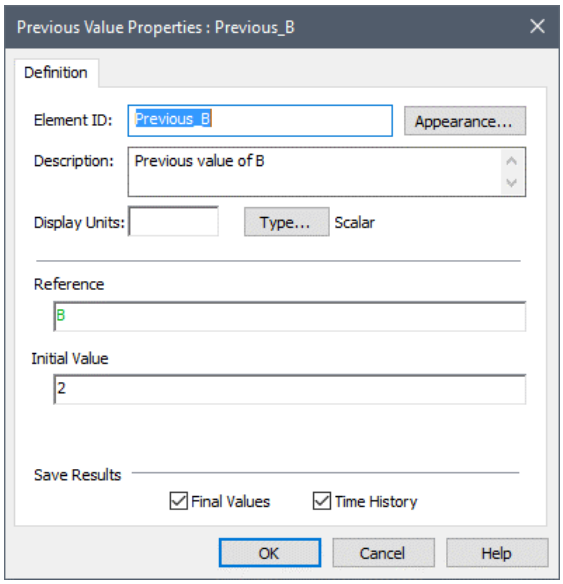
For simple systems such as the example above, this is obviously the correct approach. Note, however, that for many complex models (e.g., non-linear coupled equations), the solution could be very computationally intensive, requiring an iterative approach.

GoldSim therefore will allow you to specify such a circular system and solve the equations in an approximate manner. It does this by assuming, at every timestep, that the current value of one of the variables can be approximated by the value of that variable at the previous timestep. To solve the simple system outlined above, we would define the two equations in GoldSim as follows:

$$B = 4 - A$$

$$A = (6 - \text{Previous\_B})/3$$

In the second equation, Previous_B is the output of a Previous Value element whose input is B:



By doing so, the equations can be solved explicitly (A is solved first as a function of the previous value of B, and then B is solved as a function of A). In effect, GoldSim uses the timestepping algorithm to iterate to a solution, as illustrated in the table below:

Timestep	B at previous timestep	A	B
0	2	1.333	2.667
1	2.667	1.111	2.889
2	2.889	1.037	2.963
3	2.963	1.012	2.988
4	2.988	1.004	2.996
5	2.996	1.001	2.999
6	2.999	1.001	3.000
7	3.000	1.000	3.000

In this case, GoldSim iterated to a very good solution within 2 or 3 timesteps, and an almost exact solution in 7 timesteps. In order for this to work, however, it was necessary to specify the value of "B at the previous timestep" when time = 0. That is, it was necessary to define an Initial Value for B. For this example, an Initial Value of 2 was assumed.

This simple example model illustrating the use of Previous Value elements (PreviousValue.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Note: A more effective way to solve this particular problem would be to embed the system of equations in a looping Container. In such a case, the iteration would not require any timestepping (the iteration would occur within a single timestep). In fact, looping Containers are one of the most important uses for Previous Value elements. This is illustrated in the file LoopingContainer.gsm, which can be found in the General Examples/Containers folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu). Alternatively, you could solve such a system of equations using a Script element. This is illustrated in the file Script.gsm, which can be found in the General Examples folder in your GoldSim directory.

Read more: Using Looping Containers (page 1036); Script Elements (page 929).

When using Previous Value elements outside of looping Containers to represent recursive systems, you need to take special care to ensure that the length of the timestep you are using is small relative to the timescale over which the system is changing. If the system you are simulating is changing rapidly relative to the timestep, your computed result will be inaccurate. That is, if you are using the previous value of a variable as an approximation to the current value, and the previous value is in fact a bad approximation of the current value, then the computed result will be inaccurate (since it takes several timesteps to converge on the correct solution). Selecting a timestep for these kinds of simulations is discussed in further detail in Appendix F.

It is worth reiterating that recursive loops are conceptually different from feedback loops. Feedback loops represent a closed chain of cause and effect. Note that the terms "feedback" and "cause and effect" intentionally imply that the relationship between the variables is dynamic and the system changes over time (although systems with feedback loops can also reach a dynamic

equilibrium). GoldSim allows you to create looping systems like this without having to use Previous Value elements. In order to do so, however, the loop must meet one requirement: it must contain at least one ***state variable***.

Read more: Understanding State Variables in GoldSim (page 356).

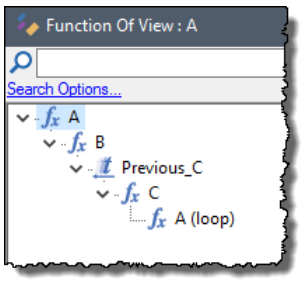
Recursive loops, on the other hand, do not represent a chain of cause and effect, and the system may not be dynamic at all. These loops do not contain state variables. Simulating systems like these in GoldSim requires approximating the solution by using Previous Value elements (which actually work by inserting an "artificial" state variable into the loop).

Finding Recursive Loops

When using the Function Of or Affects View on an element that is within a feedback or recursive loop, GoldSim will stop building a branch of the dependency tree as soon as an item is repeated (and it will mark this as a "loop").

Read more: Viewing Element Dependencies (page 114).

For example, if A is a function of B, B is a function of the previous value of C, and C is a function of A, the Function Of View for A would look like this:



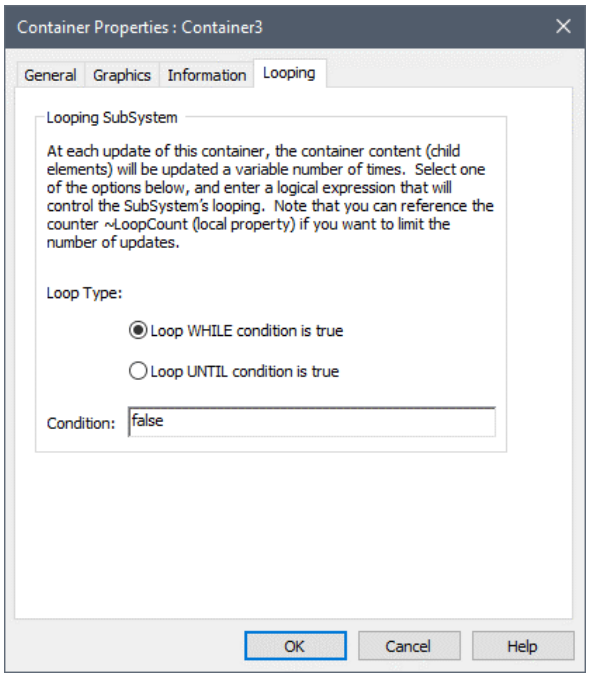
When using the Find function (**Ctrl+F**) in a Function Of or Affects view, one of the options is to search in Labels. If this is selected, and you enter "loop", GoldSim will find the next loop in the list (since it will find the word "loop" in the label for the element). When using this search method, GoldSim will find all the loops (both feedback loops and recursive loops) in the model.

Read more: Finding Elements (page 113).

Using Looping Containers

In some models, you may want to carry out an iterative calculation at each timestep. This might be useful, for example, if you have a coupled system of equations that must be solved every timestep by iterating.

You can define a Container as a looping Container by selecting the **Looping Capability** feature in the Container dialog. When you do so, a **Looping** tab is added to the Container dialog:



Looping Containers are represented in the graphics pane as follows:

Note: When you specify a Container as having **Looping Capability**, you cannot also define an **Internal Clock** for the Container (these two options are mutually exclusive).

Note: Looping Containers are useful when the looping calculation necessarily involves multiple elements (e.g., Reservoirs). For a calculation requiring simpler looping requirements (defining an array, or iterating to a solution for a simple equation), a Script element would often provide a more transparent and easier solution.

Read more: Script Elements (page 929).

Warning: When you specify a Container as a looping Container, the **Treat as SubSystem** feature is also automatically selected (and cannot be deselected unless you first turn off **Looping Capability**). That is, a looping Container, by definition, is treated as a SubSystem. Because a looping Container is treated as a SubSystem, this puts certain limitations on how these Containers can be used.

Read more: Treating a Container as a SubSystem (page 140).

Controlling the Number of Loops in a Looping Container

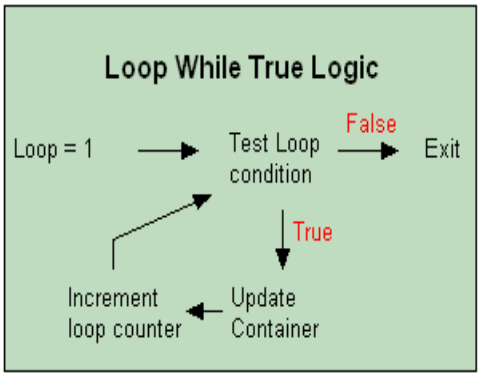
Looping Containers are intended to be used to carry out an iterative calculation at each timestep. The number of loops carried out is controlled by specifying a condition (i.e., loop while or until a specified condition is met).

You can choose between two loop types:

Loop WHILE condition is true. In this case, the loop is carried out as follows:

1. At the beginning of the calculation, the loop counter is set to 1.
2. GoldSim tests the **Condition**.
3. If the Condition is False, the looping calculation is assumed to be complete.
4. If the Condition is True, the contents of the Container are updated and the loop counter is incremented.
5. Go to Step 2.

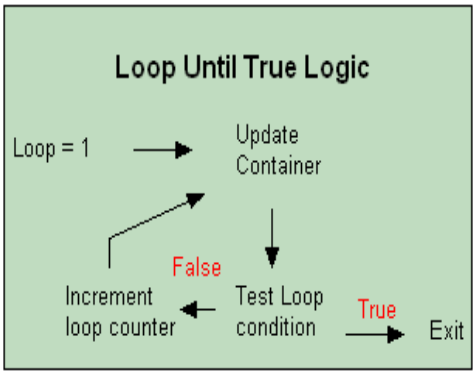
This is illustrated schematically below:



Loop UNTIL condition is true. In this case, the loop is carried out as follows:

1. At the beginning of the calculation, the loop counter is set to 1.
2. The contents of the Container are updated.
3. GoldSim tests the **Condition**.
4. If the Condition is True, the looping calculation is assumed to be complete.
5. If the Condition is False, the loop counter is incremented.
6. Go to Step 2.

This is illustrated schematically below:

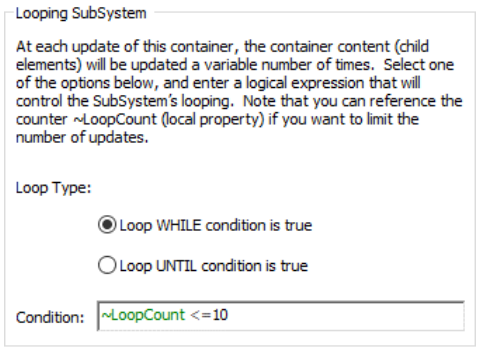


Note: "Loop Until" Containers always update at least once. "Loop While" Containers may not update at all (if the loop condition is not met).

Warning: Because the Condition for a "Loop While" Container must be evaluated before the contents of the Container are evaluated, this Condition can only reference the loop counter or elements inside the Container that have well-defined initial conditions (i.e., state variables)

Read more: Understanding State Variables in GoldSim (page 356)

The loop counter itself can be referenced by any element inside the Container (and within the **Condition** field) as "~LoopCount". For example, if the **Condition** was defined as follows:

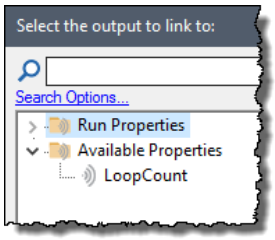


then the Container would complete exactly 10 loops.

As indicated by the way it is referenced, the loop counter is an example of a locally available property. As such, it only has meaning inside the looping Container, and cannot be referenced outside of the Container.

Read more: Understanding Locally Available Properties (page 874).

If you access the Insert Link dialog inside a looping Container (by right-clicking inside an input field of an element within the Container or in the **Condition** field itself), the loop counter appears in a Available Properties folder (displaying all of the locally available properties that can be accessed from that location):



The **Condition** must reference at least one output from within the looping Container (the loop counter is considered to be within the Container). If it does not, GoldSim will display an error message (since otherwise, the **Condition** could not change from loop to loop, and hence has no meaning).

Warning: GoldSim will not exit a loop until the **Condition** has been met, and there is no upper limit on the number of loops that can be carried out. As a result, you should be careful when defining your **Condition** to ensure that you do not define an infinite loop. You can always do so by directly referencing the loop counter (e.g., adding something to the **Condition** such as "OR ~LoopCount > 1000") If it seems that you are in an infinite loop, you should pause the simulation (using the **Pause** button in the Run Control toolbar) and evaluate the loop counter and the condition. You can subsequently stop a simulation using the **Abort** button in the Run Control toolbar.

Understanding How Elements Inside a Looping Container are Updated

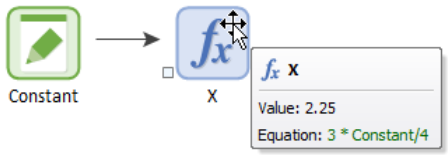
The elements inside the Container are updated as follows during the loops:

1. On the first loop, the elements are moved forward in time to the next scheduled timestep;
2. On subsequent loops, the elements are updated again without advancing time.

Hence, in order for the loops after the first to have any impact on the model, they must contain at least one state variable that changes with each loop.

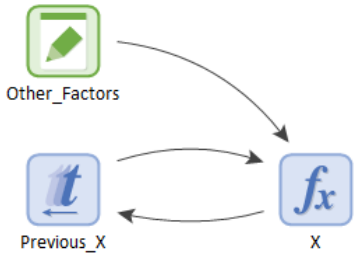
Read more: Understanding State Variables in GoldSim (page 356).

As an example, if a looping Container contained the simple system below, consisting of one Data element and one Expression (neither of which output a state variable), after the first loop, the system would not change at all:



Hence, it would serve no purpose to place a calculation such as this within a looping Container.

The most common application of a looping Container is to use it to carry out an iteration utilizing a Previous Value element. That is, some variable (e.g., X) would be computed each loop based on its value during the previous loop:



The looping system shown here would be updated every loop (changing X , and hence the previous value of X). Typically, you would specify that the looping continue until the difference between X and the previous value of X was within some specified tolerance.

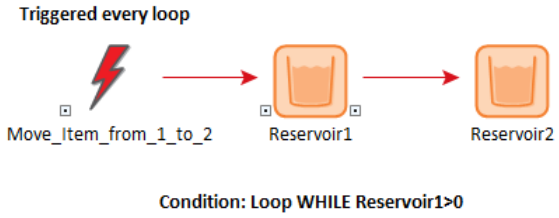
When a Previous Value element is included inside a looping Container, it takes on a special property. In particular, an additional input option is added to the dialog that specifies how the **Initial Value** is to be treated:

If **Reinitialize when looping starts** is cleared (the default), the Initial Value specified in the field is only used at the beginning of the realization (when the Container is updated for the first time), and never again.

If **Reinitialize when looping starts** is checked, the value specified in the Initial Value field is used for the first loop every time the looping Container begins its calculations (i.e., it does not "remember" the value from the previous timestep).

Read more: Inputs and Outputs to a Previous Value Element (page 1031).

Another common application of a looping Container is to use it to carry out multiple discrete transactions in a single timestep. In the simple example below, items are moved from one Reservoir to another (via discrete changes) until the first Reservoir is empty:



Read more: Modeling Discrete Changes to a Reservoir (page 401).

Examples of both of these types of applications (LoopingContainer.gsm) can be found in the Containers subfolder of the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Viewing and Modifying the Causality Sequence

When you build a model, GoldSim automatically *sequences* the elements in the order that they must be computed. For example if A was a function of B, and B

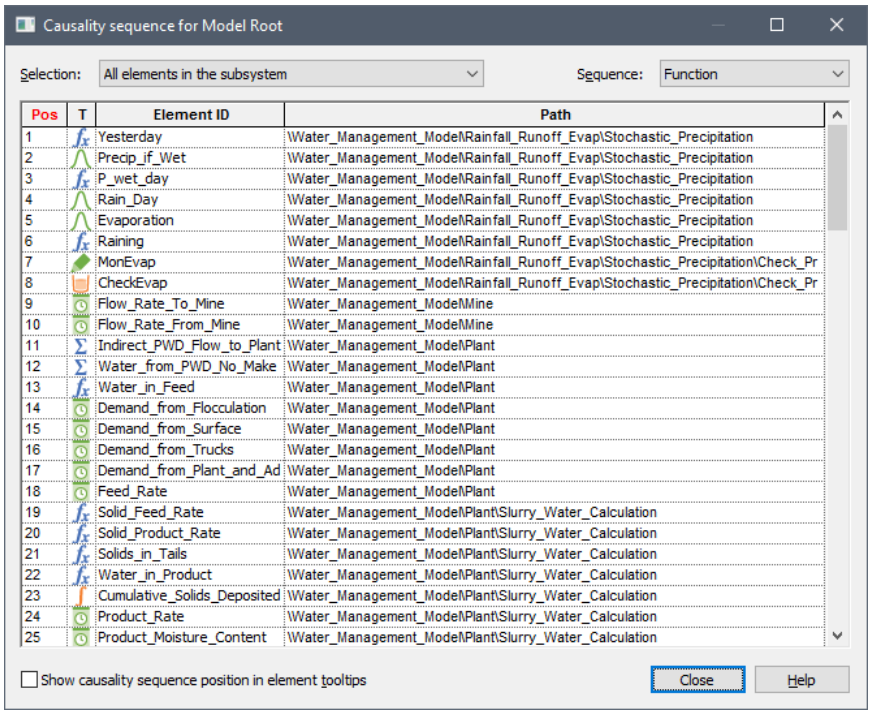
was a function of C, C would be sequenced first, followed by B, followed by A. This is referred to as the ***causality sequence***. Although in this simple example, the sequence is obvious, for complex models with looping logic, the causality sequence may not be readily apparent.

Read more: The Causality Sequence and Element Updating (page 358).

In most cases, you need not to be concerned with how GoldSim sequences the elements. However, in some cases (e.g., when simulating systems that include discrete events and looping logic or systems that have competing Resource requirements), expert users may need to understand (and subsequently manipulate) the causality sequence.

Viewing the Causality Sequence

You can view the causality sequence selecting **Model|Causality Sequence** from the main menu (or pressing **F10**). A dialog similar to this will be displayed:



Pos	T	Element ID	Path
1		Yesterday	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
2		Precip_if_Wet	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
3		P_wet_day	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
4		Rain_Day	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
5		Evaporation	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
6		Raining	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
7		MonEvap	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation\Check_Pr
8		CheckEvap	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation\Check_Pr
9		Flow_Rate_To_Mine	\Water_Management_Model\Mine
10		Flow_Rate_From_Mine	\Water_Management_Model\Mine
11		Indirect_PWD_Flow_to_Plant	\Water_Management_Model\Plant
12		Water_from_PWD_No_Make	\Water_Management_Model\Plant
13		Water_in_Feed	\Water_Management_Model\Plant
14		Demand_from_Flocculation	\Water_Management_Model\Plant
15		Demand_from_Surface	\Water_Management_Model\Plant
16		Demand_from_Trucks	\Water_Management_Model\Plant
17		Demand_from_Plant_and_Ad	\Water_Management_Model\Plant
18		Feed_Rate	\Water_Management_Model\Plant
19		Solid_Feed_Rate	\Water_Management_Model\Plant\Slurry_Water_Calculation
20		Solid_Product_Rate	\Water_Management_Model\Plant\Slurry_Water_Calculation
21		Solids_in_Tails	\Water_Management_Model\Plant\Slurry_Water_Calculation
22		Water_in_Product	\Water_Management_Model\Plant\Slurry_Water_Calculation
23		Cumulative_Solids_Deposited	\Water_Management_Model\Plant\Slurry_Water_Calculation
24		Product_Rate	\Water_Management_Model\Plant\Slurry_Water_Calculation
25		Product_Moisture_Content	\Water_Management_Model\Plant\Slurry_Water_Calculation

The dialog indicates the order within the sequence (**Pos**), the element type (**T**), the Element ID and the full element path (**Path**).

There are actually two different sequences that can be displayed: the *Static Sequence* and the *Function Sequence*. The Static Sequence consists of those elements that only need to be computed once (at the beginning of the simulation), since they cannot change with time. The Function Sequence consists of those elements that can change as a function of time.

Read more: The Causality Sequence and Element Updating (page 358).

By default, the dialog displays the Function Sequence first (as this is typically of greatest interest). You can switch between these two using the drop-list in the top right corner of the dialog.

You can sort the rows according to any column (ascending or descending) by double-clicking on the column header.

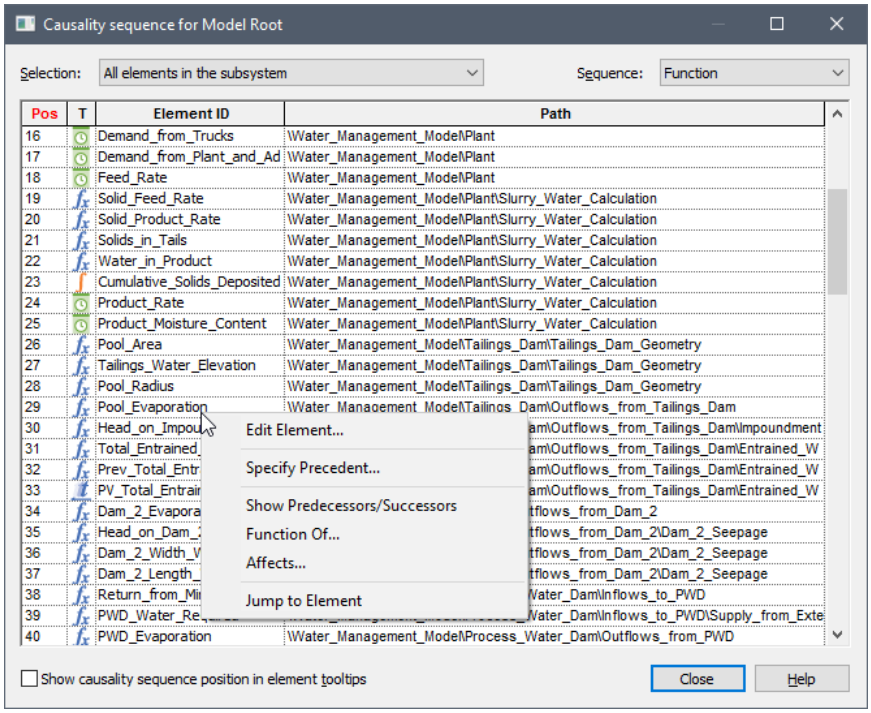
The **Selection** field at the top of the dialog allows you to limit what portion of the sequence is displayed:

- All elements in the subsystem (the default)
- Elements in current container/child containers
- Elements in the current container only

Note: You can only view the causality sequence for one subsystem at a time. The subsystem that is displayed is the one you were viewing when you displayed the sequence.

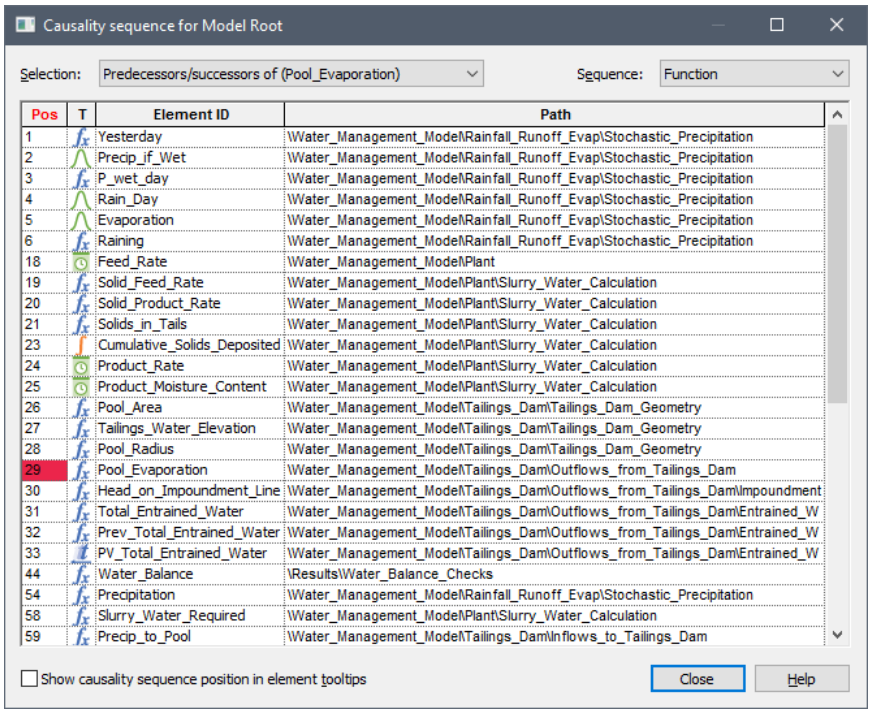
Read more: Treating a Container as a SubSystem (page 140).

Right-clicking on an element in the sequence displays the following menu:



Four of these options are self-explanatory ("Edit Element", "Function Of", "Affects", and "Jump to Element").

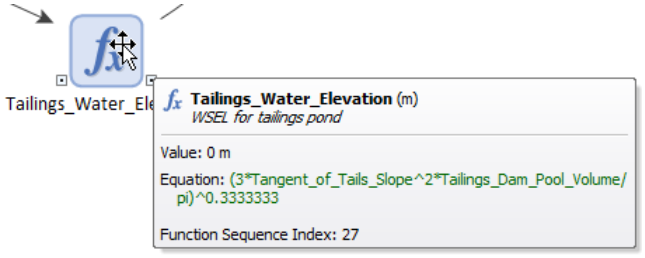
"Show Predecessors/Successors" provides a filtered view of the sequence showing only those elements that directly or indirectly either affect the selected element, or are affected by it. Note that when you choose this option, the position of the selected element is marked with a red background (making it easier to see):



Pos	T	Element ID	Path
1		Yesterday	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
2		Precip_if_Wet	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
3		P_wet_day	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
4		Rain_Day	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
5		Evaporation	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
6		Raining	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
18		Feed_Rate	\Water_Management_Model\Plant
19		Solid_Feed_Rate	\Water_Management_Model\Plant\Slurry_Water_Calculation
20		Solid_Product_Rate	\Water_Management_Model\Plant\Slurry_Water_Calculation
21		Solids_in_Tails	\Water_Management_Model\Plant\Slurry_Water_Calculation
23		Cumulative_Solids_Deposited	\Water_Management_Model\Plant\Slurry_Water_Calculation
24		Product_Rate	\Water_Management_Model\Plant\Slurry_Water_Calculation
25		Product_Moisture_Content	\Water_Management_Model\Plant\Slurry_Water_Calculation
26		Pool_Area	\Water_Management_Model\Tailings_Dam\Tailings_Dam_Geometry
27		Tailings_Water_Elevation	\Water_Management_Model\Tailings_Dam\Tailings_Dam_Geometry
28		Pool_Radius	\Water_Management_Model\Tailings_Dam\Tailings_Dam_Geometry
29		Pool_Evaporation	\Water_Management_Model\Tailings_Dam\Outflows_from_Tailings_Dam
30		Head_on_Impoundment_Line	\Water_Management_Model\Tailings_Dam\Outflows_from_Tailings_Dam\Impoundment
31		Total_Entrained_Water	\Water_Management_Model\Tailings_Dam\Outflows_from_Tailings_Dam\Entrained_W
32		Prev_Total_Entrained_Water	\Water_Management_Model\Tailings_Dam\Outflows_from_Tailings_Dam\Entrained_W
33		PV_Total_Entrained_Water	\Water_Management_Model\Tailings_Dam\Outflows_from_Tailings_Dam\Entrained_W
44		Water_Balance	\Results\Water_Balance_Checks
54		Precipitation	\Water_Management_Model\Rainfall_Runoff_Evap\Stochastic_Precipitation
58		Slurry_Water_Required	\Water_Management_Model\Plant\Slurry_Water_Calculation
59		Precip_to_Pool	\Water_Management_Model\Tailings_Dam\Inflows_to_Tailings_Dam

"Specify Precedent" allows you to manually affect the causality sequence, and is discussed in detail in the next section.

Checking **Show causality sequence position in element tooltips** adds the position number to tooltips displays in the model:



Note: In some complex looping systems, you may notice that an Element ID in the sequence will be highlighted in red. This indicates that due to the looping nature of the system, GoldSim's first choice for sequencing the element was not possible, and it was necessary to move the element upward in the sequence. GoldSim's preference is to always have referencing elements follow the elements that they reference. When GoldSim is unable to generate a valid sequence using this rule, it selectively moves elements that reference state variables ahead of the elements that calculate the state variables, and flags the moved elements in red. The resulting sequence is not invalid, but it does indicate that the sequence is ambiguous.When you see a system like this, you should take special care to look carefully at the results to determine whether or not the system is performing as you expect it to. If not, you may need to manually change the sequence.

Addressing Ambiguous Causality Sequences

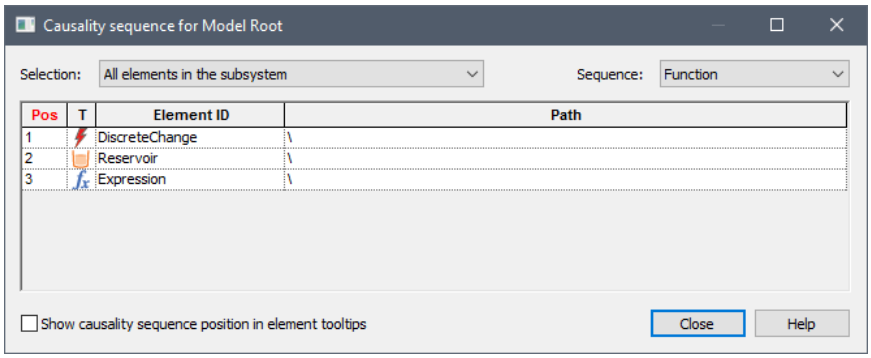
In order to determine how GoldSim is to carry out its calculations, it first must create the ***causality sequence*** for all of the elements. This represents the sequence in which the elements must be logically computed.

Read more: The Causality Sequence and Element Updating (page 358).

In some models, however, there may be more than one valid way to sequence the system, *and these different sequences may produce different results*. In these cases, GoldSim provides a way to manually force a particular causality sequence to ensure that the model accurately represents your system.

In order to better understand this, let's construct a simple system where the causality sequence is ambiguous:

By default, the causality sequence for this model looks like this:



In order to fully understand this sequence, it is first necessary to recall a special rule regarding a Function Sequence involving Discrete Changes: Discrete Changes are propagated to any affected stock elements instantaneously when the Discrete Change is updated in the sequence (regardless of where the affected stocks are located in the sequence).

So in the sequence shown above, GoldSim does the following: Every timestep, after changing the system clock, GoldSim first computes the state variables that are intrinsic functions of time. In this example, the only element that falls into this category is the Reservoir, so it is first brought up to the current time. After doing this, GoldSim then computes the Function Sequence. First, it computes the value of the Discrete Change, and instantaneously applies the Discrete Change to the Reservoir (this is actually regardless of where the Reservoir is in the Sequence). Then it computes the Reservoir (i.e., it would store all of its inputs for use in the next timestep, but this would not change its current value). Finally, the Expression is computed.

The reason this system is ambiguous is related to the fact that the Reservoir is actually computed twice. First, it is brought up to the current time (i.e., it solves a time integral). Then, it is updated a second time within the Function Sequence (it is modified by the Discrete Change). The ambiguity here arises from the fact that it is not completely clear when you might want to compute the Expression.

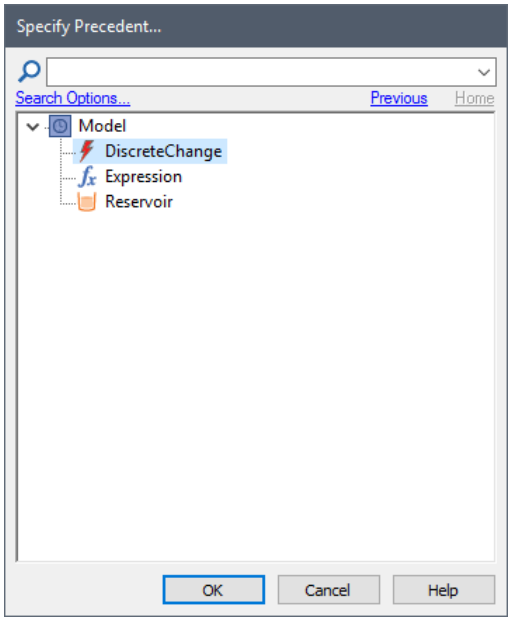
There are two options:

1. Compute the Expression after the Reservoir has been updated by the Discrete Change; or

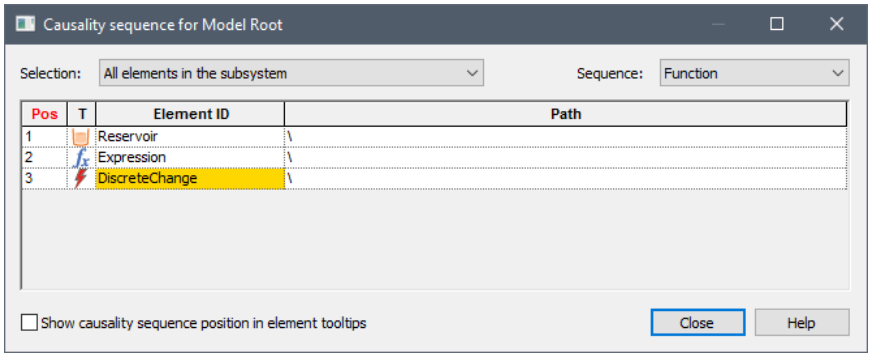
2. Compute the Expression after the Reservoir has been brought up to the current time, but before it has been updated by the Discrete Change.

GoldSim will sequence it assuming the first option is correct. However, the second option is equally valid, and will produce a different result! Hence, when you have a system such as this, you must specifically instruct GoldSim how to sequence this system to ensure it accurately represents the system you are trying to model.

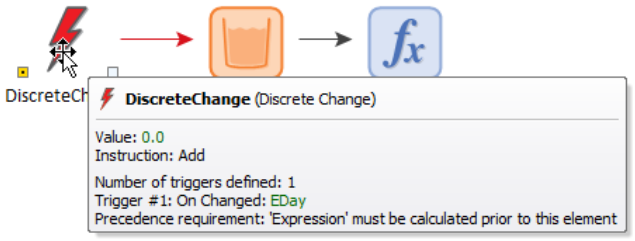
To facilitate this, GoldSim provides an option to manually force a particular causality sequence. If you right-click on an element in the sequence, one of the options is to "Specify Precedent". You can then specify a particular element that you wish the selected element to follow in the causality sequence. In this particular case, to force the second option listed above, we want the Expression to be a precedent for the Discrete Change. Right-clicking on the Discrete Change and selecting "Specify Precedent" displays this dialog:



If we select Expression here, the causality sequence now looks like this:



Note that Expression is now in front of the Discrete Change. The Discrete Change is highlighted in gold (indicating that it has a "forced" precedence). The input port for the Discrete Change is also highlighted in gold, and its precedence requirement is added to its tool-tip:



If you right-click on the Discrete Change, you would see that there is a new option ("Remove Precedent").

Three other points regarding forced precedence should be noted:

- You can only specify one precedence requirement for an element (although an element can have multiple elements that use it as a precedent).
- GoldSim will not allow you to specify a precedent that results in an invalid causality sequence (e.g., a recursive system). It only allows you to force sequences that are still valid.
- Precedence requirements do not create a link to the element being referenced (i.e., the precedent). As a result, if the precedent is deleted and replaced with an element with the same ID, the precedence will not be recreated.

An example of the use of forced precedence to control sequencing (Bounce.gsm) can be found in the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Using SubModels to Embed Models Within Models

In some cases, you may want to embed an entire GoldSim model within another GoldSim model. GoldSim provides a special element called a SubModel to facilitate this.

A SubModel superficially looks like a Container, and conceptually shares some aspects with Containers. However, the functionality of a SubModel is quite different from a Container. Whereas a Container is simply a grouping of elements within a model, a SubModel is a completely separate "inner" model within an "outer" model. That is, it has its own simulation settings (time and Monte Carlo options) that are independent of the simulation settings of the outer GoldSim model within which the SubModel element is placed. Hence, when a SubModel element (i.e., the inner model) is triggered to do a calculation by the outer model, it runs a complete simulation.

The sections below provide the details on the use of SubModels in GoldSim.

What Can I Do With a SubModel?

Before describing the details of how SubModels are created and used, it is worthwhile to first discuss why you might want to use a SubModel.

Recall that a SubModel is a complete "inner" model that has been embedded in an "outer" model. The inner model and the outer model can take on a number of forms (e.g., static/dynamic, deterministic/Monte Carlo, simulation/optimization). This provides a wide variety of potential uses. The most common are summarized below.

Manipulation of Monte Carlo Statistics. In some cases, after carrying out a Monte Carlo simulation, you may want to carry out further calculations using the statistical outputs of the simulation. For example, you may want to carry out a calculation that is some function of the mean and the 95th percentile of a particular output in a Monte Carlo simulation. Without the use of SubModels, the only way to accomplish this is by exporting results from a Monte Carlo simulation manually to another application (e.g., a spreadsheet or a separate GoldSim model). With SubModels, this is easily accomplished within a single GoldSim model by inserting a SubModel (that performs a Monte Carlo simulation) into an outer model (that is static and simply manipulates the statistical outputs of the inner model).

Explicit Separation of Variability from Uncertainty. Many models have uncertain parameters as well as randomly variable parameters. An uncertain parameter represents ignorance that can theoretically (but perhaps not practically) be reduced through investigation (e.g., the mean failure time for a batch of light bulbs). Variability is inherent in many systems (e.g., the distribution of failure times for a batch of light bulbs) and cannot be reduced. It is often valuable to explicitly separate variability from uncertainty in a model. With SubModels, this is accomplished by inserting a SubModel (e.g., a dynamic Monte Carlo simulation) within an outer model (e.g., a static Monte Carlo simulation). This is referred to as "nested" Monte Carlo simulation. In the example above, the outer model would sample a probability distribution that represents the uncertainty in the mean lifetime of a light bulb, and the inner model would simulate the performance of a number of random light bulbs (whose lifetime is sampled from a distribution with the mean specified by the outer model). The result of this type of analysis is a probability of probabilities.

Probabilistic Optimization. If you wish to optimize a probabilistic (uncertain) system, the objective function to be optimized cannot be a single deterministic output. Rather, it must be a statistic. That is, if X was an output of a probabilistic model (and hence was output as a probability distribution), optimizing X itself would be meaningless. Rather, you would need to optimize a particular statistic (e.g., the mean or 50th percentile) of the output X. With SubModels, this is accomplished by inserting a SubModel (e.g., a dynamic Monte Carlo simulation) within an outer model (e.g., a static optimization).

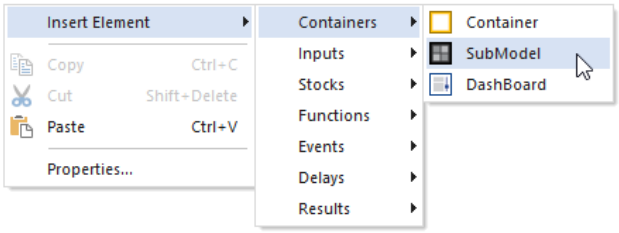
Dynamic Optimization During a Simulation. Imagine a situation where you were simulating the operation of a facility over a period of one year. Every month, the operators make a decision based on the current state of the system. This decision is based on a simple optimization analysis using currently available data (i.e., at every month during the simulation). The optimization chooses the optimum values of a few control variables that they will use for the next month. With SubModels, you could simulate this by inserting a SubModel (e.g., a static optimization) within an outer model (e.g., a dynamic simulation).

Example files describing all four of these applications (SubModel1.gsm, SubModel2.gsm, SubModel3.gsm, and SubModel4.gsm) can be found in the General Examples folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) in the subfolder named SubModels.

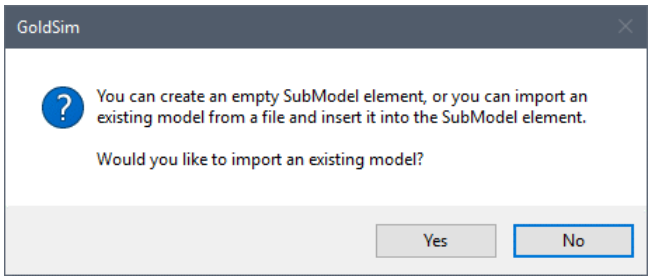
Read more: SubModel Examples (page 1087).

Creating a SubModel

SubModels are listed under Container in the Insert Element context menu:



When you insert a SubModel, you are presented with a dialog asking if you want to create a new (empty) SubModel, or create the SubModel by importing an existing standalone model:

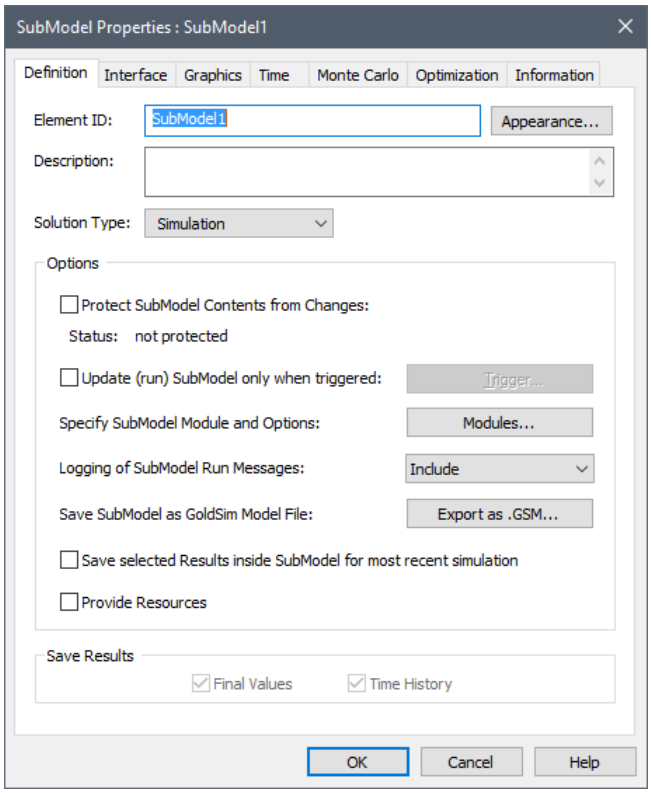


If you choose to import a standalone model, you will be prompted for the file name and a SubModel with the contents of that model will be inserted into GoldSim. Otherwise, a new (empty) SubModel will be created.

Read more: Importing SubModels (page 1083).

The default icon for the SubModel element looks like this:

The property dialog looks like this:



Like all GoldSim elements, you first specify an **Element ID** and a **Description**.

After inserting the SubModel element, the steps for building a SubModel are generally as follows (although they will typically be done iteratively, rather than in this exact order):

1. Specify the Solution Type (Simulation or Optimization).
2. Specify (or if an existing model was imported, edit) the GoldSim modules required by the SubModel.
3. Build (or if an existing model was imported, edit) the contents of the SubModel.
4. Specify (or if an existing model was imported, edit) the simulation settings for the SubModel.
5. Create an input interface between the SubModel and the parent (outer) model.
6. Create an output interface between the SubModel and the parent (outer) model.
7. Specify when the SubModel is to be run.

These steps are described in detail in the sections below.

Specifying the Solution Type for a SubModel

The first step in creating a SubModel (after inserting the element) is to specify the **Solution Type**. There are two options: "Simulation" and "Optimization".

This option determines how the SubModel is being used. For most applications, you should choose "Simulation", which is the default.

"Optimization" will normally only be used when a SubModel is being used to carry out a dynamic optimization (i.e., at specified times) during a simulation. For example, imagine a situation where you were simulating the operation of a

facility over a period of one year. Every month, the operators make a decision based on the current state of the system. This decision is based on a simple optimization analysis using currently available data (i.e., at every simulated month during the simulation). The optimization chooses the optimum values of a few control variables that they will use for the next month.

To represent this in GoldSim, you would need to specify the **Solution Type** for the SubModel as "Optimization", and the SubModel itself would represent the optimization calculations carried out by the simulated operator.

Note: If the Solution Type is "Optimization", Monte Carlo options for the SubModel must be set to "Deterministic".

Read more: Specifying the Simulation Settings for a SubModel (page 1053).

If you do choose the Simulation Type as "Optimization", you will also need to specify the optimization settings in the **Optimization** tab for the SubModel.

Read more: Running an Optimization Within a SubModel (page 1079).

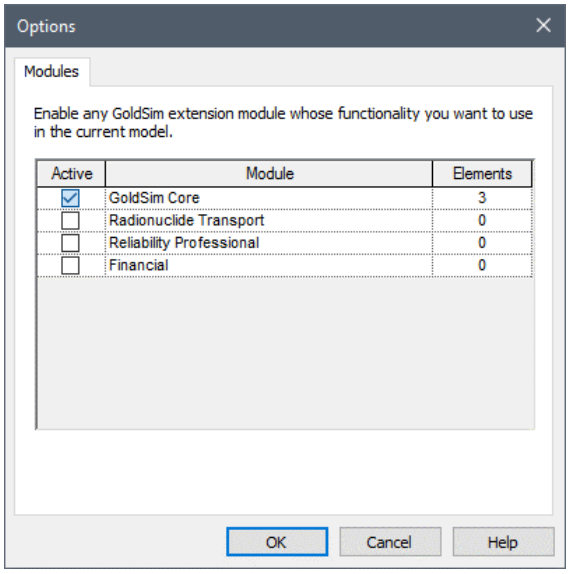
Specifying the Modules and Module Options for a SubModel

Because a SubModel is effectively a separate model (as opposed to a Container), you may choose to use different extension modules in a SubModel than in the outer model. For example, your SubModel may require the Contaminant Transport Module, while the outer model may not.

When you create a SubModel, the modules that are activated by default are the same as those that would be activated by default if you created a new model. (These defaults are set by the user by pressing the **Set as Default** button when activating modules in the **Modules** tab of the Options dialog).

Read more: Activating and Deactivating Extension Modules (page 18).

To specify the modules that will be activated for a SubModel, press the **Modules…** button on the SubModel dialog. The following dialog will be displayed:



All extension modules that you are licensed to use appear in the dialog. If your license does not allow you to use a particular module, it will not be listed. You

can activate and deactivate modules that you are licensed to use by clicking the **Active** checkbox.

If you deactivate a module, the specialized elements associated with that module will be deleted from your SubModel (if any are present) and any associated menu options will be removed in the current file. If you make a module active, the various options associated with that module are made available again.

Note: If a module that is active in a SubModel has special options (that are normally accessed via a tab in the **Options** dialog for a standalone model), these options will appear in a tab on the Modules dialog for the SubModel.

Building the Contents of the SubModel

Once you have selected the Solution Type and modules to be used by a SubModel, building the contents of a SubModel is, for the most part, identical to building the contents of a Container.

Like a Container, you enter a SubModel by clicking on the plus sign in the upper left hand corner of the element. SubModels (and their contents) are also displayed in the browser in the same manner as Containers.

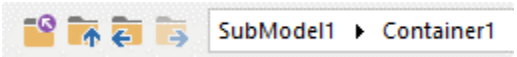
You can add elements, Containers, and even other SubModels to a SubModel, just as you would to a Container. Of course, you can also copy elements that are outside of a SubModel and paste them into the SubModel.

Note: In addition to creating a model manually inside a SubModel, you can also choose to import an existing (standalone) model into a SubModel.

Read more: Importing SubModels (page 1083).

There are several important points to note when building and navigating a SubModel:

- When you are inside a SubModel, the navigation bar at the top of the graphics pane only shows the location with respect to the SubModel. It does not show the path relative to the parent model:

- Within a SubModel, you cannot reference outputs that exist outside of the SubModel in the same way you would from inside a Container. That is, by default, the SubModel is a self-contained system (i.e., a separate model) that cannot "see" anything on the outside. In fact, within a SubModel, the Insert Link dialog accessed via the context menu for input fields does not list any elements outside of the SubModel. In order to access outputs from outside the SubModel, you need to take some specific actions (i.e., add the output to the SubModel's input interface).

  Read more: Creating the Input Interface to a SubModel (page 1055).

- Because the SubModel is a self-contained system (i.e., a separate model), elements on the outside cannot directly reference outputs inside the SubModel. Of course, in order to be of any value, a SubModel must have some way to communicate with (i.e., provide outputs to) the

outer model. However, in order to provide outputs from inside the SubModel to elements in the outer model, you need to take some specific actions (i.e., add the outputs to the SubModel's output interface), and the SubModel outputs themselves have added complexity (since they may represent complex results, such as a distribution resulting from a Monte Carlo simulation).

Read more: Creating the Output Interface to a SubModel (page 1059).

- Results inside a SubModel behave differently than results that have been added to the SubModel's output interface. In particular, because a SubModel is a separate simulation (that will typically be carried out multiple times during a simulation of the outer model), results *inside* of a SubModel are typically overwritten during a simulation of the outer model. As a result, although you can choose to save the results inside of a SubModel, only results from the *last* simulation of the SubModel (i.e., the last time the SubModel was run) are available for viewing *inside* the SubModel at the end of your simulation. Note, however, that this does not apply to results that have been added to the SubModel's output interface. A wide variety of complex results can be accessed via the interface, including various statistics and raw data for *all* SubModel time histories for all simulations of the SubModel.

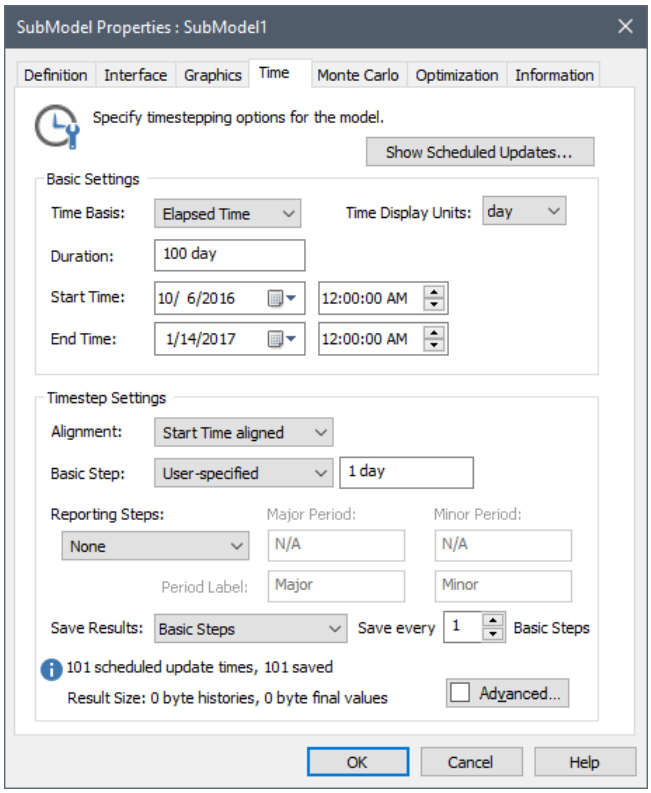
  Read more: Saving and Viewing Results Inside a SubModel (page 1066); Creating the Output Interface to a SubModel (page 1059).

Specifying the Simulation Settings for a SubModel

Because a SubModel is a separate model, it requires its own simulation settings (i.e., timestepping and Monte Carlo options). That is, a SubModel does not use the simulation settings specified by the outer model.

The simulation settings for a SubModel are accessed via tabs at the top of the SubModel dialog.

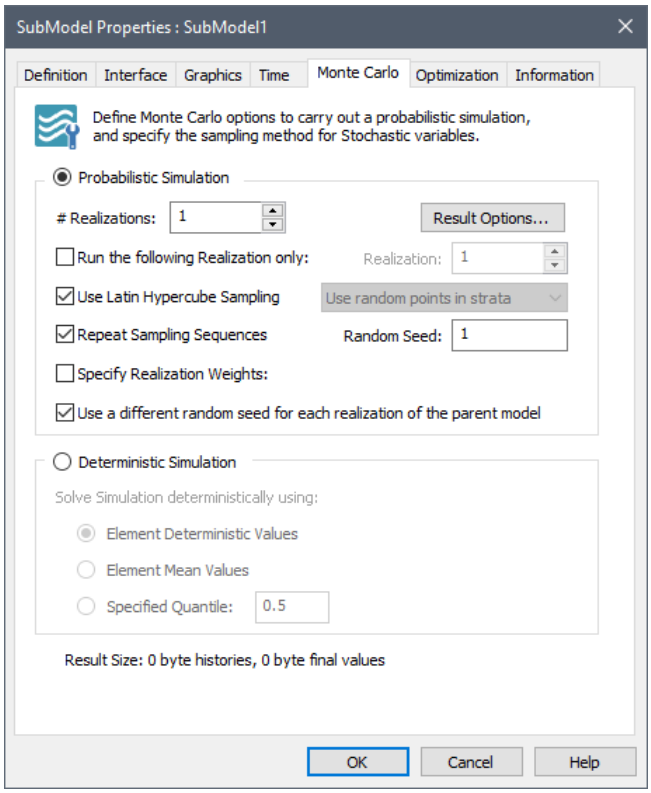
The **Time** tab is used to specify the time options for the simulation:



The inputs to be entered here are identical to those provided in the **Time** tab of the Simulation Settings dialog for a model.

Read more: Setting the Basic Time Options (page 471).

The **Monte Carlo** tab is used to specify the Monte Carlo options for a simulation:



With one exception, the inputs to be entered here are identical to those provided in the **Monte Carlo** tab of the Simulation Settings dialog for a model.

Read more: Setting the Monte Carlo Options (page 497).

The one exception is the **Use a different random number seed for each realization of the parent model** field. If this option is checked (the default), the Monte Carlo SubModel will behave randomly, producing a different result for each realization of the parent model and for each time the SubModel is calculated. If this box is cleared, the Monte Carlo SubModel will behave identically for each realization of the parent model, so that, for example, realization 17 of the inner model is the same for every realization of the parent model.

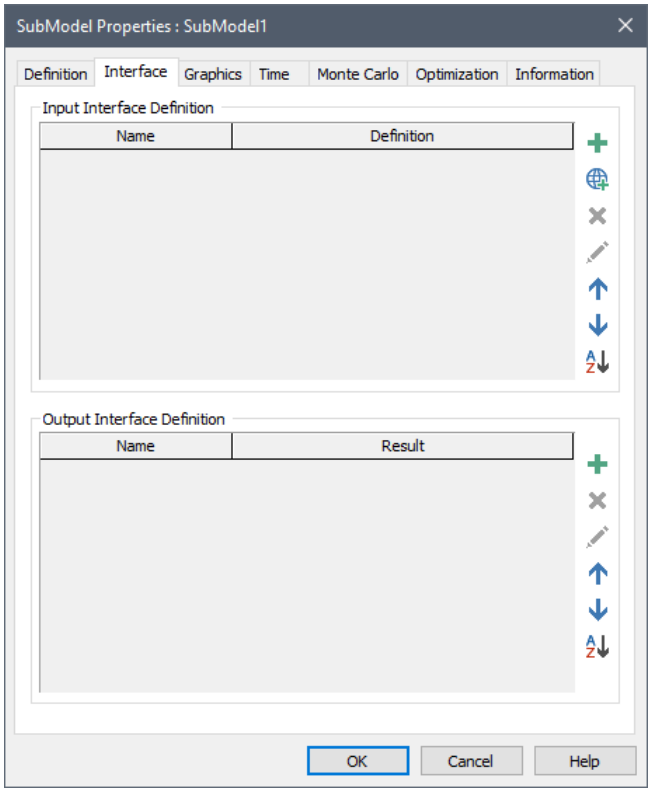
Note: You can choose to specify some of the simulation settings for a SubModel via the Input Interface for the SubModel. If you do this, some of the input fields in the **Time** and **Monte Carlo** tabs will become locked.

Creating the Input Interface to a SubModel

Because a SubModel is a self-contained system (i.e., a separate model), elements inside a SubModel cannot "see" anything on the outside (i.e., in the outer model). As a result, you cannot reference outputs that exist outside of the SubModel in the same way you would from inside a Container. (In fact, within a SubModel, the Insert Link dialog accessed via the context menu for input fields does not list any elements outside of the SubModel).

Of course, in order to be of any value, a SubModel must have some way to communicate with (e.g., access outputs of) the outer model. This is done by creating an interface between the SubModel and the outer model.

The interface is accessed via the **Interface** tab on the SubModel dialog:

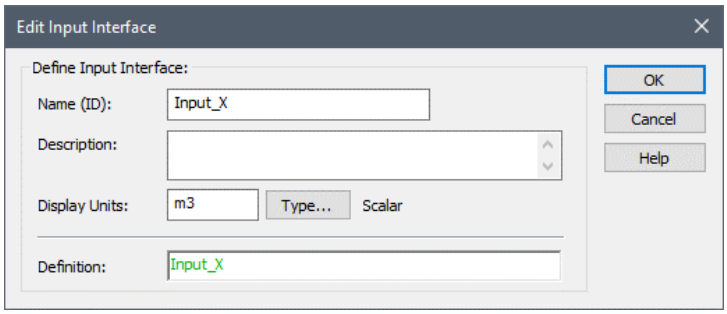


The top part of this dialog is used to define the input interface. The bottom portion is used to define the output interface.

Add button

In order to access an output outside of the SubModel, you must add the output to the input interface. This is done by pressing the Add button in the Input Interface portion of the dialog. When you do this, GoldSim displays the Insert Link dialog, allowing you to select an output outside of the SubModel to add to the interface).

After selecting an output, the following dialog is displayed:



The **Name (ID)** is the name by which the output variable can be referenced inside the SubModel. This has the same restrictions as an element ID. The **Description** is an optional description of the variable.

You must then specify the **Display Units** and **Type** information (e.g., value/condition, scalar/vector/matrix) for the variable. Finally, you specify the **Definition** for the input. Typically, this will be a link to an output in the outer model that you selected. However, it can also be an equation (with links), or a constant value.

Note: If you select a link (rather than pressing **Cancel**) when adding the interface input, the Definition, Display Units and Type will automatically be entered.

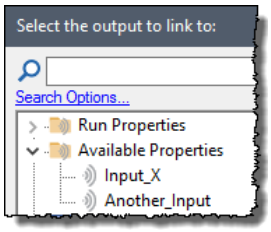
In addition to Values and Conditions, three types of complex outputs can be specified as inputs to a SubModel Input interface: Time Series Definitions, Lookup Table definitions, and Distribution definitions. These are specified via the **Type** button. In the two former cases, additional information (e.g., what the Time Series represents, units for the independent variables for a Lookup Table) must also be specified in the input interface dialog.

A Time Series definition can be produced by a Time Series element, an External element or another SubModel. A Lookup Table definition can be produced by an External element. A Distribution definition is one of the outputs of a Stochastic element (and can also be produced by another SubModel). Passing these definitions through the input interface allows you to pass complete time series, lookup table and distribution definitions into the SubModel, where they can be used to define Time Series, Lookup Table or Stochastic elements.

Read more: Referencing a Time Series Definition Output (page 230); Using an External Element to Define Lookup Tables (page 1011); Externally-Defined Distribution (page 172).

Once you have added an output from the outer model to the Input Interface of a SubModel, you can subsequently reference the output within the SubModel by using the specified **Name** that you defined previously, preceded by a ~. For example, if you create an interface input called X, you could reference it in input fields within the SubModel as ~X.

You can also use the Insert Link option to reference an item on the Input Interface by right-clicking in an input field within the SubModel. When you do so, all of the items on the Input Interface to the SubModel will be displayed within the "Available Properties" folder:



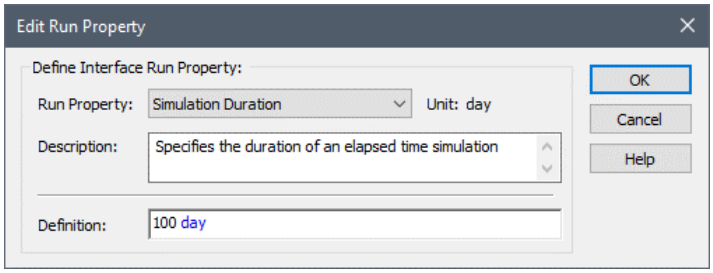
Note: In this case, the ~ indicates that this output has some special characteristics (in particular, it is coming from outside of the SubModel). This is an instance of what is referred to as a locally available property in GoldSim. Locally available properties are accessed by using a ~.

Read more: Understanding Locally Available Properties (page 874).

In some cases, you may want to control some of the simulation settings (i.e., time and Monte Carlo options) of the SubModel from outside of the SubModel (e.g., using values provided by the outer model). To facilitate this, GoldSim allows you to add run properties to the input interface.

Add Run Property button

This is done by pressing the Add Run Property button in the Input Interface portion of the dialog. When you do this, the following dialog is displayed:



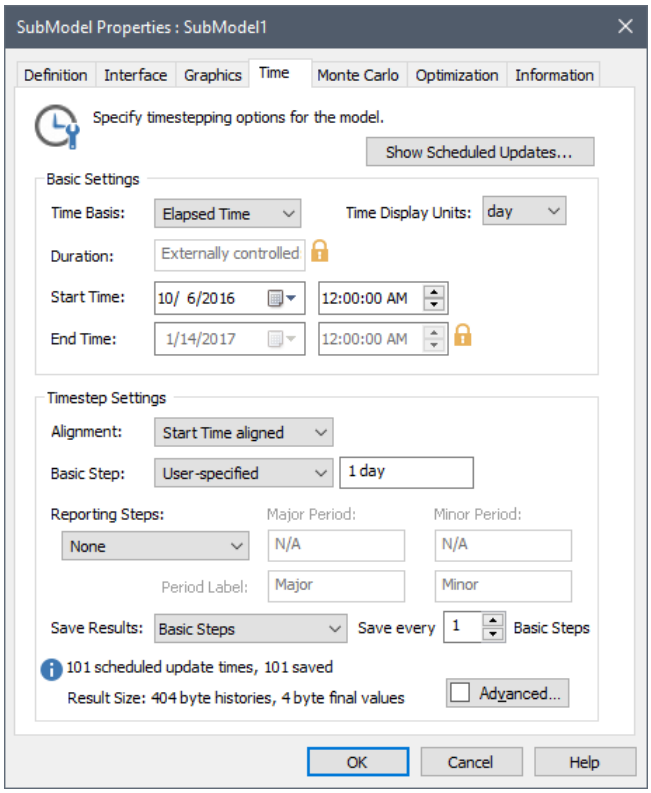
The Run Property field provides a drop-list of options for the SubModel simulation setting that you wish to control. The options are:

- Simulation Duration;
- Maximum time between updates;
- Number of Realizations; and
- Realization to Run

The **Definition** field determines the value that will be used for the selected simulation setting input. Typically, this will be a link to an output in the outer model (the **Definition** field's context menu can be used to access an Insert Link dialog that lists all elements in the outer model). However, it can also be an equation (with links), or a constant value.

Note: If you wish to control the Number of Realizations Run Property, the value must always be set to a number greater than 1. That is, you cannot switch between a single realization run and a multi-realization run of the SubModel dynamically via the Input Interface.

Note that when you select one of these options, the appropriate input fields are automatically locked (and cannot be edited) in the **Time** and **Monte Carlo** tabs for the SubModel:



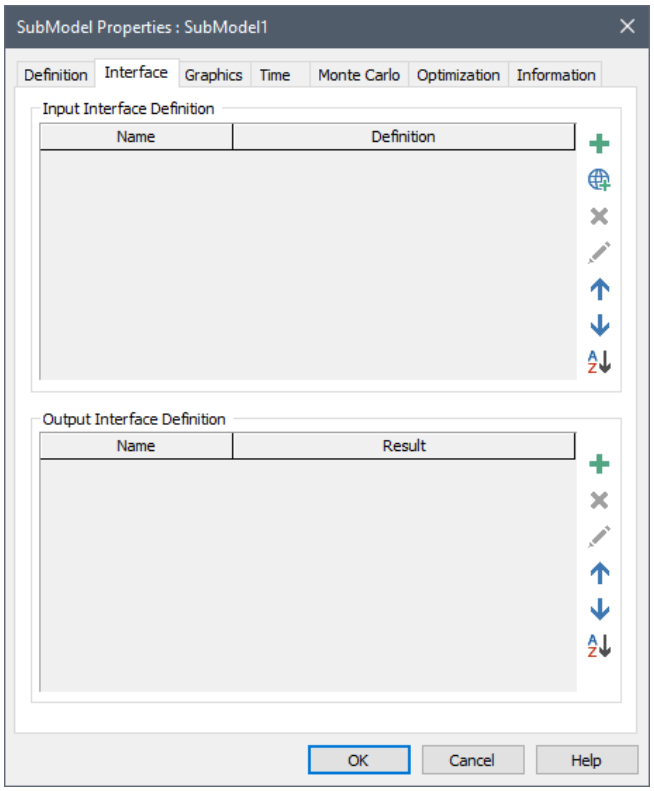
Note: Buttons for deleting, editing, moving and alphabetically sorting the inputs on the interface are available directly below the Add and Add Run Property buttons.

Creating the Output Interface to a SubModel

Because a SubModel is a self-contained system (i.e., a separate model), by default, elements outside a SubModel cannot "see" anything on the inside. Moreover, because a SubModel is a separate simulation (that will often be carried out multiple times during a simulation of the outer model), intermediate results of a SubModel are typically overwritten during a simulation of the outer model and are not available in the outer model.

Of course, in order to be of any value, a SubModel must have some way to communicate with (e.g., provide outputs to) the outer model. This is done by creating an output interface between the SubModel and the outer model.

The output interface is accessed via the **Interface** tab on the SubModel dialog:



The top part of this dialog is used to define the input interface. The bottom portion is used to define the output interface.

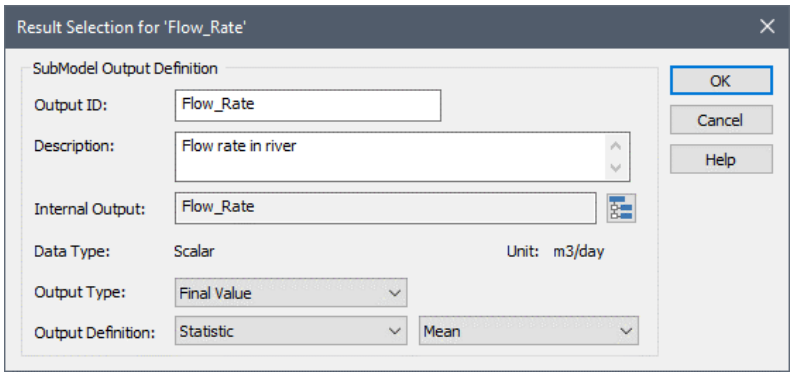
Add button

The output interface allows you to specify the outputs that you want the SubModel to provide to the outer model. It is important to understand that the output interface represents the only mechanism by which you can access outputs of a SubModel outside of the SubModel.

In order to allow the outer model to access an output of the SubModel, you must select the output and add it to the output interface. This is done by pressing the Add button in the Output Interface portion of the dialog.

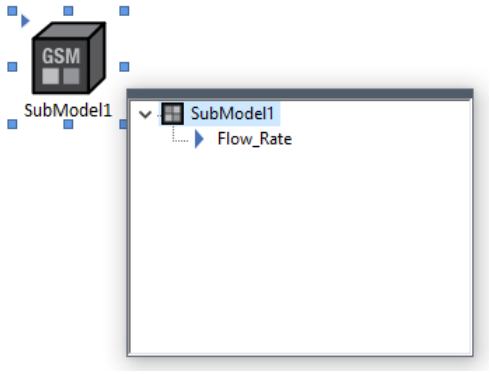
When you press this button, you will be presented with a browser displaying the outputs inside the SubModel. You must select the output that you are interested in.

After you select an output, the following dialog will be displayed:



The **Output ID** is the name by which the output variable can be referenced in the outer model. This ID has the same restrictions as an element ID.

Note that the outputs defined in the output interface are added to the output port interface of the SubModel and can be accessed there (in exactly the same manner the outputs from other kinds of elements are accessed). The Output ID is what is shown in the interface:



The **Description** is an optional description of the output. The **Internal Output** field displays the selected output (which you can change using the button to the right of the field).

The **Data Type** and **Unit** fields are automatically populated based on the **Internal Output** selection.

After selecting the **Internal Output** you must then select what type of result is to be made available to the parent model on the output interface. This is controlled by two fields: **Output Type** and **Output Definition**. For some **Output Definition** selections, a third field will be presented to the immediate right of the **Output Definition** field.

There are two options for **Output Type**:

- Final Value. The following **Output Definitions** are available (some of which are only valid selections under specific circumstances):
  - Last Calculated. This selection is always valid.
  - Statistic. This selection is only valid for Probabilistic SubModels (it is not valid for Deterministic SubModels). A specific Statistic must be defined immediately to the right of the **Output Definition** field.
  - Distribution. This selection is only valid for Probabilistic SubModels and scalar outputs (it is not valid for Deterministic SubModels or for array outputs).
- Time History. The following **Output Definitions** are available:
  - Last Calculated. This selection is only valid for dynamic SubModels and scalar outputs (it is not valid for Static SubModels or for array outputs).
  - Statistic History. This selection is only valid for Probabilistic, dynamic SubModels and scalar outputs (it is not valid for Deterministic or Static SubModels or for array outputs). A specific Statistic must be defined immediately to the right of the **Output Definition** field.
  - Realization Histories. This selection is only valid for Probabilistic, dynamic SubModels and scalar outputs (it is not valid for Deterministic or Static SubModels or for array outputs).

Note: For some advanced applications, you may select a Time Series Definition output (from an External element or Time Series element inside the SubModel) rather than a Value as the **Internal Output**. If you do so, the **Output Type** is automatically set to be a Time Series Definition (rather than a Final Value or Time History).

When you add an output to the Output Interface and select the **Output Type** and **Output Definition**, you will be notified if your selections are invalid.

The Output Interface provides a summary of all of the outputs (as well as their **Output Type** and **Output Definition)**:

Output Interface Definition

Name	Result
Flow_Rate_Final	Final Value
Flow_Rate_Mean	Statistic (Mean)
Flow_Rate_Distribution	Final Value Distribution
Flow_Rate_History	All Realization Histories
Flow_Rate	Time History

If you change the settings such that some of the selections are no longer valid, the Results will be identified in red (and the model will not run). In the example below, the SubModel has been set to Deterministic, invalidating those Output Types that require a Probabilistic SubModel:

Output Interface Definition

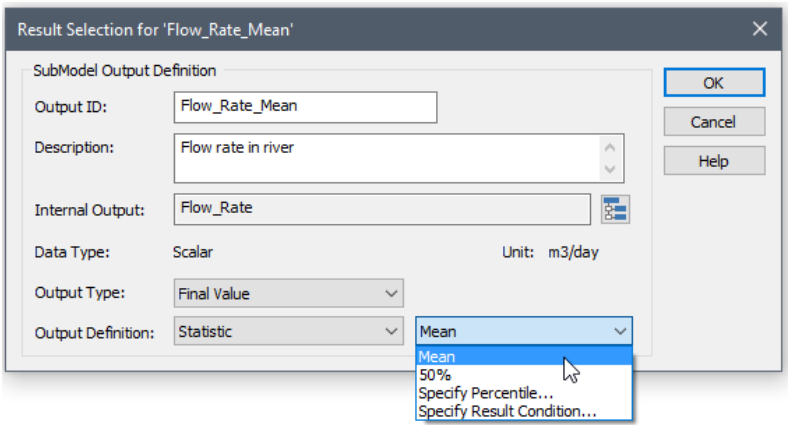
Name	Result
Flow_Rate_Final	Final Value
Flow_Rate_Mean	*Statistic (Mean)*
Flow_Rate_Distribution	*Final Value Distribution*
Flow_Rate_History	*All Realization Histories*
Flow_Rate	Time History

It is important to understand what these various results are and how they can be used in the parent model:

Final Value Results

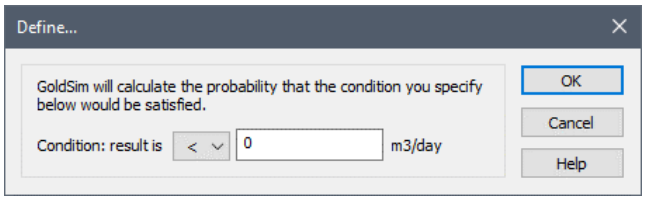
Last Calculated. This result is simply the final value of the output that was computed at the end of the simulation (for the final realization of the SubModel if multiple realizations were run). This will be listed in the Output Interface as "Final Value". It can be used directly in the parent model as any other value (or condition) output could be used.

Statistic. If this is selected as the Output Definition, a third field appears directly to the right:



The first two options are "Mean" and "50%" (the Median). The third option provides access to a dialog where you can specify any percentile. In these three cases, the result represents the specified statistic (computed over all realizations of the SubModel) for the final value of the selected output (i.e., the value computed at the end of each realization).

The fourth option ("Specify Result Condition") provides access to the following dialog:



In this case, the result represents the probability (computed over all realizations of the SubModel) that the final value of the output satisfies the specified condition. In the example above, within the parent model, the result would represent the probability that the final value of the selected SubModel output was less than 0 m3/day.

In all cases, the result will be listed in the Output Interface as "Final Value (*Statistic*)", where *Statistic* is the selected option. It can be used directly in the parent model as any other value (or condition) output could be used.

Distribution. This result is a complex output (referred to as a Distribution output) that represent all the statistical information necessary to define a probability distribution computed by the SubModel. It can be used to define a Stochastic in the parent model (as an "externally-defined" distribution). More frequently, it will serve as an input to specialized functions that operate on distributions. For example, PDF_Mean(X) returns the mean of the distribution X; PDF_Value(X,0.95) returns the 95% percentile. Under certain conditions (nested Monte Carlo simulation), Final Value Distributions can represent a distribution of distributions.

The result will be listed in the Output Interface as "Final Value Distribution". Unlike other results, because it is a complex type of output, it can only be used in the parent model in specific locations (e.g., as input to an externally-defined Stochastic, as input to a specialized distribution function, within a Distribution Result element).

Read more: Externally-Defined Distribution (page 172); Specialized Functions That Operate on Distributions (page 188); Adding a Distribution Output to a Distribution Result (page 686); Carrying Out Nested Monte Carlo Simulation Using a SubModel (page 1067).

Time History Results

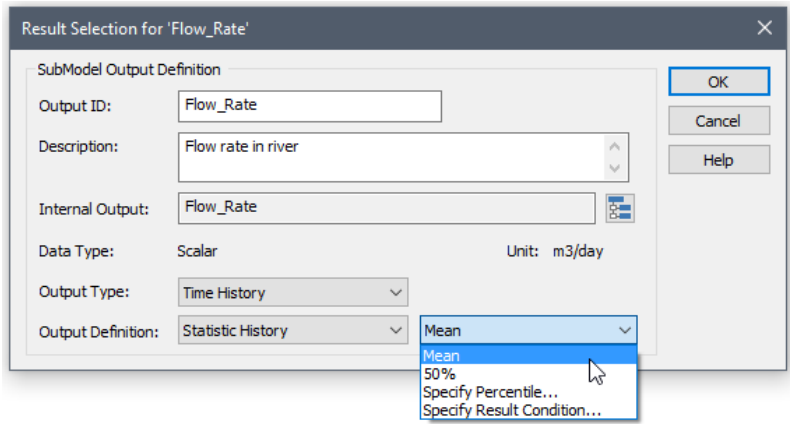
Time History results on a SubModel Output Interface are complex outputs that represent all the information necessary to define a time series. As such, they can only be used in three places within the parent model: 1) to define a Time Series element in the parent model; 2) as an input to an External (DLL) element; or 3) directly within a Time History Result.

Read more: Referencing a Time Series Definition Output (page 230); Using an External Element to Read and/or Output Time Series (page 1013); Viewing SubModel Results in Time History Result Elements (page 640).

Last Calculated. This result is the time history of the output for the final realization of the SubModel (which is equivalent to the *only* realization if the

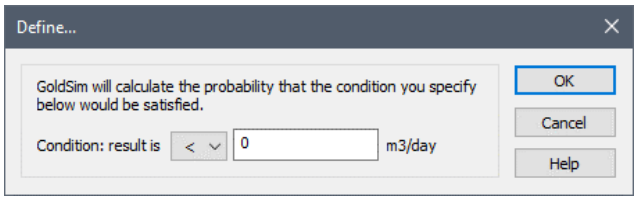
SubModel Monte Carlo Settings do not specify multiple realizations). Hence, regardless of whether the SubModel is probabilistic or deterministic, it always consists of a single time history (for each realization of the parent model). This will be listed in the Output Interface as "Time History".

Statistic History. If this is selected as the Output Definition, a third field appears directly to the right:



The first two options are "Mean" and "50%" (the Median). The third option provides access to a dialog where you can specify any percentile. In these three cases, the result represents a time history of the specified statistic (computed over all realizations of the SubModel) for the selected output.

The fourth option ("Specify Result Condition") provides access to the following dialog:



In this case, the result represents a time history of the probability (computed over all realizations of the SubModel) that the output satisfies the specified condition. In the example above, within the parent model, the result would represent the time history of the probability that the selected SubModel output was less than 0 m3/day.

In all cases, regardless of whether the SubModel is probabilistic or deterministic, it always consists of a single time history (for each realization of the parent model). This will be listed in the Output Interface as "Statistic History (*Statistic*)", where *Statistic* is the selected option.

Realization Histories. This result is the time history of the output for *all* realizations of the SubModel. Hence, unless the SubModel Monte Carlo Settings do not specify multiple realizations, it consists of multiple time histories (for each realization of the parent model). Hence, when running nested Monte Carlo simulation (i.e., in which both the parent model and the SubModel are probabilistic), this can result in a very complex set of results. For example, if the parent model was run for 100 realizations, and the SubModel was run for 50 realizations, the results being displayed in a Time History Result element within the parent model would be based on 5000 individual time histories (50 * 100). Fortunately, GoldSim provides some powerful tools to view this complex set of results.

Read more: Carrying Out Nested Monte Carlo Simulation Using a SubModel (page 1067); Viewing SubModel Results in Time History Result Elements (page 640).

This type of result will be listed in the Output Interface as "All Realization Histories".

Note: Calculations in GoldSim are carried out in double-precision. However, outputs of a SubModel are reduced to single precision when they pass through the output interface.

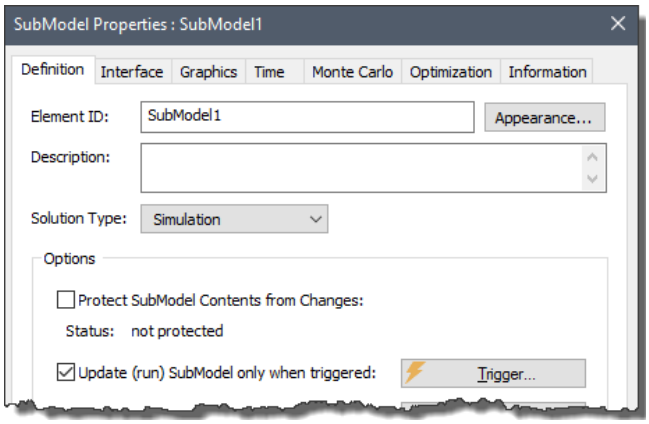
Note: Buttons for deleting, editing, moving and alphabetically sorting the outputs on the interface are available directly below the Add button.

At the bottom of the Definition tab for SubModels are options to Save Results for **Final Values** and **Time History**. The outputs for a SubModel, of course, are those results that have been added to the output interface. However, it is important to understand that these flags do not apply to *all* outputs in the output interface. In particular, they only apply to "standard" outputs (which must be Last Calculated or Statistic Final Values). They do not apply to the special output types discussed above (Distribution outputs or Time Series Definition outputs). These output types can only be viewed through Result elements in the parent model. (Note that time histories of "standard" SubModel results as viewed in a dynamic parent model would only change if the SubModel was called multiple times during simulation of the parent model).

Controlling When a SubModel is to be Run

By default, a SubModel is treated like any other element in GoldSim and is updated (i.e., run) whenever required to do so by the parent model (e.g., when inputs change).

In some cases, however, you may want to manually control when a SubModel is updated. You can do so by checking the **Update (run) SubModel only when triggered** checkbox. When you do this, access is provided to a standard trigger dialog:



You can explicitly control when a SubModel is run by defining one or more triggers (e.g., "On True: X > Y").

Read more: Understanding Event Triggering (page 369).

By default, when this box is checked, no triggers are defined. This means that the SubModel will never run.

Note: You can tell if a trigger has been defined from the appearance of the **Trigger…** button. If a trigger is defined, the rectangle next to the lightning bolt is bright green; otherwise it is dark green. And like all **Trigger…** buttons, it displays a tool-tip. If there is no trigger defined, the tool-tip will display "Never updates SubModel".

If you wish the SubModel to run when its parent Container activates, set the update trigger to **Auto Trigger**. Note that if a SubModel is set to **Auto Trigger** and it is not within a conditional Container, it activates when the Model (root) Container activates (i.e., at the start of the realization).

Prior to a SubModel being triggered, its outputs are all zero. The outputs are updated when the SubModel is triggered, and outputs remain constant until the SubModel is triggered again.

Other SubModel Options

Several advanced options are available for SubModels.

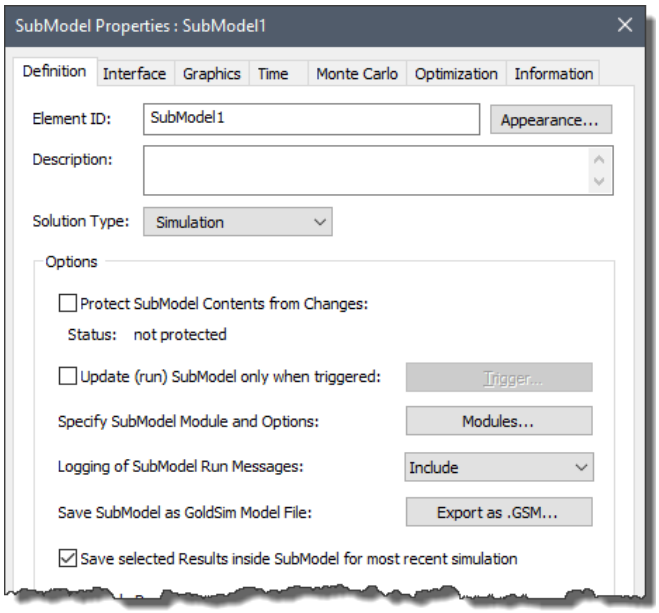
These are discussed in the sections below.

Saving and Viewing Results Inside a SubModel

Because a SubModel is a separate simulation (that will often be carried out multiple times during a simulation of the parent model), results *inside* of a SubModel are typically overwritten during a simulation of the parent model.

Accordingly, by default, other than results passed through the SubModel's output interface, no results are actually saved (and hence, you cannot view results inside a SubModel after running a simulation).

However, you can choose to save (and view) the results of the *last simulation* of the SubModel. This can be done by checking the **Save Results for most recent Simulation** checkbox on the SubModel's **Definition** tab:



If this box is checked, results from the *last* simulation of the SubModel (i.e., the last time the SubModel was run) are available for viewing inside the SubModel at the end of your simulation. Note that the SubModel's results could represent

multiple realizations, and in such a case, both time history and probabilistic results would be available for viewing inside of the SubModel. However, if the SubModel was run multiple times by the outer model (e.g., every timestep of the outer model), only the results from the last time the SubModel was run would be available.

Note: There are two important exceptions to this. In particular, under certain circumstances, Result elements in the parent model can display multiple realizations from the SubModel: 1) If you are running a nested Monte Carlo simulation (both the SubModel and the parent model are running multiple realizations), Distribution Result elements in the parent model modify their behavior to enable you to view multiple sets of realizations produced by the SubModel. 2) You can select a special option in Time History Result elements in the parent model to enable you to view multiple time histories from within a SubModel.

Read more: Carrying Out Nested Monte Carlo Simulation Using a SubModel (page 1067); Viewing SubModel Results in Time History Result Elements (page 640).

Several points should be noted regarding saving and viewing results inside a SubModel:

- When carrying out distributed processing simulations (using the Distributed Processing Module), results *are not saved* inside a SubModel, even if you choose to **Save Results for most recent Simulation**.

Note: The Distributed Processing Module is discussed in detail in the **GoldSim Distributed Processing Module User's Guide**.

- If the **Save Results for most recent Simulation** box is cleared, results will *not be saved* inside the SubModel, even if the SubModel contains Result elements and/or the Save Results options are selected for each element. (If you click on a Result element in Result Mode inside such a SubModel, it will be ignored).
- If 1) you have chosen to **Save Results for most recent Simulation**, 2) have added a Time History Result element; and 3) the element is specified to automatically export results to a spreadsheet or text file, GoldSim will not automatically export the results. If you wish to export the results of the last simulation from inside a SubModel, it can only be done manually.

Read more: Exporting from a Time History Result Element to a Spreadsheet (page 786); Exporting from a Time History Result Element to a Text File (page 794).

Carrying Out Nested Monte Carlo Simulation Using a SubModel

Many models have uncertain (epistemic) parameters as well as randomly variable (aleatory) parameters. An uncertain parameter represents ignorance that can theoretically (but perhaps not practically) be reduced through investigation (e.g., the mean failure time for a batch of light bulbs). Variability is inherent in many systems (e.g., the distribution of failure times for a batch of

light bulbs) and cannot be reduced. It is often valuable to explicitly separate variability from uncertainty in a model.

With SubModels, this is accomplished by inserting a SubModel (e.g., a dynamic Monte Carlo simulation) within an outer model (e.g., a static Monte Carlo simulation). This is referred to as "nested" Monte Carlo simulation. The inner model simulates the random variability of the system, while the outer model represents the ignorance in key parameters.

In the example above, the outer model would sample a probability distribution that represents the uncertainty in the mean lifetime of a light bulb, and the inner model would simulate the performance of a number of random light bulbs (whose lifetime is sampled from a distribution with the mean specified by the outer model).

Note that for this kind of model, if you were to link an output from the SubModel to the Output Interface as a distribution, conceptually on the outside of the SubModel the output would actually represent a *distribution of distributions*. That is, because the SubModel is a Monte Carlo model, every time it is called, it produces a distribution. However, because the outer model itself is a Monte Carlo simulation, every element inside it results in a distribution of results. Hence, running the outer model multiple times results in a distribution of distributions for any SubModel output.

If you were to go inside the SubModel and view a result, it would display only the results from the last time the SubModel was run (and only if **Save Results for most recent Simulation** was checked).

However, on the outside of the SubModel, for a nested Monte Carlo run, it is necessary to display the *distribution of distributions*. Of course, GoldSim's standard Distribution Result only displays a single distribution. (It can display distributions from multiple outputs, but this is not the same as displaying nested distributions).

Read more: Viewing Distribution Results (page 662).

To support nested Monte Carlo simulations, Distribution Result elements modify their behavior under certain circumstances to enable display of nested Monte Carlo results. In particular, Distribution Result elements modify their behavior if and only if the following conditions are all met:

- The Distribution Result element is located in the outer model (i.e., not in a SubModel);
- A single result is selected for display in the Result element;
- The selected result references a distribution type output from a Monte Carlo SubModel (for this to occur, the SubModel must be configured to run multiple realizations);
- The result was added to the Result element prior to running the model;
- The SubModel whose result is being referenced is located within the main model (i.e., it cannot be nested inside another SubModel); and
- The outer model is configured to run multiple realizations.

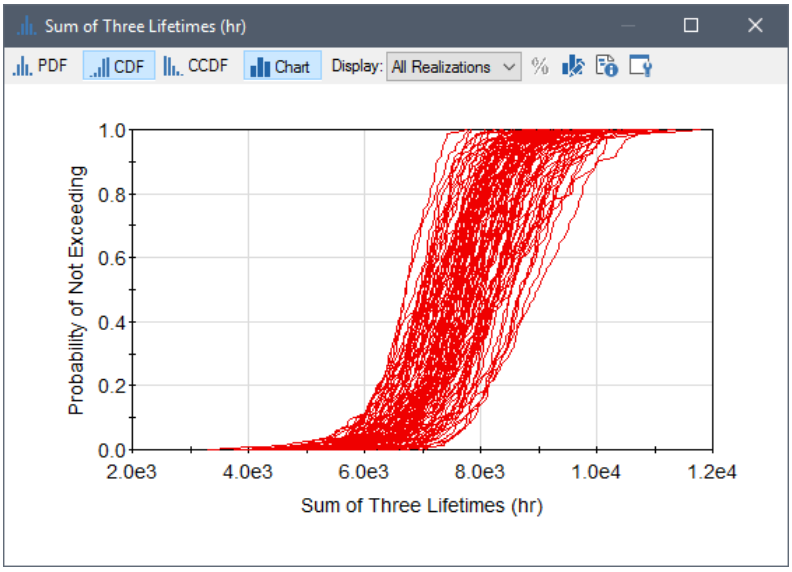
Under these circumstances, there are two differences from a standard Distribution display:

1. There is no option to display a Table; and
2. A **Display** option is provided. The options are:

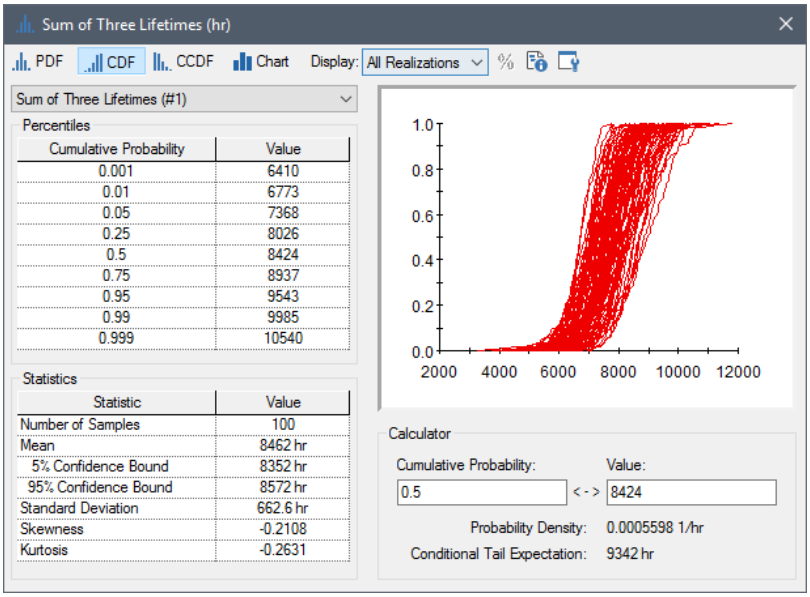
- All Realizations
- Realization
- Statistics
- Probability
- All Results

The various displays (and what they represent) are as follows:

All Realizations. "Realizations" refers to realizations of the outer model. Since each realization of the outer model produces a distribution, showing "All Realizations" simply displays multiple distributions (one for each realization of the outer model). The chart display looks like this:

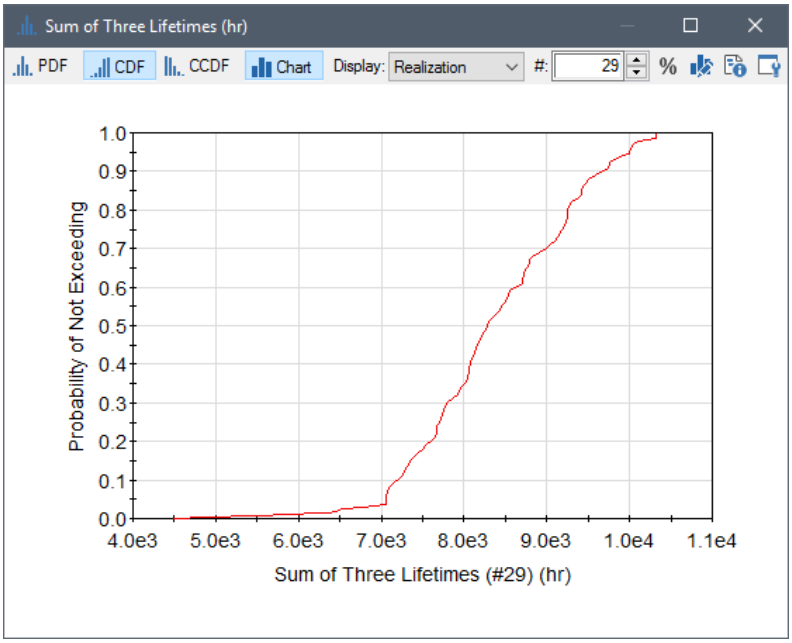


The Distribution Summary view looks like this:

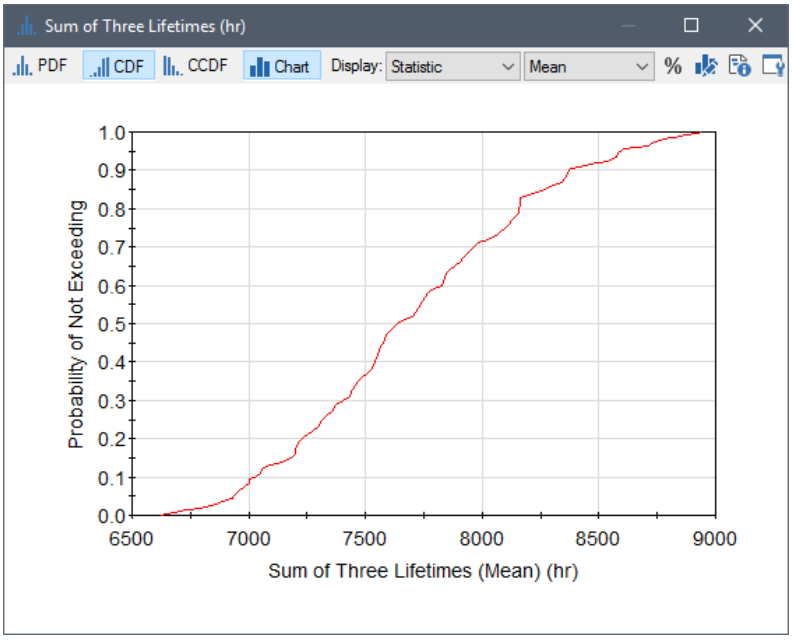


Statistics can only be shown for one realization at a time (which you can select from a drop list at the top of the dialog). In the example above, statistics are being shown for realization #24 of the outer model.

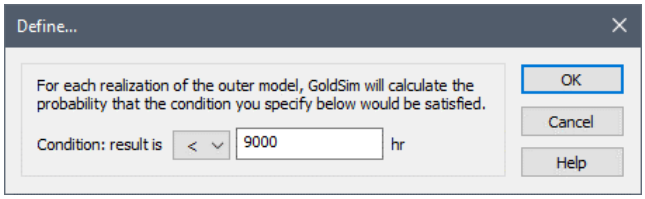
Realization. "Realization" refers to the realization of the outer model (which you must select). The chart (and Distribution Summary) then show that single outer model realization (i.e., a single distribution):



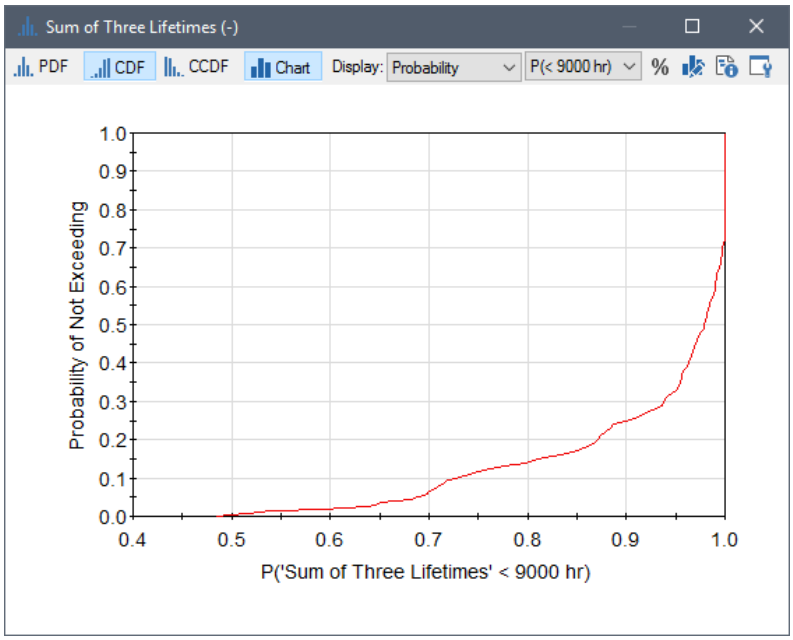
Statistic. When you select this option, a drop-list to the immediate right allows you to select or define a statistic. The result displayed is then the distribution of the specified statistic (each outer model realization produces one value for this statistic):



Probability. This option displays a probability distribution of probabilities. When you select this option, a drop-list to the immediate right allows you to define the probability that you are interested in, based on a condition:



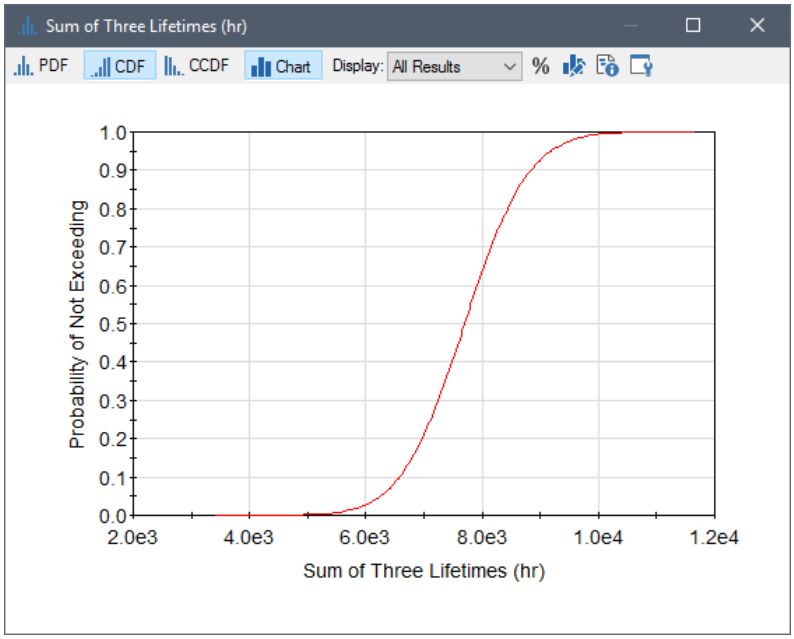
This instructs GoldSim to compute the (inner model) probability of a particular outcome for the specified result. Each outer model realization produces one value for this probability. It is the probability of the inner model's result being <, <=, =, >= or > the specified value. In the example above, for each outer model realization, GoldSim computes a single value: the probability of the output being less than 9000 hours. The overall result then displays a distribution that quantifies the uncertainty in this particular probability:



How do we interpret such a distribution? This is meant to represent a complex concept (a probability distribution of a probability!). Perhaps this is best understood by examining this particular example. In this example, we could state the following:

- There is approximately a 70% chance that the probability of the result being less than 9000 hours will be less than one. That is, in 70% of the outer model realizations, the probability of the result being less than 9000 hours was less than one, and in 30% of the realizations it was exactly one.
- There is no chance that the probability of the result being less than 9000 hours is below (approximately) 48%. That is, in none of the outer model realizations was the probability of the result being less than 9000 hours less than (approximately) 48%.

All Results. This combines all realizations together to form a single distribution that represents both variability (from the inner SubModel) and uncertainty (from the outer model). Hence, if you run 50 realizations of the SubModel and 100 realizations of the outer model, the distribution would be constructed from 5000 realizations.The chart (and Distribution Summary) then show the single distribution that represents all model uncertainties:



The text above describes how *distribution results* can be viewed for a nested Monte Carlo simulation. But what if you wanted to view time history results? Viewing time history results for nested Monte Carlo simulations is complicated by the fact that Time History Definition SubModel outputs consist of *multiple* time histories for each realization of the parent model. As a result, if the parent model was run for 100 realizations, and the SubModel was run for 50 realizations, the corresponding time history results would be based on 5000 individual time histories (50 * 100).

Read more: Viewing SubModel Results in Time History Result Elements (page 640).

To support nested Monte Carlo simulations, Time History Result elements modify their behavior under certain circumstances to enable display of nested Monte Carlo results. In particular, Time History Result elements modify their behavior to display such results if and only if the following conditions are all met:

- The Time History Result element is located in the outer (parent) model (i.e., not in a SubModel);
- Within the Result Properties dialog, "SubModel Time" is selected for the **Time Display Setting**.
- A single result is selected for display in the Result element. The selected result must reference a Time History Definition output from a SubModel. The **Output Definition** for the output must be "Realization Histories" (for this to occur, the SubModel must be configured to run multiple realizations);

Read more: Creating the Output Interface to a SubModel (page 1059).

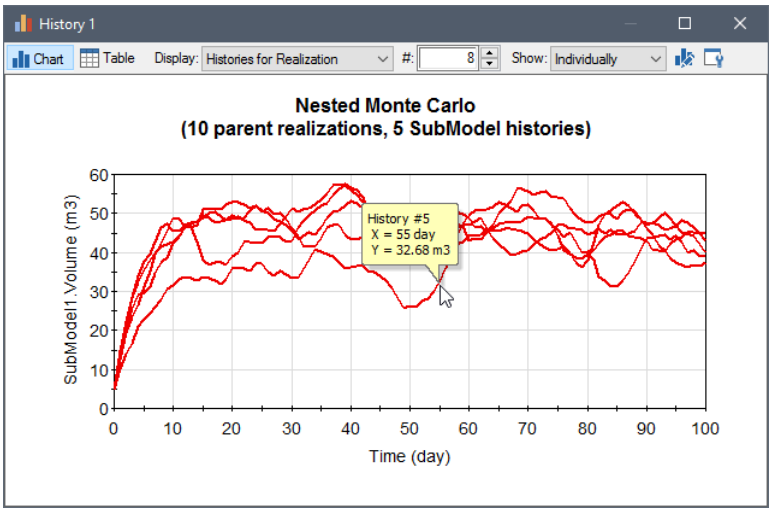
- The SubModel whose result is being referenced is located within the main model (i.e., it cannot be nested inside another SubModel); and
- The outer (parent) model is configured to run multiple realizations.

Under these circumstances, special **Display** options are provided at the top of the Time History display dialogs:

- Histories for Realization
- Statistic for each Realization
- Histories for all Realizations

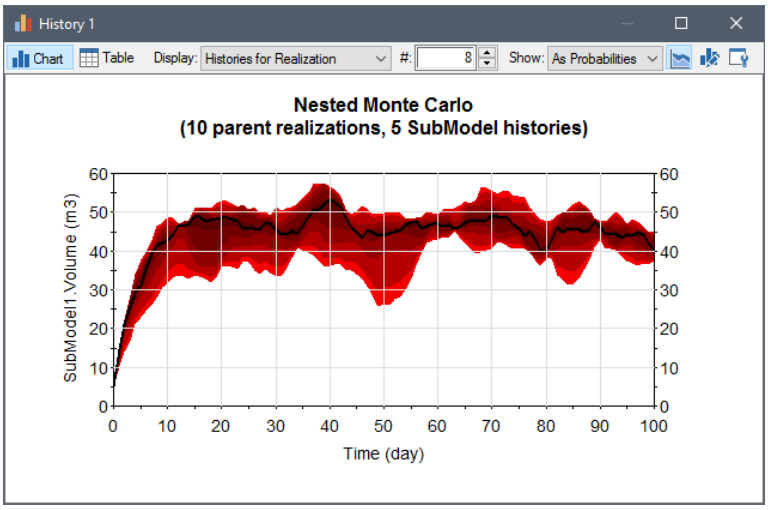
The various displays (and what they represent) are as follows:

Histories for Realization. "Realization" refers to the realization of the parent model (which you must select). Since each realization of the parent model produces multiple histories for the SubModel, showing "Histories for Realization" simply displays multiple SubModel histories for the selected parent model realization. The chart display looks like this:



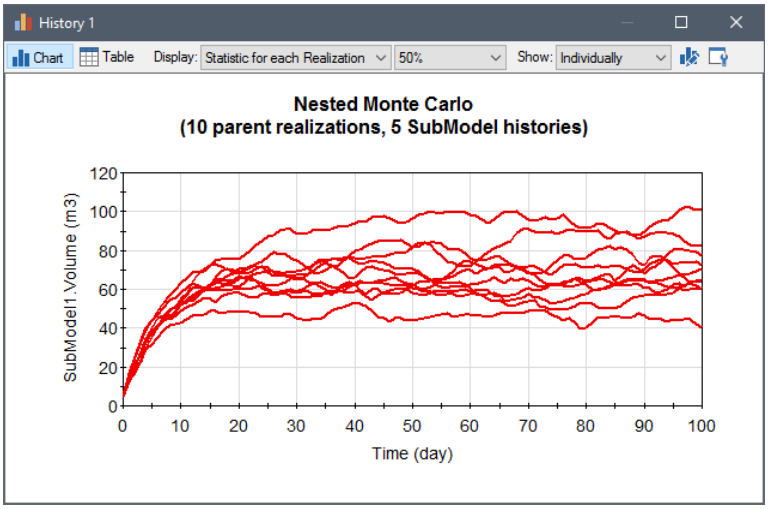
Note that the display also provides a separate field (**Show**). In the figure above, the SubModel histories for the specified parent realization (in this case, #8) are being displayed "Individually". The tool-tip indicates that the particular result indicated by the cursor corresponds to SubModel history #5.

A second option allows these 5 histories to be displayed "As Probabilities" (i.e., percentile ranges):

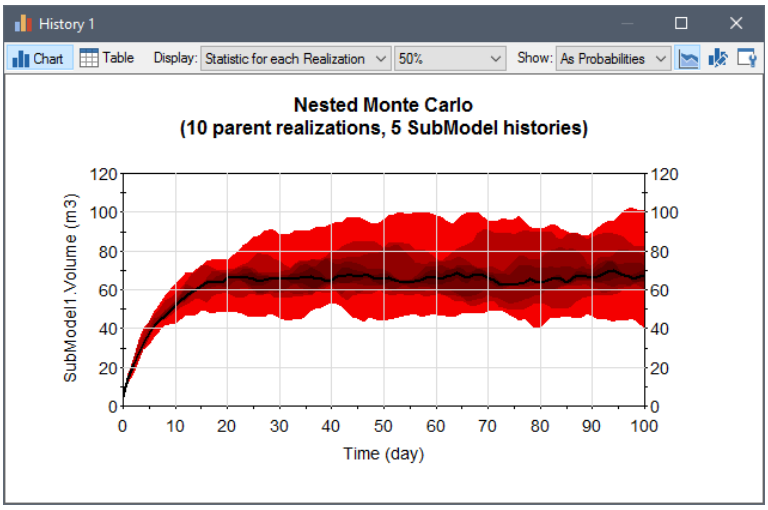


Read more: Viewing Probability Histories for Multiple Realizations (page 623).

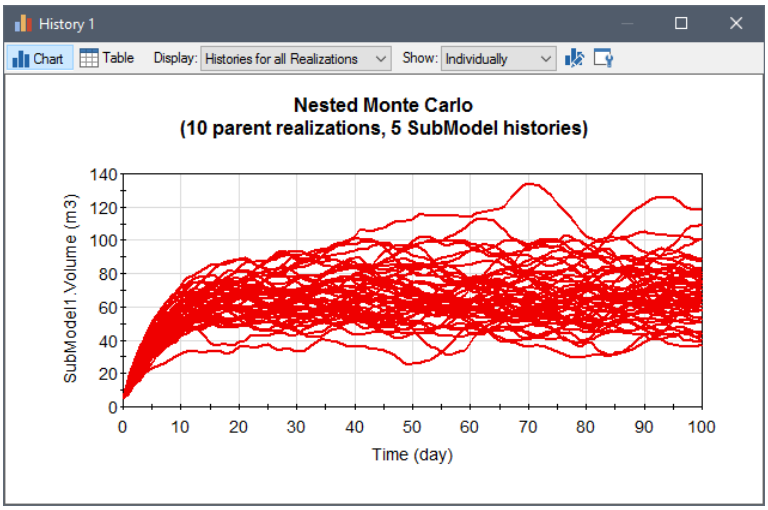
Statistic for each Realization. "Realization" refers to the realization of the parent model. Since each realization of the parent model produces a single statistic (which you must specify) for the SubModel histories, showing "Statistic for each Realization" displays a single time history for each realization of the parent model. Each individual realization represents a statistic computed using the SubModel histories.The chart display looks like this:



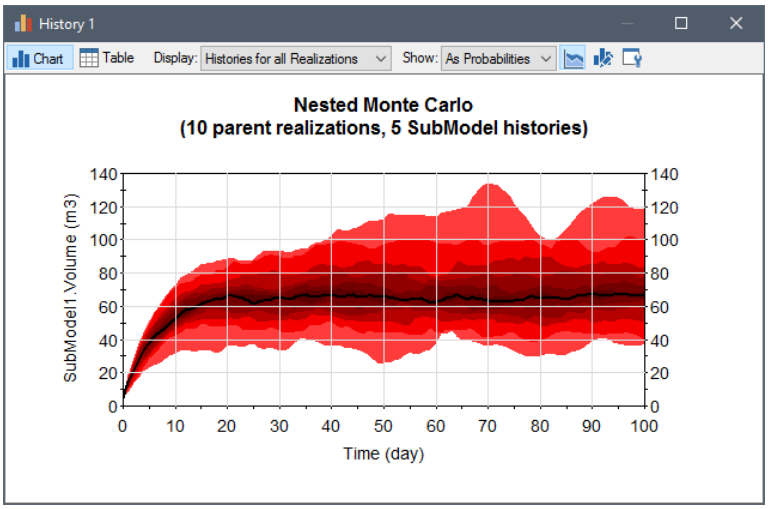
In the figure above, there are 10 realizations shown (one for each parent realization). Each realization represents the 50th percentile computed using the 5 SubModel histories that were produced for that parent realization. In this case, each parent realization is being displayed "Individually". Note that the display also provides a separate field (**Show**). A second option allows these 10 parent realizations to be displayed "As Probabilities":



Histories for all Realizations. Since each realization of the parent model produces multiple histories for the SubModel, showing "Histories for all Realizations" simply displays all SubModel histories for all parent realizations. The chart display looks like this:



In the figure above, there are 50 histories shown (5 SubModel histories for each of 10 realizations of the parent model). In this case, each history is being displayed "Individually". Note that the display also provides a separate field (**Show**). A second option allows these 50 histories to be displayed "As Probabilities":



Note: If you have applied screening to the inner model (the SubModel), the screening is ignored for nested Monte Carlo runs. However, if you have applied screening and/or categories to the parent model, the screening is used to create the displays.

Read more: Classifying and Screening Realizations (page 601).

Note: You cannot export time history results (i.e., to a spreadsheet or text file) from a SubModel.

An example illustrating how nested Monte Carlo simulation is carried out (SubModel2.gsm) can be found in the General Examples/SubModel folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

Read more: SubModel Example: Explicit Separation of Variability from Uncertainty (page 1088).

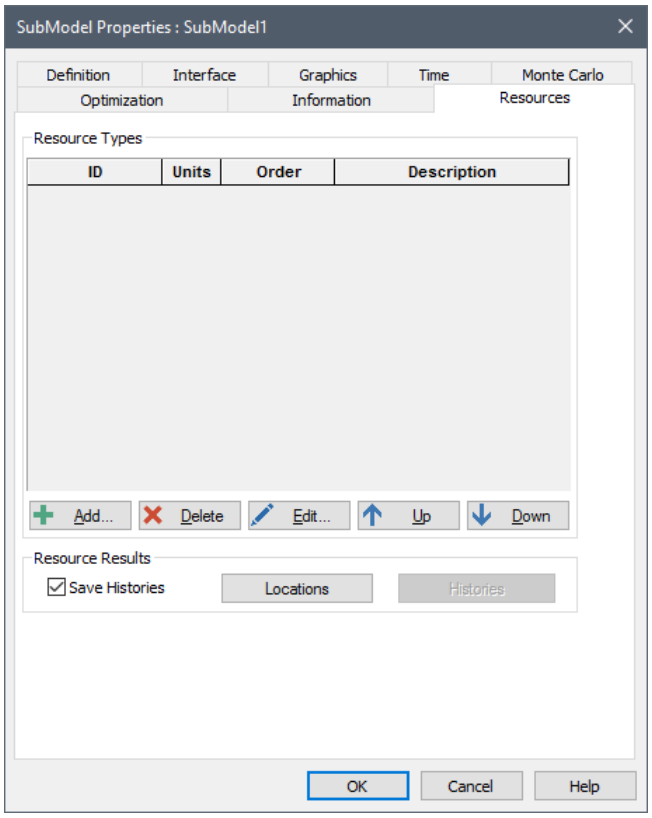
Using Resources Inside a SubModel

Like standalone models and Containers, a SubModel can provide Resources to elements inside it.

Read more: Using Resources (page 906).

To provide Resources to elements inside the SubModel, check the Provide Resources checkbox on the SubModel's **Definition** tab:

When you do so, a Resources tab is added to the SubModel's dialog:



This tab can be used to create Resource Types (and global stores) for use inside the SubModel.

Several points should be noted regarding the use of Resources inside SubModels:

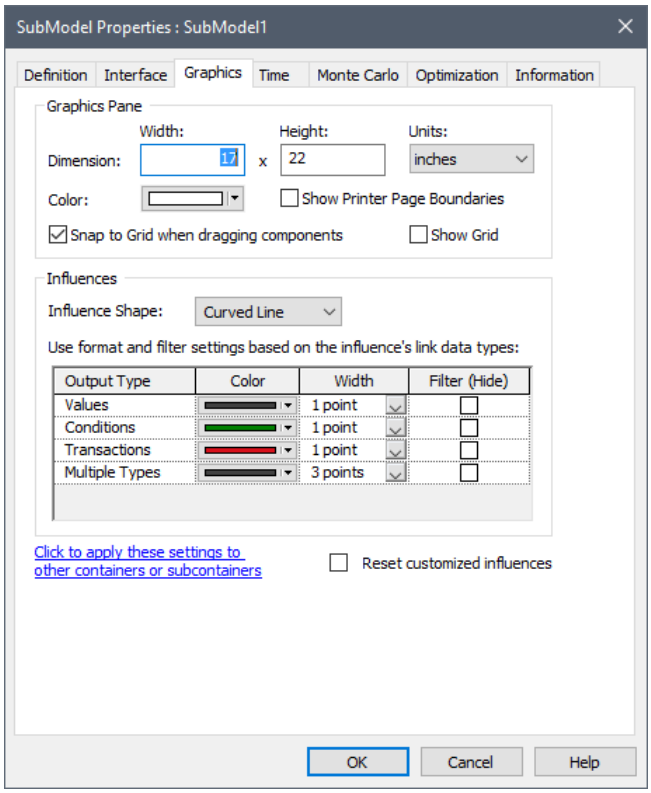
- Elements inside a SubModel have no access to Resource Types or Resource Stores outside of the SubModel. Resources in the SubModel are completely separate and independent from Resources in the parent model.
- If you create a SubModel by importing a GoldSim model, and that model has Resources defined, the **Provide Resources** checkbox will automatically be checked, and any Resource Types and Stores defined in the original model will become part of the SubModel.

  Read more: Importing SubModels (page 1083).
- If you export a SubModel, any Resource Types and Stores in the SubModel will become available in the exported standalone model.

  Read more: Exporting SubModels (page 1082).

Controlling the Appearance of the Graphics Pane for a SubModel

The **Graphics** tab of the SubModel dialog provides access to options for controlling the appearance of elements inside the SubModel:



The top portion of the dialog (the Graphics Pane section) is used to define the size of the graphics pane, a background color for the graphics pane, and whether or not a grid is displayed.

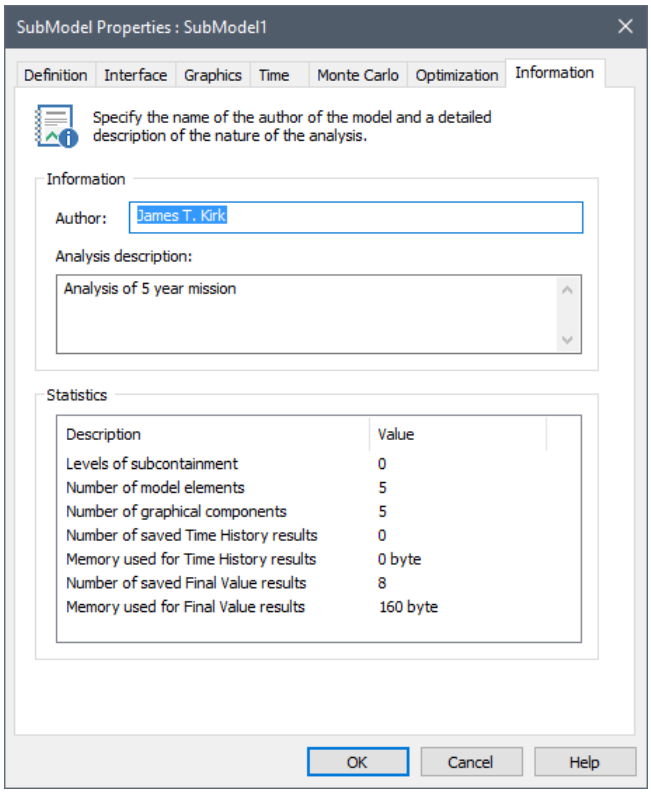
Read more: Adjusting the Size of the Graphics Pane (page 444); The Graphics Pane Grid and Background (page 442).

The bottom portion of the dialog (the Influences section) is used to specify the default shapes for influences in the SubModel, and to define whether and in what manner influences within the SubModel are filtered (hidden). The options in this portion of the dialog are quite important, as they can be used to ensure that your models are easy to view and understand.

Read more: Links and Influences (page 81); Editing the Appearance of Influences (page 445); Filtering Influences (page 448).

Viewing and Editing SubModel Summary Information

The **Information** tab of the SubModel dialog displays some summary information regarding the SubModel:



The top part of the dialog provides two fields (**Author** and **Analysis description**) which allow you to identify the author and provide a brief description for your SubModel.

The bottom part of the dialog provides some useful summary statistics for the SubModel, including the number of model elements and graphical components, and the degree of subcontainment. The number of levels of subcontainment does not refer to the number of Containers; it refers to the number of hierarchical levels of Containers. For example, if the SubModel A contained Containers B and C, A would have 1 level of subcontainment; if the SubModel contained B, and B contained C, it would have 2 levels of subcontainment.

The dialog also indicates the total size of the results being saved for all elements within the SubModel. This information can be very useful in helping you to manage the size of the model file.

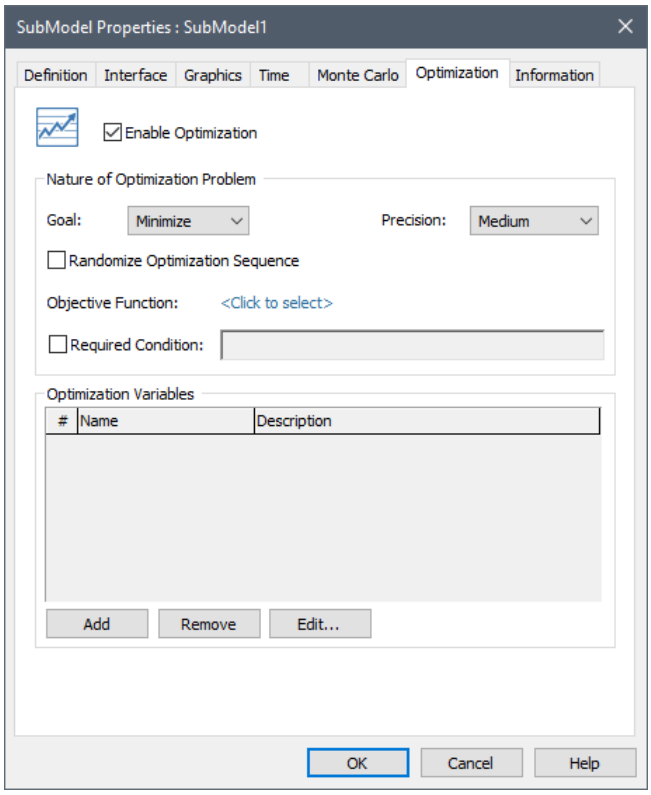
Running an Optimization Within a SubModel

One of the applications for a SubModel is to carry out a dynamic optimization (i.e., at specified times) during a simulation. For example, imagine a situation where you were simulating the operation of a facility over a period of one year. Every month, the operators make a decision based on the current state of the system. This decision is based on a simple optimization analysis using currently available data (i.e., at every simulated month during the simulation). The optimization chooses the optimum values of a few control variables that they will use for the next month.

To represent this in GoldSim, you would need to specify the **Solution Type** for the SubModel as "Optimization", and the SubModel itself would represent the optimization calculations carried out by the simulated operator.

Note: If a SubModel is set to carry out an optimization, it cannot contain any Spreadsheet elements.

When you select "Optimization" for the **Solution Type**, GoldSim enables optimization for the SubModel and immediately switches to the **Optimization** tab for the SubModel:



This is the standard optimization dialog that is also used for stand-alone models, and is described elsewhere in detail.

Read more: Running an Optimization (page 548).

Several points regarding use of this dialog for SubModel optimization, however, are worth noting:

- Optimization Variables can be defined in terms of variables that are outside of the SubModel. That is, initial values, upper bounds and lower bounds for Optimization Variables can be defined in terms of a variable that is placed on the input interface to the SubModel.
- In most cases, all of the Optimization Variables themselves (and perhaps the Objective Function) should be placed on the output interface to the SubModel (since the purpose of the SubModel is typically to determine these variables). When running an Optimization in a SubModel, the only applicable result type is Final Value. At the end of the optimization, the SubModel outputs the final (optimized) values of the Optimization Variables.
- Optimizations can sometimes fail or may be unable to converge. GoldSim provides different types of error messages when carrying out optimizations. If an optimization of a SubModel fails, a fatal warning

message will be displayed (and the simulation is halted). If the optimization completes, but cannot fully converge, a message will be written to the run log (but the simulation will not be halted).

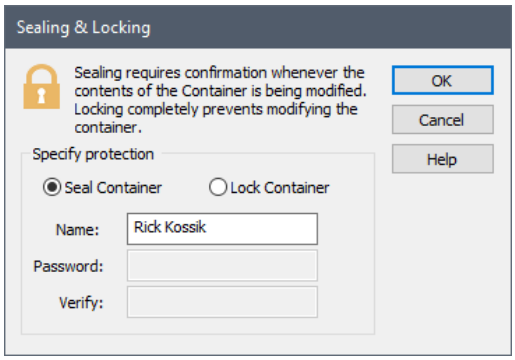
Read more: Understanding Optimization Warning Messages (page 558).

Protecting the Contents of a SubModel

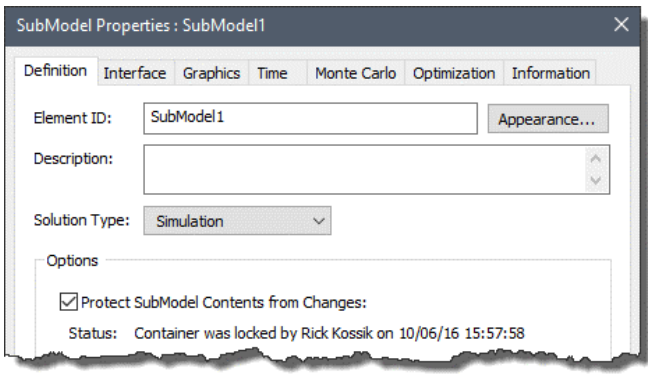
In some cases, you may want to protect the contents of your SubModel by sealing or locking it. SubModels can be sealed and locked in the same manner as Containers.

Read more: Sealing and Locking Containers (page 148).

To access the sealing/locking dialog for a SubModel, check the **Protect SubModel Contents from Changes** checkbox in the SubModel dialog. When you do so, the Sealing/Locking dialog will be displayed:



After you seal or lock the SubModel, the protected status of the SubModel is displayed in the SubModel dialog:

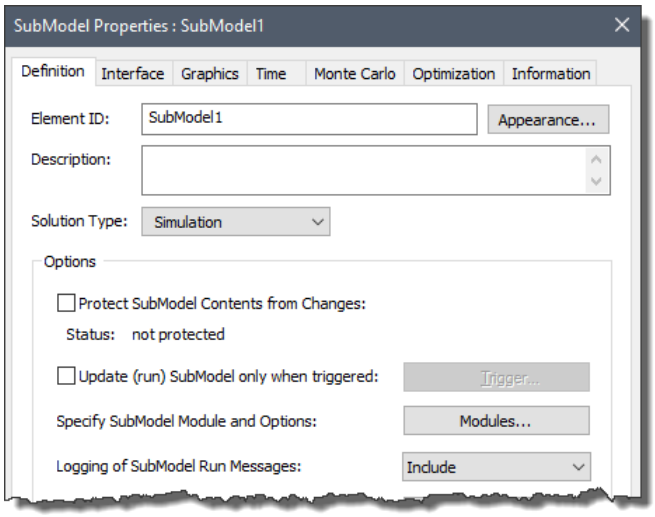


Controlling How Run Messages are Logged for a SubModel

When using SubModels, you can control whether or not Run Log messages related to the SubModel are written to the parent model's Run Log.

Read more: The Run Log (page 569).

This can be controlled from within the SubModel dialog:



By default, **Logging of SubModel Run Messages** is set to "Include". Optionally, however, you can set this to "Ignore".

When SubModel messages are sent to the Run Log, it is clearly indicated which model or SubModel generates the message.

Exporting SubModels

In some cases, you may want to run a SubModel as a standalone model. This is useful, for example, if you want to debug, test, and/or refine it separate from the parent model. Although you can't run the SubModel directly from within a parent model, you can export it, run it separately, and then import it back into the parent model. You may also choose to export a SubModel so that you can subsequently import it into a different model.

Read more: Importing SubModels (page 1083).

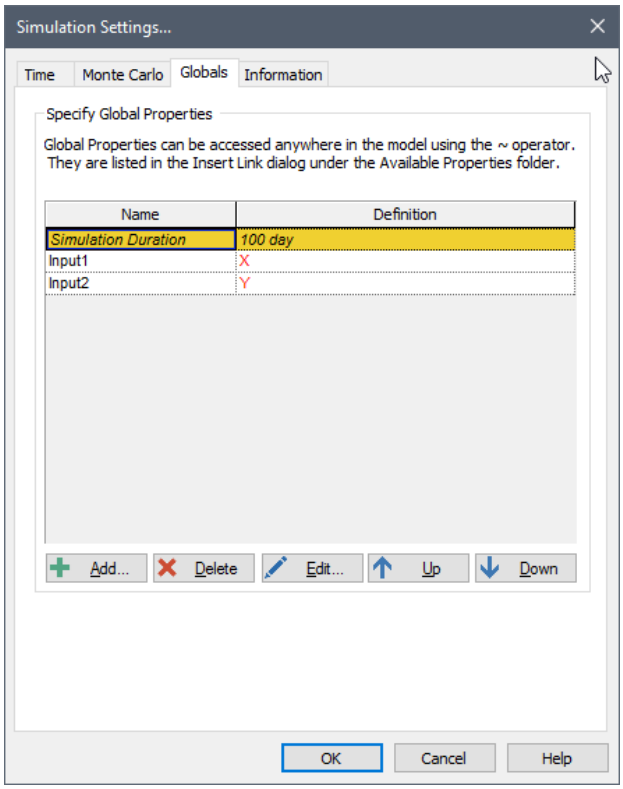
You can export a SubModel by pressing the **Export as .GSM…** button in the SubModel dialog. When you do so, you will be prompted for a file name (and location) for the saved file.

When exporting a SubModel, several points should be noted:

- All of the options (specified in the parent model's Options dialog) are exported with the new model.
- All user-defined units and array label sets specified in the parent model are exported with the new model.
- If you export a SubModel, any Resource Types and Stores in the SubModel will become available in the new model.

  Read more: Using Resources Inside a SubModel (page 1076).

In addition, the input and output interfaces are exported to the stand-alone model. The output interface is not accessible in the stand-alone model, but the input interface is accessible, and can be edited. In particular, the input interface is accessible via the **Globals** tab in the stand-alone model's Simulation Settings dialog:



Read more: Defining and Referencing Global Properties (page 503).

In the example shown above, Parameter1 and Parameter2 in the SubModel were referencing outputs X and Y in the parent model. Once the SubModel was exported, of course, it no longer had access to X and Y "outside" of the model (since there is no "outside" to a stand-alone model). Hence if you tried to run the stand-alone model an error would be displayed.

In order to run the stand-alone model, the Definitions for the Globals would need to be changed to values. Note, however, that the original exported Definitions are saved with the file separately. Therefore, if you subsequently import the stand-alone model into another model (as a SubModel), the original input (and output) interface that was exported will be automatically recreated.

Note: You can only export a SubModel that has values or conditions on the input interface. If the input interface contains Time Series Definitions, Lookup Table Definitions or Distribution Definitions, you will not be able to export the model (as these could not be represented as values on the **Globals** tab.

If the exported SubModel's input interface included externally defined Run Properties (e.g., such as Simulation Duration), these interface items will appear in the Globals list. However, they will not be used by the stand-alone model, and cannot be edited. They can, however, be deleted.

Importing SubModels

In some cases, you may want to import an existing stand-alone model into another file as a SubModel. This is useful, for example, if you want to export a SubModel to test (and refine it) outside of the parent model, and then import it back into the parent model.

Read more: Exporting SubModels (page 1082).

To import a stand-alone model into your current model as a SubModel, you must insert a SubModel from the Insert Element menu. When you insert a SubModel, you are presented with a dialog asking if you want to create a new (empty) SubModel, or create the SubModel by importing an existing standalone model. You should choose the latter. When you do so, you will be prompted for a filename and location. After selecting it, the specified file will be inserted into the parent model as a SubModel.

There are several rules that must be met in order for the model to be successfully inserted as a SubModel:

- The stand-alone model must have been saved using the same version of GoldSim that is trying to import it.
- The stand-alone model must be in Edit Mode.

Note: If the model being imported contains Scenarios, the scenario information will be removed when it is imported and only the information pertaining to the Active Scenario will be imported.

Read more: Creating, Running and Comparing Scenarios (page 525).

When importing a model, all of the information on the Globals tab of the Simulation Settings dialog in the stand-alone model is imported into the input interface for the SubModel.

Read more: Defining and Referencing Global Properties (page 503).

Note: If the model being imported was previously exported from a SubModel to a stand-alone model, the original exported Definitions for the input and output interface will be automatically recreated when the model is imported to recreate it as a SubModel. Any changes to existing input Definitions will be ignored (the Definitions that existed when the model was exported will be used). Any new input Definitions that were added after the model was exported, however, will be added to the interface.

If you import a GoldSim model as a SubModel, and that model has Resources defined, the **Provide Resources** checkbox will automatically be checked, and any Resource Types and Stores defined in the original model will become part of the SubModel. The Resources in the SubModel and those in the parent model are completely separate and independent. Elements in the SubModel cannot see or interact with Resources in the parent model.

Read more: Using Resources Inside a SubModel (page 1076).

Because the parent model and the imported model potentially could have conflicting definitions (for units, array label sets and version stamps), the following rules are followed during the import to ensure consistency.

Ensuring Consistency of Array Label Sets

When importing an existing model as a SubModel, all of its array label sets are imported into the parent model. Therefore, existing sets and imported sets must be merged. The following rules apply when importing array label sets:

- Any set that exists in the imported model but not in the parent model is automatically added to the parent model.
- If the imported model and the parent model have sets with identical names (set names are not case-sensitive) that are not otherwise identical (i.e., they must have the same number of items with the same index names), an error is displayed and the import of the model will fail.

Read more: Understanding Array Labels (page 849).

Ensuring Consistency of Units

When importing an existing model as a SubModel, all available user-defined units in the existing model are imported into the parent model. Therefore, existing units and imported units must be merged. The following rules apply when importing units:

- If the imported unit name is unique, it is added to the parent's unit list.
- If the imported unit name is identical to an existing unit name, and the units have the same dimensions, but are assigned to different categories, then the unit is assigned to the category specified by the parent model.
- If the imported unit name is identical to an existing unit name, and the units have the same dimensions, but are assigned different conversion factors, then the conversion factor is assigned the value specified by the parent model.
- If the imported unit name is identical to an existing unit name, but the units have different dimensions, an error is displayed and the import of the model will fail.

Read more: Creating New Units (page 460).

Ensuring Consistency of Versioning

When importing a model file that includes versioning information, GoldSim evaluates the version stamps and compares them against the version stamps in the existing model (if it uses versioning).

If all version stamps are identical (i.e., all properties must match: stamp number, name, description, user name), then the imported model elements keep their individual version logging information. Globally logged information from the imported model, however, is lost.

If the version stamps are not identical, or if the existing (parent) model does not use versioning, all version information is removed from the imported model and its elements.

Read more: Tracking Model Changes (page 1099).

Interrupting and Pausing a Simulation Within a SubModel

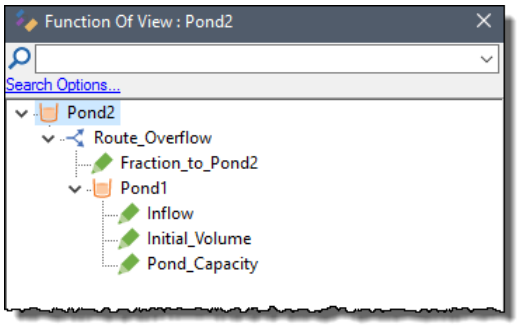
When you pause a model using the Run Control toolbar or via an Interrupt element message, if the model was in the middle of computing an element within a SubModel, GoldSim will pause the model at that point.

Read more: Pausing and Stepping through a Simulation (page 522); Continuing, Pausing and Aborting a Simulation After an Interrupt (page 426).

Note, however, that when a model is paused, the status bar always displays the status of the outermost parent model.

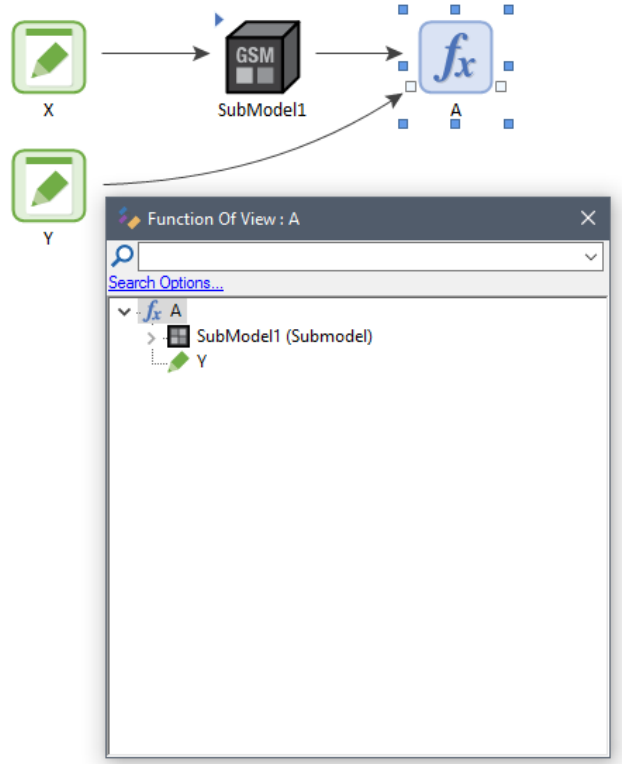
Viewing Element Dependencies Within a SubModel

In complex models, it is often useful to explore the interdependencies of the various elements (i.e., who affects who). GoldSim provides two very powerful utilities for doing this: the ***Function Of View***, and the ***Affects View***. If you right-click on an element in either the graphics pane or the browser (to access the context menu) and select **Function Of…** or **Affects…**, a floating browser window is displayed that shows the element dependencies in the form of a tree:



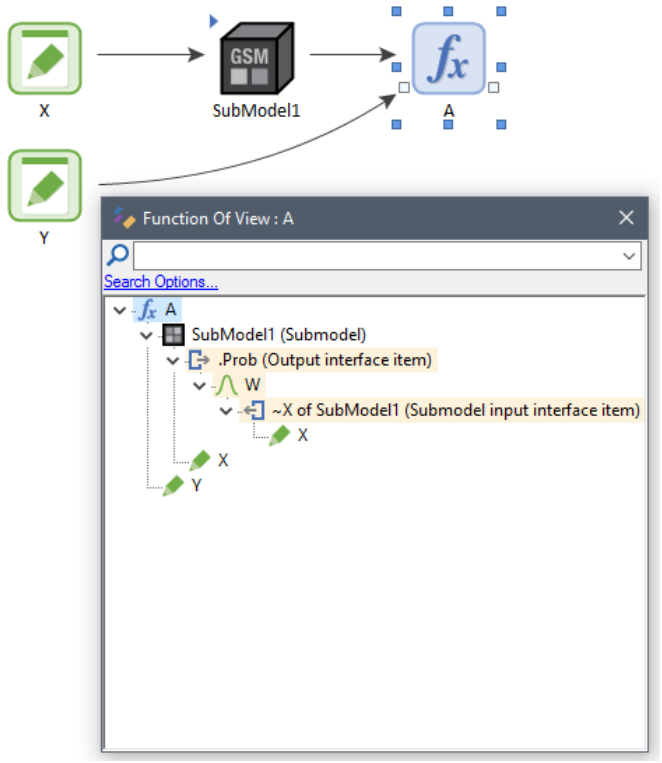
Read more: Viewing Element Dependencies (page 114).

If the tree includes a SubModel, the SubModel is effectively treated as an element (this is in contrast to a Container, which generally would not show up in the tree at all). That is, the SubModel is treated as any other element with inputs and outputs would be treated. With regard to the dependency tree, it is simply a "custom" element. In the example below, the Expression A is shown to be a function of Y and the SubModel:



In many instances, however, you may be interested in looking inside the SubModel to view the dependencies. That is, it may not be enough to know that A is a function of SubModel1; you may want to explore exactly what A is a function of within the SubModel.

To facilitate this, GoldSim allows you to expand SubModels within a Function Of or Affects tree:



When GoldSim displays items inside a SubModel in this way, it always does the following:

- The SubModel is clearly labeled as such.
- The contents of the SubModel in the tree are shaded (orange) to indicate that these items are inside the SubModel. (If there are SubModels within SubModels, different shades are used to indicate this).
- In addition to showing the elements inside the SubModel, GoldSim also displays any items on the input and output interfaces that may be involved (and these are clearly labeled as such). In the example above, the tree is indicating that A is a function of the "Prob" output on the SubModel interface, which is a function of the element W inside the SubModel, which is a function of the "~X" input on the SubModel interface, which is a function of the X element outside of the SubModel.

SubModel Examples

Several example models illustrating the use of SubModels are described below. These examples can be found in the General Examples/SubModel folder in your GoldSim directory.

These examples cover the four most common applications for SubModels.

Read more: What Can I Do With a SubModel? (page 1047).

SubModel Example: Manipulation of Monte Carlo Statistics

A common use of SubModels is to manipulate Monte Carlo statistics. That is, after carrying out a Monte Carlo simulation, you may want to carry out further calculations using the statistical outputs of the simulation. For example, you

may want to carry out a calculation that is some function of the mean and the 95th percentile of a particular output in a Monte Carlo simulation.

Without the use of SubModels, the only way to accomplish this is by exporting results from a Monte Carlo simulation manually to another application (e.g., a spreadsheet or a separate GoldSim model). With SubModels, this is easily accomplished within a single GoldSim model by inserting a SubModel (that is a Monte Carlo simulation) into an outer model (that is static and simply manipulates the statistical outputs of the inner model).

Example model MonteCarloStatistics.gsm in the General Examples/SubModel folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) provides a simple illustration of such an application. In this model, the SubModel contains a single Stochastic. The SubModel carries out a Monte Carlo simulation. The outer model is a static deterministic simulation that contains a single Expression element. The Expression is a function of statistics (the mean and 95th percentile) of the Stochastic within the SubModel.

SubModel Example: Explicit Separation of Variability from Uncertainty

Another common use of SubModels is to explicitly separate variability from uncertainty. That is, many models have uncertain parameters as well as variable parameters. An uncertain parameter represents ignorance that can theoretically (but perhaps not practically) be reduced through investigation (e.g., the mean failure time for a batch of light bulbs). Variability is inherent in the system (e.g., the distribution of failure times for a batch of light bulbs) and cannot be reduced.

It is often valuable to explicitly separate uncertainty from variability in a model. With SubModels, this is accomplished by inserting a "variability" SubModel (e.g., a dynamic Monte Carlo simulation) within an outer "uncertainty" model (e.g., a static Monte Carlo simulation). This is referred to as nested Monte Carlo simulation.

Read more: Carrying Out Nested Monte Carlo Simulation Using a SubModel (page 1067).

Example model UncertaintyVariability.gsm in the General Examples/SubModel folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) provides a simple illustration of such an application. In this model, a nested Monte Carlo simulation is used to calculate the confidence in the performance of a system of light bulbs. The outer model samples two probability distributions for values that describe the shape of the failure distribution for the light bulb. The fact that these are distributions indicates that we are uncertain about the precise shape of the failure distribution. The inner model then simulates the performance of the light bulbs (whose lifetime is sampled from a failure distribution with the (uncertain) variables provided by the outer model). The result of this type of analysis is a probability of probabilities (e.g., what is the chance that the probability of the light bulbs lasting less than 6000 hours will be less than one?).

SubModel Example: Probabilistic Optimization

Another common use of SubModels is to optimize a probabilistic model. If you wish to optimize a probabilistic (uncertain) system, the objective function to be optimized cannot be a single deterministic output. Rather, it must be a statistic. That is, if X was an output of a probabilistic model (and hence was output as a probability distribution), optimizing X itself would be meaningless. Rather, you would need to optimize a particular statistic (e.g., the mean or 50th percentile) of the output X.

With SubModels, this is accomplished by inserting a SubModel (e.g., a dynamic Monte Carlo simulation) within an outer model (e.g., a static optimization).

Example model ProbabilisticOptimization.gsm in the General Examples/SubModel folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) provides a simple illustration of such an application. In this model, the SubModel is a Monte Carlo simulation containing a single Stochastic. The outer model is an optimization. The variable being optimized is a function of another element in the outer model and a statistic (the 95th percentile) of the Stochastic in the SubModel.

SubModel Example: Dynamic Optimization During a Simulation

Another common use of SubModels is to do a dynamic optimization during a simulation. Imagine a situation where you were simulating the operation of a facility over a period of one year. Every month, the operators make a decision based on the current state of the system. This decision is based on a simple optimization analysis using currently available data (i.e., at every month during the simulation). The optimization chooses the optimum values of a few control variables that the operators will use for the next month.

With SubModels, you could simulate this by inserting a SubModel (e.g., a static optimization) within an outer model (e.g., a dynamic simulation).

Example model DynamicOptimization.gsm in the General Examples/SubModel folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) provides a simple illustration of such an application. In this model, the outer model is a dynamic deterministic simulation, and the SubModel is a static deterministic optimization. The objective function in the SubModel is a function of a parameter that is passed in from the outer model (and changes every timestep). Hence, every timestep, the SubModel carries out a new optimization and the results are used in the parent model for the next timestep.

Customized Importance Sampling Using User-Defined Realization Weights

For risk analyses, it is often necessary to evaluate the low-probability, high-consequence portions of the probability distribution of the performance of the system, and that can require carrying out a very large number of Monte Carlo realizations. Because the models for such systems are often complex (and hence need significant computer time to simulate), it can be difficult to use the conventional Monte Carlo for such risk analyses.

To facilitate this type of analysis, GoldSim allows you to utilize an importance sampling algorithm to modify the conventional Monte Carlo approach so that selected portions of input distributions (which could correspond to high-consequence, low-probability outcomes) are sampled with an enhanced frequency. During the analysis of the results that are generated, the biasing effects of the importance sampling are reversed. The result is high-resolution development of "high-consequence, low-probability outcomes", without paying a high computational price.

Stochastic elements provide built-in functionality to force importance sampling on either the low end or high end of a Stochastic element's range (i.e., the tails of distribution). Timed Event and Random Choice elements provide similar functionality.

Read more: Applying Importance Sampling to a Stochastic Element (page 187); Timed Event Elements (page 379); Random Choice Elements (page 387).

In some cases, however, it may be necessary apply importance sampling not just over the tails, but over user-defined regions of the Stochastic element's range. For example, if it was known that the important results of a model were highly sensitive to values of a particular Stochastic that were close to the 40th percentile, you would want to focus sampling in that region.

GoldSim supports this by providing three specialized functions that provide biased sampling (and compute the appropriate weights) for a targeted range within a probability distribution. All three functions require a Target probability and a Width. For example, if you specify a Target of 0.4 and a Width of 0.05, biased importance sampling will be focused in the region between probability level 0.375 and 0.425. The functions provided by GoldSim are as follows:

ImpProb(Old,Target,Width): Takes a sampled probability (Old) and returns a probability biased toward the specified region (the manner in which this is done is discussed below).

ImpWeight(Prob,Target,Width): Takes a biased probability (produced by ImpProb) and returns a weight.

ImpOld(Prob,Target,Width): Takes a biased probability (produced by ImpProb) and returns the unbiased probability. This is the inverse of ImpProb.

By using these functions in conjunction with GoldSim's option for the user to manually specify realization weights, a customized importance sampling scheme can be implemented.

The steps required to implement importance sampling on a single Stochastic element (e.g., named Stoch1) with a Target of 0.4 and a Width of 0.05 are as follows:

1. Create a Stochastic element (e.g., U) defined as a Uniform between 0 and 1. This will generate a random number.
2. Create an Expression element (e.g., Prob) defined as "ImpProb(U,0.4,0.05)". This will generate biased random numbers with which to sample Stoch1.
3. Create an Expression element (e.g., Stoch1Value) with the same dimensions of Stoch1, defined as "PDF_Value(Stoch1.Distribution,Prob)". This will generate the biased sample of Stoch1.

   Read more: Specialized Functions that Operate on Distributions (page 188).
4. Create an Expression element (e.g., Weight) defined as "ImpWeight(Prob,0.4,0.05)". This computes the appropriate weight to use for the realization.
5. Open the Simulation Settings dialog, and go to the **Monte Carlo** tab. In the Probabilistic Simulation section, check the **Specify Realization Weights** box. An Insert link dialog will appear, and you should select the Weight element defined in the previous step. This then instructs GoldSim how to appropriately weight each realization when computing results (e.g., CDFs).

   Read more: Probabilistic Simulation Options (page 498).

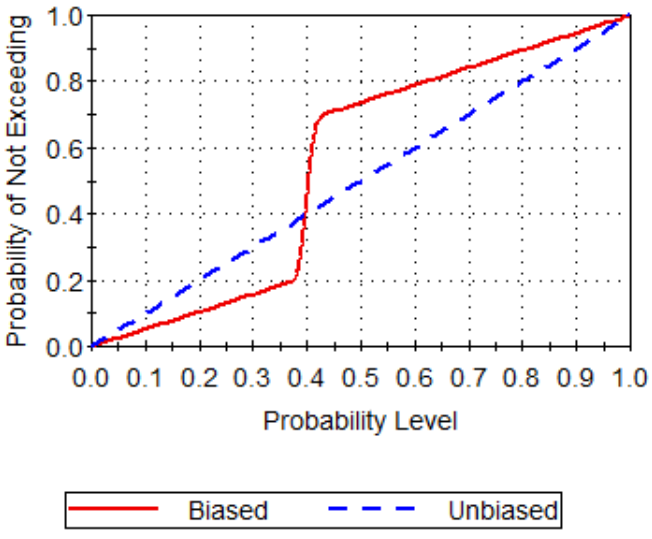
This specific example can be found in the file CustomImportance.gsm in the General Examples/Stochastic folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

How does GoldSim actually implement this importance sampling? The implementation is as follows:

During the Monte Carlo simulation half of all the random numbers generated by the importance sampling function (ImpProb) will lie outside of the enhanced-sampling region (defined as the region from Target – Width to Target + Width), and half inside it. The 'outside' and 'inside' regions are sampled differently:

- The half of the samples that are outside the region are distributed uniformly.
- The sampling of the half that are inside of the zone depends on whether the target probability is close to 0 or 1:
  - Normally, these samples have increased sampling rates closer to the target value. The sampling rate within the enhanced sampling zone is distributed according to a truncated normal distribution, with a standard deviation equal to one quarter of the width of the zone.
  - However, if the target probability level is less than the specified width, or greater than (1 – the specified width), then the enhanced samples are also uniformly distributed, though sampled at a higher rate than the samples outside of the region.

The figure below shows how a set of random numbers (generated by sampling from a uniform distribution between 0 and 1) is modified (biased) using the ImpProb function to focus on the specified Target. An unbiased uniform distribution simply produces a CDF that is a straight line with a slope of 1. The biased distribution of random numbers (in this case with a Target of 0.4 and a Width of 0.05 focuses 50% of the samples to fall between 0.375 and 0.425. The remaining 50% falls outside this range (in this case 20% below and 30% above).



Of course, the weights of these samples are adjusted accordingly (using the ImpWeight function) such that in this case, the 50% of the samples falling between 0.375 and 0.425 account for only 10% of the total weight.

The following points should be noted regarding customized importance sampling:

- The Target must be defined as a value between 0 and 1.

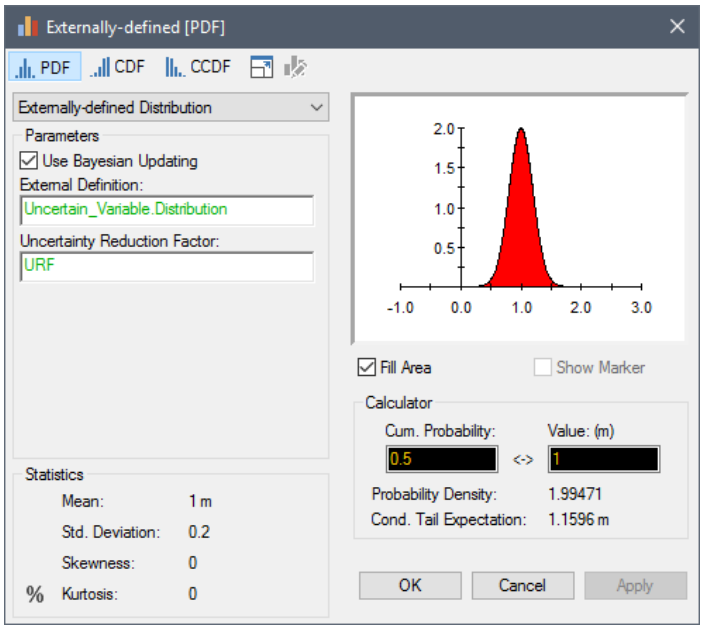
- The Width must be between 1E-6 and 0.5.
- Using the approach outlined above, any correlation factor specified for Stoch1 will be ignored (since the value is not generated by the distribution, but via the PDF_Value function).
- This approach can readily be applied to do enhanced sampling of multiple Stochastic elements. It is simply necessary to 1) use a different (uncorrelated) random number (U in the example above) for each element;and 2) multiply all of the independent realization weights together to generate the Realization Weight used in the Simulation Settings dialog. However, when multiple elements use importance sampling it is important not to use narrow sampling regions, as this can lead to numerous 'wasted' realizations that have negligible realization weights.
- The custom importance sampling approach is compatible with the built-in functionality to force importance sampling on either the low end or high end of a Stochastic element's range. Hence, your model could contain some elements that use the "built-in" approach and others that use the custom approach.

Dynamically Revising Distributions Using Simulated Bayesian Updating

GoldSim provides an advanced feature for dynamically revising distributions during a simulation using "simulated Bayesian updating". This feature is most valuable when using GoldSim to simulate a project of some kind (e.g., developing a new product, building a new facility). It is often the case that as a project progresses, additional information about uncertain variables is acquired. From the project operator's point of view, their uncertainty is decreasing, and hence as time progresses, the probability distributions used in their model of the project are converging towards the true values of the variables. As their knowledge increases they are better able to make appropriate decisions for the project's path forward.

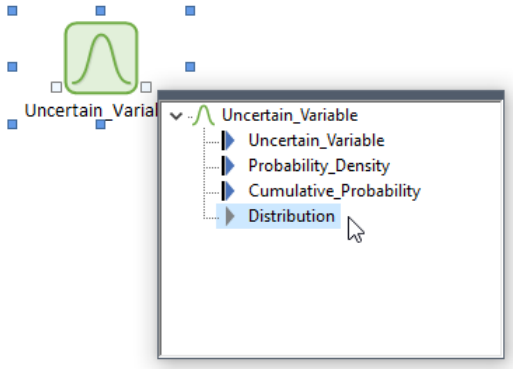
When simulating a project in this manner using GoldSim, the model that is constructed will use Stochastic elements to specify the initial probability distributions of uncertain parameters, and a Monte Carlo sampling process will be used to pick the 'true' values of those parameters. Given that starting point, simulated Bayesian updating can be used to simulate the additional information that will accrue as the project progresses. This in turn can be used to simulate the decisions that would be made based on the new information.

To support this, GoldSim allows you to define an "uncertainty reduction factor" for an uncertain variable. To do so, you must create a new Stochastic and specify its distribution type as an "Externally-defined Distribution":



Read more: Externally-Defined Distribution (page 172).

The uncertain variable (whose uncertainty is being reduced as the model progresses) is entered in the **External Definition** field for this new Stochastic. This must be a link to the Distribution output of a Stochastic element. The Distribution output is a complex output that contains all the information regarding the distribution. It is the fourth output of a Stochastic:



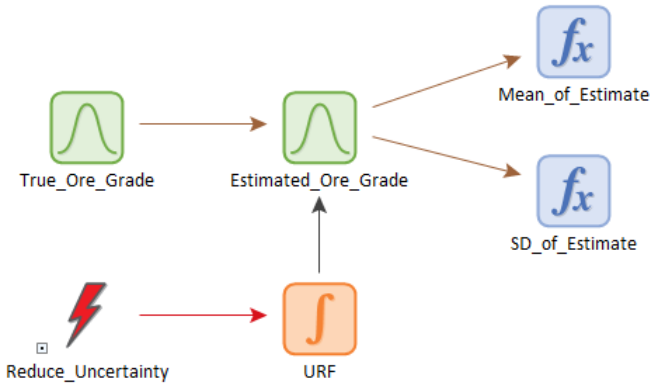
Read more: Stochastic Elements (page 158).

You must then check the **Use Bayesian Updating** checkbox, and then enter a value for the **Uncertainty Reduction Factor**. This dimensionless factor, which must be between 0 and 1, approximates the extent to which the original distribution's standard deviation has been reduced at any point in time. Essentially, this allows you to define how the initial uncertainty about the original distribution is reduced. As such, the **Uncertainty Reduction Factor** will almost always have an initial value of 1 (no reduction of uncertainty), and become smaller as a function of time (typically by changing in discrete steps representing points in time when new information has been obtained).

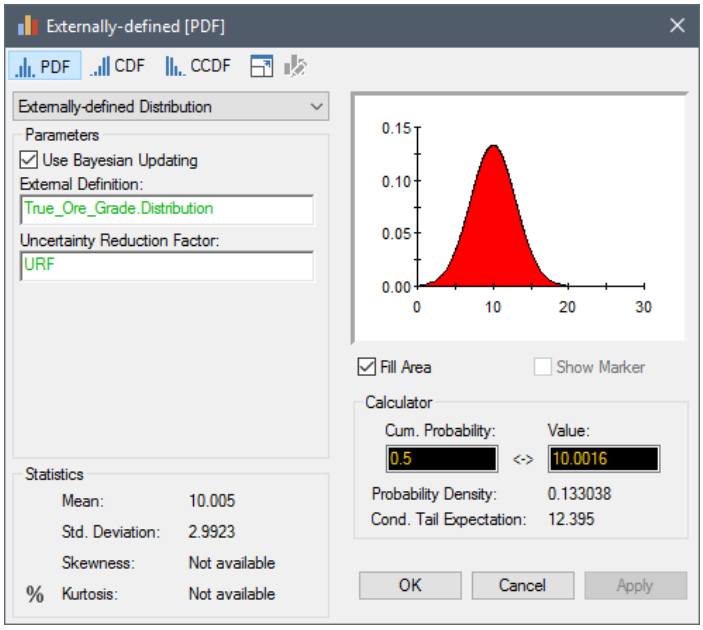
To understand the mechanics of how simulated Bayesian updating works, let us first examine a simple model that illustrates how the Externally-defined distribution is modified by a time-variable **Uncertainty Reduction Factor**. Subsequently, we will describe a (simplistic) real-world application.

The example model described here can be found in the file BayesianUpdating.gsm in the General Examples/Stochastic folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu). It is recommended that your open that file and follow along during the discussion below.

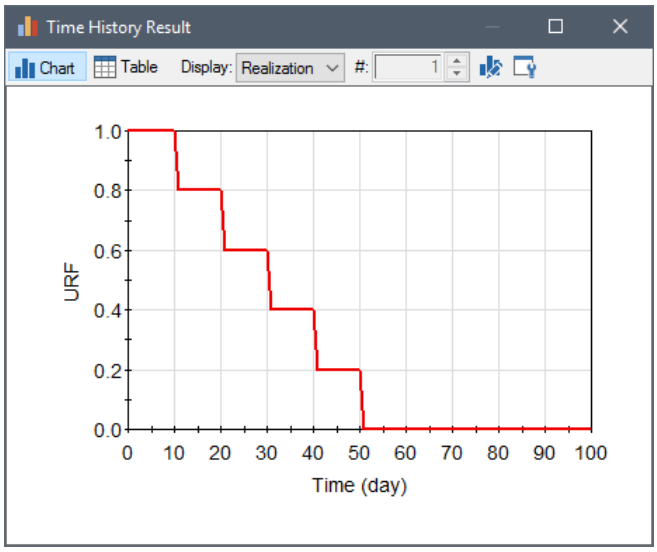
In a Container named "Basic_Concepts", you will see a very simple model that looks like this:



The True_Ore_Grade represents the variable that is being studied (and whose uncertainty is being reduced during the simulated project). In this example, it is a Normal distribution with a mean of 10 and a standard deviation of 3. The Estimated_Ore_Grade represents the updated distribution resulting from studies carried out on the ore grade during the project. It is an External Distribution whose primary input is the True_Ore_Grade, and whose Uncertainty Reduction Factor is defined by the variable URF:



URF is simply an Integrator with an initial value of 1 (no uncertainty reduction) that is updated by a Discrete Change at discrete points in time (representing studies that have reduced the uncertainty in the ore grade). In this example, URF is simply reduced by a factor of 0.2 every 10 days for a period of 50 days:

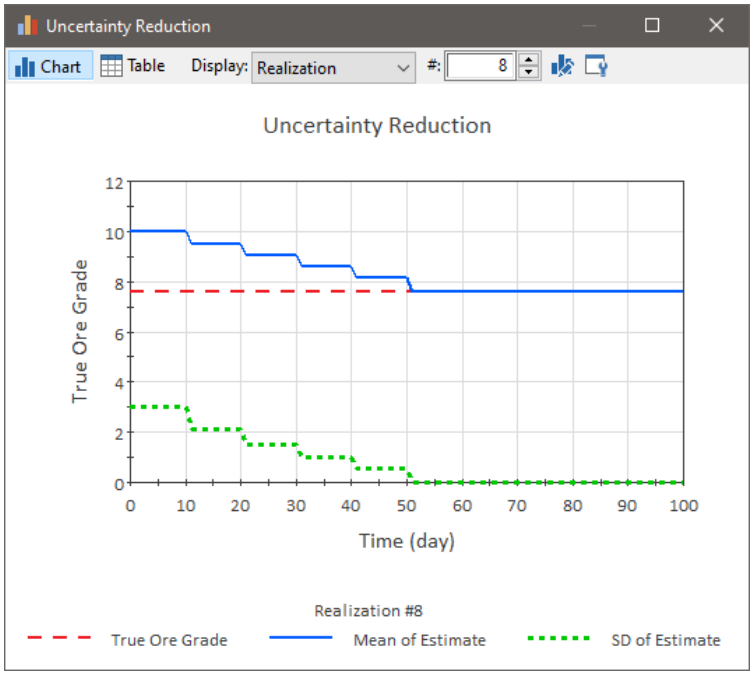


Hence, after 5 days, the uncertainty in the ore grade has actually been reduced to zero (i.e., it is assumed that the ore grade is perfectly known at 50 days).

Given this information, it is instructive to view how the Estimated_Ore_Grade distribution changes as a function of time. Although we can't easily view the distribution in the middle of a simulation, we can examine its statistics and see how they change with time. To do so, we take advantage of two of GoldSim's built-in functions: PDF_Mean and PDF_SD, which return the mean and standard deviation, respectively, of a specified distribution.

Read more: Specialized Functions that Operate on Distributions (page 188).

The plot below shows how the mean and the standard deviation of the Estimated_Ore_Grade distribution change with time. The plot also includes the True_Ore_Grade:



Every realization of the model produces a different sampled True_Ore_Grade. In this particular realization, the True_Ore_Grade was sampled to be just less than 8. As can be seen, the initial mean and standard deviation of the Estimated_Ore_Grade are 10 and 3, respectively (the same as the statistics for the True_Ore_Grade distribution). However, starting at 10 days, more information is learned about the ore grade. This has two effects on the Estimated_Ore_Grade distribution: 1) the standard deviation is reduced; and 2) the mean approaches the true value. Whenever new information is obtained (in this example, every 10 days), the standard deviation is further reduced, and the mean moves closer to the true value. At 50 days (when it is assumed that "perfect information" is obtained), the standard deviation goes to zero, and the mean converges to the true value.

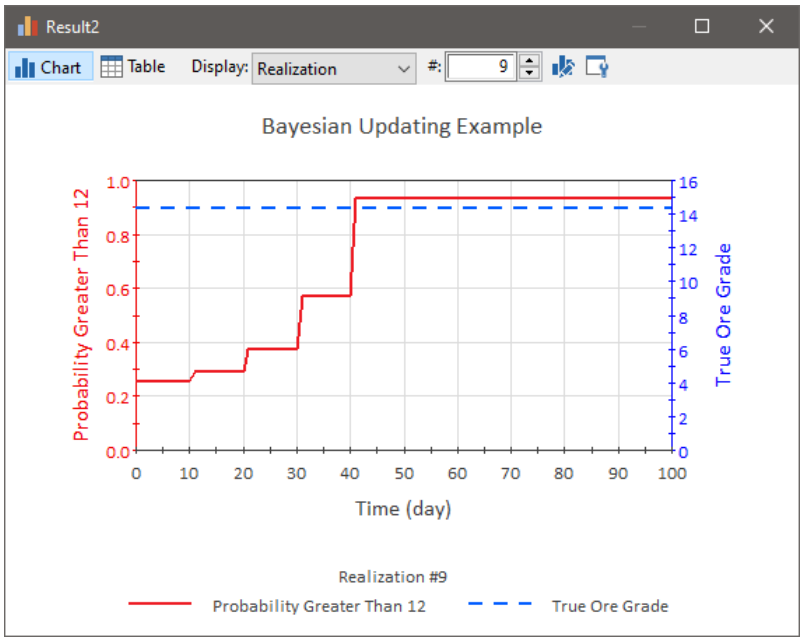
Now that we have explained conceptually how simulated Bayesian updating is carried out, let's now expand on this example slightly to illustrate how it might actually be used in a real model. The example model described here can be found in the same file (BayesianUpdating.gsm) in the General Examples/Stochastic folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu). It is in a Container named "Example_Application".

The example considers the case of a proposed new mine. Initially the mean ore grade may have considerable uncertainty, but as successive studies are carried out, additional information is obtained and the uncertainty about the mean ore grade is reduced. Let's further assume that once you have a particular level of certainty regarding the value, you will act in one way or another.

We will represent this by starting with the previous example, and making one change and one addition:

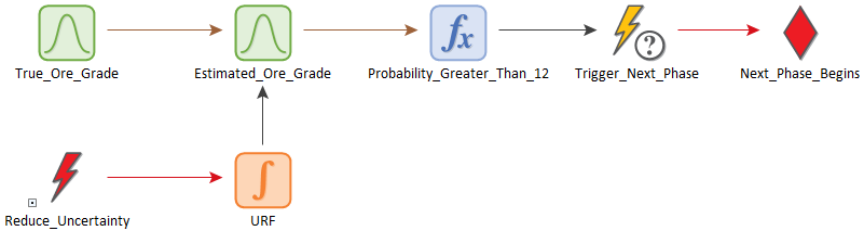
- We will assume that only four studies are carried out (at 10, 20, 30 and 40 days), each reducing the Uncertainty Reduction Factor by 0.2, such that (as would be realistic) perfect information regarding the ore grade is never obtained.
- We will assume that the estimated ore grade must be greater than 12 for the project to proceed. Because the ore grade cannot be known with certainty, however, this decision must be based on probabilities. In particular, when simulating the project, it is assumed that the project will proceed if and only if we have at least 50% confidence that the ore grade is greater than 12 (i.e., we will proceed if the probability of the ore grade being at least 12 exceeds 50%).

The probability of the ore grade being at least 12 is another statistic (that is changing with time as more information is obtained) that can be computed using one of GoldSim's built-in functions (PDF_CumProb). The plot below shows how the probability of the ore grade being at least 12 changes with time for a particular realization:



In this realization, the true value is sampled to be approximately 14.3. Given the original distribution (Normal distribution with mean 10 and standard deviation 3), the original probability of the value being greater than 12 is about 25%. As the uncertainty in the ore grade is reduced, the probability of the ore grade being greater than 12 increases, until at 30 days, it jumps above 50% to 57% (and at 40 days jumps to 93%), and hence the project can proceed.

In this simplified model, when this occurs, an event is triggered which in a real model could trigger the next phase to begin:

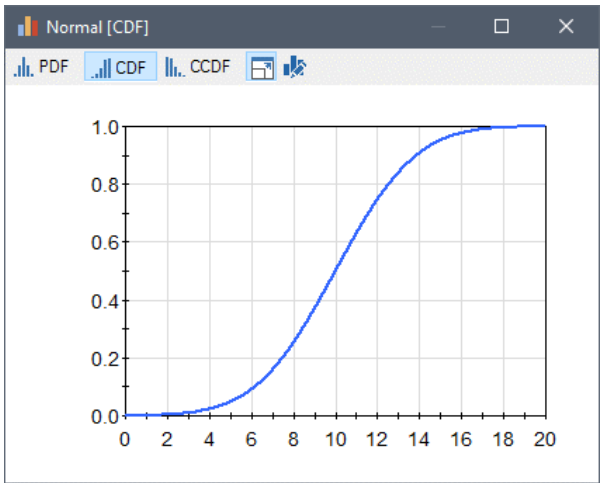


Although this example is simple, it illustrates how simulated Bayesian updating can be used to simulate additional information that is obtained as a project progresses, and how this can in turn be used to simulate the decisions that would be made based on the new information.

Mathematics of Simulated Bayesian Updating

The conventional approach to sampling an uncertain variable is to first sample a random value (from a uniform distribution between 0 and 1), and then use this value as input to the inverse cumulative distribution function for the uncertain variable.

For example, the CDF for a Normal distribution (with mean 10 and standard deviation 3) looks like this:



To sample this distribution, GoldSim would first sample a random value from a uniform distribution between 0 and 1 (such that all values were equally likely), and use this as the cumulative probability level for the sampled variable. It would then map that probability to a value. For example, if 0.4 was sampled from the uniform distribution, that would map to a value for the variable of approximately 9 in this case.

To understand how simulated Bayesian updating is carried out, recall that two separate Stochastic elements must be defined to carry it out: 1) a Stochastic representing the "true" value; and 2) a Stochastic (defined as an Externally-defined distribution with a specified Uncertainty Reduction Factor) representing the "updated" distribution. When doing Bayesian updating, the key point is that the random value on the probability axis for the "updated" distribution is not sampled from a uniform between 0 and 1; rather, it is sampled from a beta distribution, whose shape depends on the sampled "true" value and the specified Uncertainty Reduction Factor for the "updated" distribution.

The specific way this is done is as follows:

1. A random number is selected in order to sample the distribution representing the "true" value.

2. In order to sample the "updated" distribution, a beta distribution is created on the probability axis for the distribution. This beta distribution has a minimum value 0 and maximum value 1. Its standard deviation is calculated as the product of the default standard deviation value for sampling the probability axis (0.288675, for a uniform distribution) and the Uncertainty Reduction Factor. The mean of the beta moves linearly from the original mean (0.5 for a uniform distribution) towards the sampled probability level for the original Stochastic as the Uncertainty Reduction Factor ranges from 1 to 0.

   Hence, if we assume that the sampled random number for the "true" value is 0.3, and the Uncertainty Reduction Factor is 0.5, then the beta distribution that is created would have a mean of 0.4 (half way between 0.5 and the sampled value 0.3) and a standard deviation of 0.288675*0.5.

3. This beta distribution is then sampled (returning a value between 0 and 1).

4. This value is then used as input to the inverse cumulative distribution function for the original Stochastic.

Note that as the Uncertainty Reduction Factor approaches 0, the "updated" value approaches the "true" value.

The approach described above is used for all continuous distributions. As described above, it effectively increases the likelihoods of "updated" values closer to the "true" result, and reduces the likelihoods of values that are further away from it. This is usually an appropriate approach, as most tests of continuous variables will have a limited accuracy and resolution, and as such, the probabilities of nearby values are correlated. However, for a discrete distribution (e.g. 'is it an apple, an orange, or a pear?') there is likely no correlation between the probabilities of nearby values (and for Boolean, the concept of "nearby" values does not even apply). Accordingly, a different approach (described below) is used for Boolean and Discrete distribution types. However, the approach described above for continuous distributions is also used for the results of binomial, Poisson, and other discrete-valued distributions, as there typically would be a correlation between nearby values for these distributions.

For the Boolean and the Discrete distributions the uncertainty reduction works differently. In these cases, for the "updated" distribution, the probability of the "true" value is increased linearly from its original probability level to a value of 1 as the Uncertainty Reduction Factor drops from 1 to 0. For all other outcomes, the original probabilities are simply multiplied by the Uncertainty Reduction Factor, dropping to 0 as the Factor approaches 0. As was the case for the continuous distributions, sampling is accomplished via an auxiliary probability distribution that modifies the sampled probability levels, but instead of a beta distribution, a cumulative distribution is used in order to have the desired effect.

Tracking Model Changes

GoldSim provides the ability to track changes that you have made to your model file. This feature (referred to as ***versioning***) allows you to quickly determine the differences between the current version of your model file and some previous version of the file.

Providing this configuration management capability is particularly useful for:

- coordinating model changes when multiple people can access and modify the model file;
- as a Quality Assurance/Quality Control feature enabling you to demonstrate and document when and what changes have been made to a model file.

Versioning Overview

Changes to a model file are tracked by creating model file versions. A version is an internal "snapshot" of your model file at a particular point in time. You must tell GoldSim when to take a "snapshot" by creating a version, and assigning it a title (e.g., "1-12-2002", "Initial Model", "Revision A"). Once you have created at least one version, you can then compare the current model (the model as it exists right now) to any previous model version you have created.

GoldSim can report the differences between the current model and any previous version. Note that GoldSim does not actually tell you *how* a model has changed; in general, it only reports *what* has changed.

For example, if you change some of the inputs to a Reservoir element between versions, GoldSim will report that the element has been changed, but it does not store or report which inputs changed or what their previous values were. Similarly, if you delete an element from a Container, GoldSim will report that an element with a particular ID was deleted from the Container, but it does not

record the type of element (or the manner in which the element was defined). This keeps the size of the model file (where all of the changes are stored) manageable.

Generally, you will want to create a version whenever some project milestone has been met. The milestone might be the end of a particular phase of the project, or after you have made some major modification to the model. In some cases, you may want to create versions on a regular basis (e.g., every Friday).

Immediately after you create a version, it may be useful to archive a copy of the model file. If you do so, you will then be able to determine the details of the changes that were made between versions.

Read more: Saving, Opening and Closing GoldSim Files (page 62).

For example, when GoldSim reports that element A was modified between version X and the current version, you can open and compare the file that was archived when version X was created to determine how the element was defined at that point. When you archive a copy of your current model, GoldSim records the name of the archived file (along with the version number) in your current model.

Read more: Changes Tracked Between Versions (page 1102).

Enabling Versioning

In order to enable versioning in a file, select **Model|Versioning…** from the main menu. The first time you do this, a message is displayed asking you to confirm that you want to enable versioning.

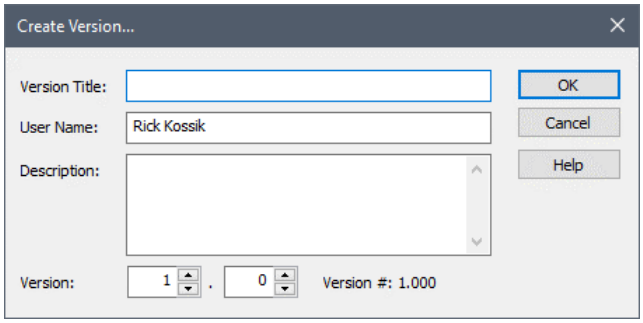
After confirming your request, you will immediately be prompted to create a version of the file (take a "snapshot" of the current model file and "stamp" it as a version).

Once you create the first version, versioning will be enabled, and will remain enabled until you choose to disable it.

Read more: Disabling Versioning (page 1102).

Creating Versions

When you first enable versioning, or whenever you choose to create additional versions via the Version Manager, a dialog for creating versions is displayed.



Read more: The Version Manager (page 1101).

You must assign a **Version Title** to each version. This Title is not required to be unique (although in most cases it should be). It is used in messages and reports when comparing versions, and should be something meaningful and explicit (e.g., "Draft #1", "Final Model", "Jim's Modifications", "January 12").

The **User Name** will also appear in difference reports and messages, and is intended to identify the model user who created the version. By default, the Windows user name will appear, although you can edit this.

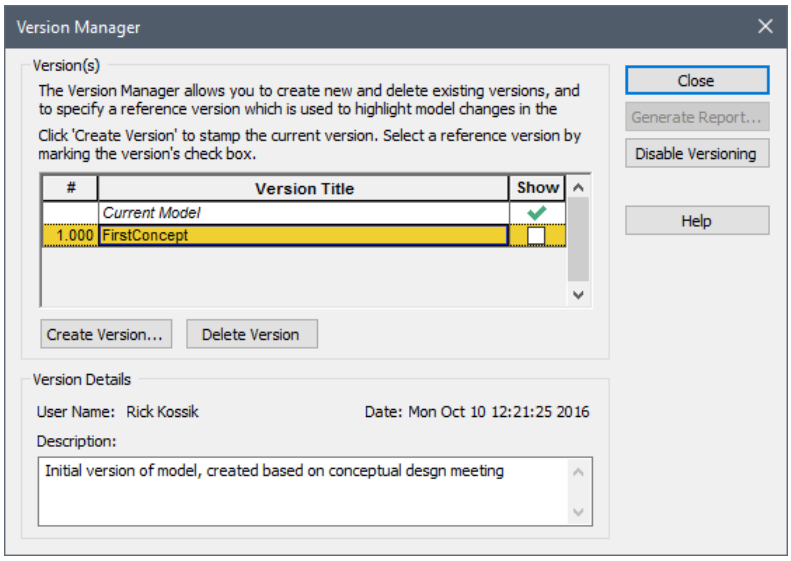
The **Description** field can be used to add descriptive text for each new version.

Finally, you must assign a **Version** number of the form X.yyy (e.g., 1.003). GoldSim ensures that new version numbers are always greater than the previous version number.

The Version Manager

Once you have defined your first version, or if you select **Model|Versioning…** after versioning has already been enabled, the Version Manager dialog is displayed.

The Version Manager lists all the versions that you have created. If you select one of these versions, the details of that version (user name, date created, and description) are displayed at the bottom of the dialog:



You can edit the **Description** here, but cannot change any other details about the version.

You can create new versions by pressing the **Create Version…** button, which provides access to the Create Version dialog.

Read more: Creating Versions (page 1100).

Deleting a Version

You can delete an existing version by selecting it in the Version Manager and pressing the **Delete Version** button. Note, however, that when you delete a version, you also automatically delete all previous versions.

When you delete a version, the version number is never used again. For example, if you had a single version (1.000), and you deleted this version and then re-enabled versioning and created another major version, it would be numbered as 2.000.

If you choose to delete the most recent version (and hence all versions in the model), GoldSim will automatically disable versioning (until you enable it again by creating a new version).

Specifying the Reference Version

Once you have created at least one version, you can then compare the current model (the model as it exists right now) to any previous model version you have created. In order to do so, you must identify the ***Reference Version*** (the version to which the current model is compared).

This is done by selecting the checkbox to the right of the version in the Version Manager. Only one checkbox can be selected at a time (i.e., there can be only one Reference Version).

You can readily change the Reference Version while you are viewing differences.

Read more: Displaying Version Differences (page 1103).

Disabling Versioning

You disable (remove) versioning by pressing the **Disable Versioning** button in the Version Manager dialog. When you disable versioning, all versioning information is deleted (and cannot be recovered). Hence, before doing so, GoldSim will ask you to confirm that you want to delete all versioning information.

Changes Tracked Between Versions

When versioning is enabled, GoldSim can report the differences between the current model and any previous version. GoldSim does not actually tell you *how* a model has changed; it only reports *what* has changed. For example, if you modify an input field of an element, GoldSim does not store what field was edited or what the previous value was. Rather, it simply reports that "one or more of the element's attributes have been changed".

The changes that are logged by GoldSim can be divided into two categories: global changes and element-specific changes. Global changes pertain to the entire model. Element-specific changes pertain to a particular element.

The following global changes are recorded and stored within the model file when versioning is enabled:

- A new version is created.
- A version is deleted.
- Versioning is disabled.
- The model filename has changed via a Saved As command (the previous filename is recorded).
- The model filename has been changed outside of GoldSim since the file was last opened (the previous filename is recorded).
- The model file has been archived (the archived filename is recorded).
- One or more of the Simulation Settings have changed.
- A user-defined unit has been created or modified.
- An array label set has been added, deleted or changed.
- A global database download has been carried out.
- A file has been locked onto or unlocked by a Spreadsheet, External or File element.
- One or more options in the Options dialog associated with an extension module have changed.

The following element-specific changes are recorded and stored within the model file when versioning is enabled:

- An element is added, moved, deleted.
- An element is cloned or a cloned element is freed.
- The element's ID has been changed (the previous ID is recorded).
- The element's description has changed (the previous description is recorded).
- Any of the element's attributes or input definitions have changed.

- A database download to the element is carried out.
- Data is imported into a Lookup Table or a Time Series element.
- The checkbox in the Options dialog controlling whether or not Timed Events are mapped to the next timestep has changed.

The following points regarding the changes tracked by GoldSim should be noted:

- A Container is considered to be changed if an element is added to, removed from, or deleted from it.
- Locking/unlocking and sealing a Container are not recorded as changes.
- Purely graphical or cosmetic modifications to the model such as changing an element's symbol or adding a graphic or text to the graphics pane are not recorded as changes.
- Adding, deleting or modifying Classification categories are not recorded as changes.
- Adding, deleting or editing a Note to an element is not recorded as a change.
- If an element is changed multiple times between versions, GoldSim records that the element has changed, but does not record the number of times or the number of changes that have been made.
- If an element is changed and then changed back (e.g., if the ID is changed and then changed back to its original ID), GoldSim still records this as a change.

Displaying Version Differences

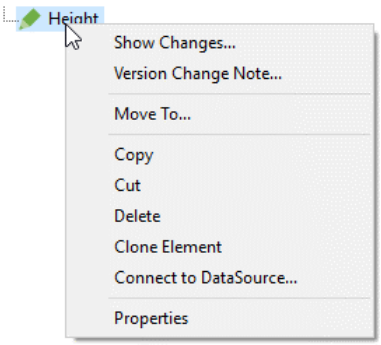
In order to display the differences between the current model and any previous version, you must specify the Reference Version in the Version Manager dialog.

Once a Reference Version is specified, GoldSim identifies changed elements in all browsers as follows:

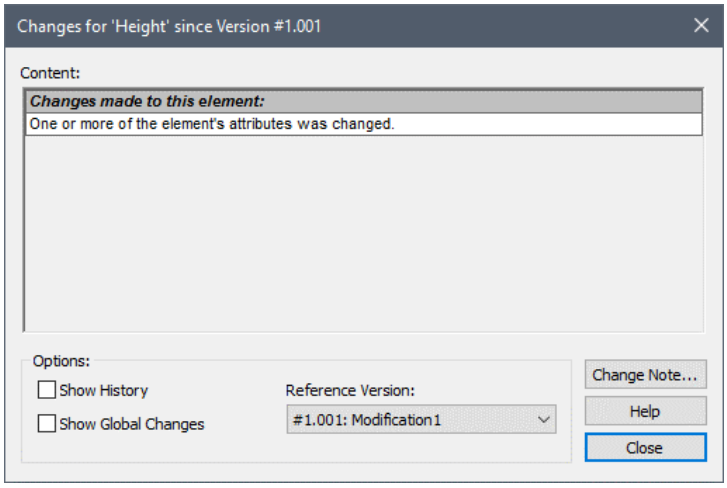
- If an element has been changed since the reference version, the element will appear red in all browsers. (If it is sealed or locked *and* it has changed, it will appear light red.)
- If any element inside a Container has been modified, but the Container itself has not been modified (e.g., no elements have been added or removed from it), the Container will appear blue in all browsers. (If the Container is sealed or locked and elements within it have been changed, it will appear light blue.)

Warning: If a Reference Version is not selected, none of the changed elements will be indicated in the browser. Hence, you must specify a Reference Version in order to view changes.

If you right-click on a colored element (e.g., a red element or a blue Container) in the browser, a menu item, **Show Changes…**, is available toward the top of the menu:

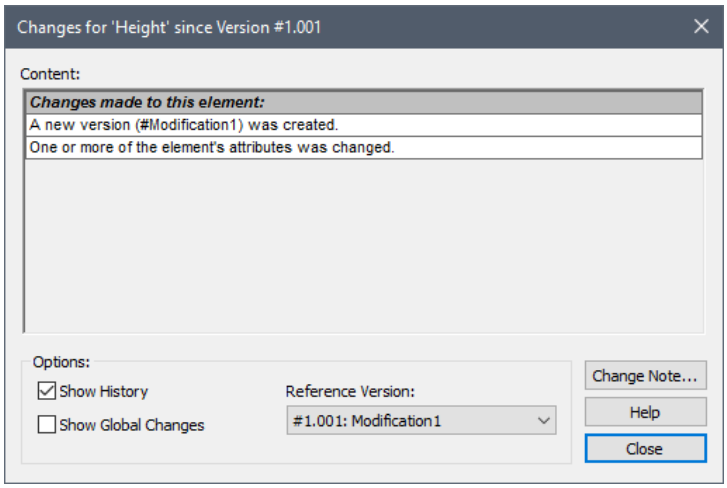


If you select this menu option, the Changes dialog is displayed:



This dialog displays all of the changes that have been made to the element since the specified Reference Version. The Reference Version (selected in the Version Manager) is displayed at the bottom of the dialog. You can change the Reference Version directly from this dialog by selecting a version from the drop-list.

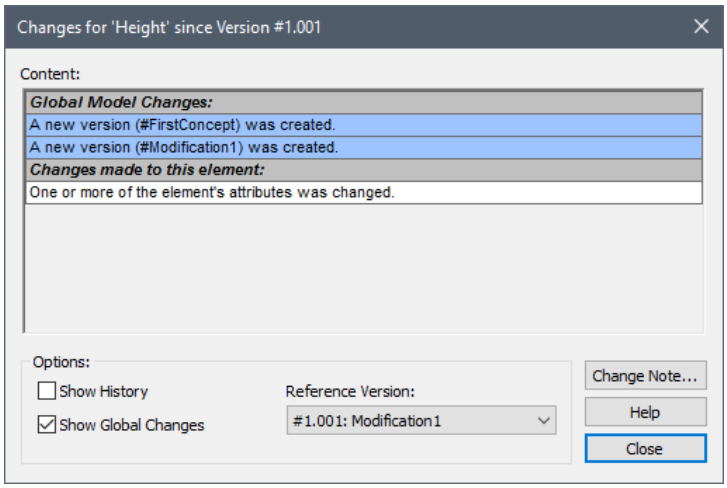
Clicking the **Show History** checkbox shows a history of all the changes between the Reference Version and the current model.



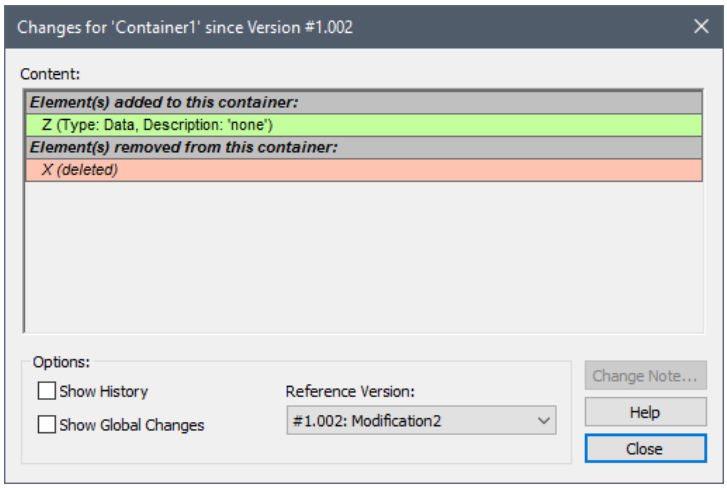
If the **Show History** box is cleared, only a summary of the differences between the Reference Version and the current model are shown. Hence, if the element was changed several different times, the Show History display will indicate this,

while the summary display (with **Show History** cleared) will only indicate that the element has changed since the Reference Version.

Clicking the **Show Global Changes** checkbox displays the Global changes to the model (in addition to the changes to elements):



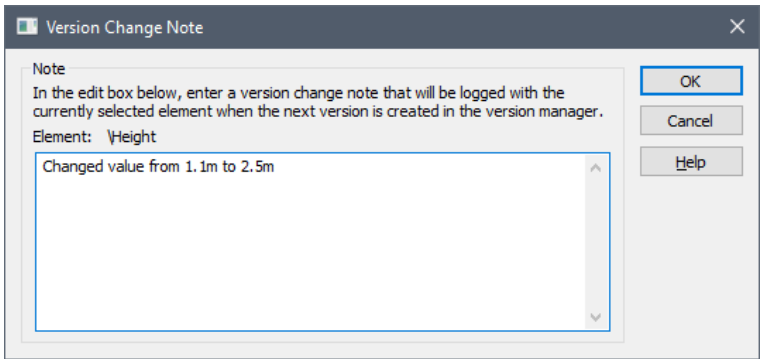
If the selected element is a Container, the Changes dialog identifies any elements added to the Container, any elements removed (or deleted) from the Container, and whether any Container properties (e.g., conditionality settings) have been changed.



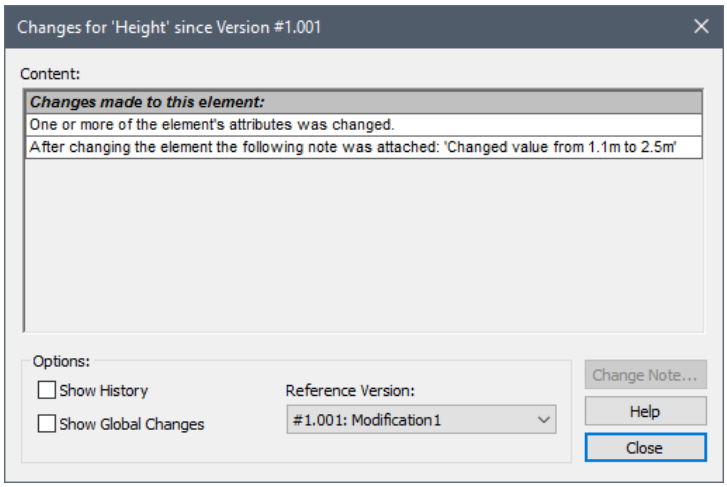
Manually Documenting Changes to an Element

After an element has been changed, you can add a Change Note to the element that will also be displayed in the Changes dialog.

If an element has been changed since the last (most recent) version stamp, the **Version Change Note…** option is available in the context menu for the element, and the **Change Note…** button is available on the Changes dialog for the element. Selecting either of these buttons will display a dialog for adding a change note to the element:



If you add a note, the note is saved with the next version that is created, and is displayed in the element's Changes dialog:

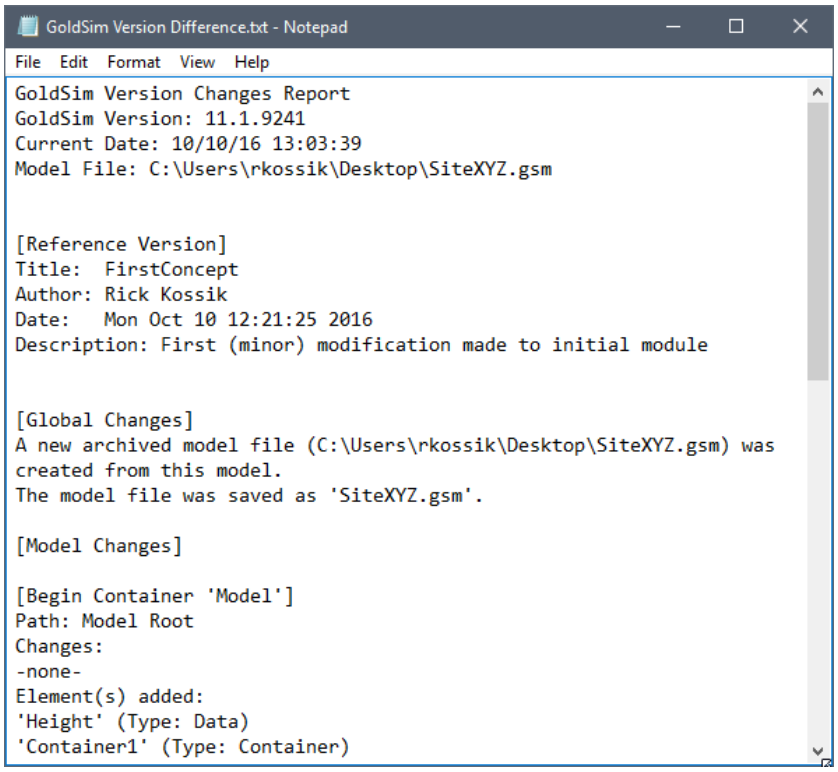


Note: A Change Note is intended to be applied for a particular version. Therefore, whenever a new version is created, the element Change Notes for that version are recorded with the version and then immediately cleared. As a result, if you create a subsequent version, the previous note does not appear in the Changes dialog for the new version.

Generating a Version Report

In some cases, rather than viewing changes to individual elements, you may want to create a report of all of the changes made between the Reference Version and the current model. You can do so by pressing the **Generate Report…** button in the Version Manager dialog.

An ASCII text file summarizing all the changes will be generated and immediately opened in the default application associated with .txt files (e.g., Notepad):



This file is written to the directory containing the model file. If it cannot be saved there (due to access issues), GoldSim will save it to the user's temporary folder (and provide the location of the file in a message).

By default, the name of the Version Report file is "GoldSim Version Difference.txt".

Note: On rare occasions, you may want to instruct GoldSim to insert the model filename into the name of the Version Report filename. To do this, you must edit the Windows Registry. In particular, add a DWORD registry key under HKEY_CURRENT_USER\Software\GTG\Settings named *VersionReportEmbedModelName* and set it to a non-zero value. If you do so, the name of the Version Report file will be "ModelFilename _VersionReport.txt. For example, if the model filename was called "Example.gsm", the Version Report file would be named "Example_VersionReport.txt".

Linking Elements to a Database

In simulations which require a great deal of input, it may be desirable (or even mandated) that the simulation model can access the various data sources directly to facilitate and ensure the quality of the data transfer.

One way to accomplish this in GoldSim is to import data from spreadsheets into a Spreadsheet element or into Lookup Tables or Time Series elements.

Read more: Linking a Lookup Table to a Spreadsheet (page 319); Importing Data into a Time Series from a Spreadsheet (page 199); Spreadsheet Elements (page 982).

GoldSim also provides a more powerful method. In particular, GoldSim data entry elements can be linked directly to an ODBC-compliant database.

After defining the linkage, you can then instruct GoldSim to download the data at any time. When it does this, GoldSim internally records the time and date at which the download occurred, along with other reference information retrieved from the database (e.g., document references), and this is stored with the model in the Run Log. This information is also displayed in the tool-tip for the linked element.

This allows you to confirm that the correct data were loaded into your model, and provides very strong and defensible quality control over your model input data.

The following elements can be downloaded from a database:

- Data elements;
- 1-D and 2-D Lookup Table elements; and
- Stochastic elements.

There are three steps involved in linking an element to a database:

1. Creating a database which is compatible with GoldSim;
2. Adding the database as a *data source* to your computer; and
3. Linking an element to the database and downloading the data.

Creating a Compatible Database

GoldSim can interact with three types of databases: 1) a Generic Database; 2) a Simple GoldSim Database; and 3) an Extended GoldSim Database. Each of these databases have specific formats and different capabilities, as outlined below:

Generic Database: Generic databases have a very simple format (consisting of a single table). They can download only to scalar, vector and matrix Data elements. They are the only type of database which can download to vector and matrix Data elements.

Simple GoldSim Database: Simple GoldSim databases are more structured than Generic databases. As such they can not only download to scalar, vector and matrix Data elements, but they can also download to Stochastic elements. The database is structured to allow you to store different versions of the same datum (e.g., associated with different dates). You specify from *within the database* which version is to be used when linked to GoldSim.

Extended GoldSim Database: The Extended GoldSim database format is the most complex of the three formats. They can download to scalar, vector and matrix Data elements, Stochastics, and 1-D and 2-D Table elements. The database is structured to allow you to store different versions of the same datum (e.g., associated with different dates). You can specify from *within GoldSim* which version is to be used when linked to GoldSim.

The table below summarizes the key features of the three database formats:

	Download to Scalar Data Elements	Download to Vector and Matrix Data Elements	Download to Stochastics	Download to 1-D and 2-D Tables	Store Different Versions of the Same Datum
Generic	X	X			
Simple GoldSim	X	X	X		X
Extended GoldSim	X	X	X	X	X

The specific formats for these three types of databases are described in Appendix E.

Adding Data Sources to Your Computer

Before using GoldSim's database features you must first identify the database(s) you need to access using the Windows Control Panel ODBC Data Sources (32bit) option. This allows you to define a name for each data source, and associate the data source with a specific database file.

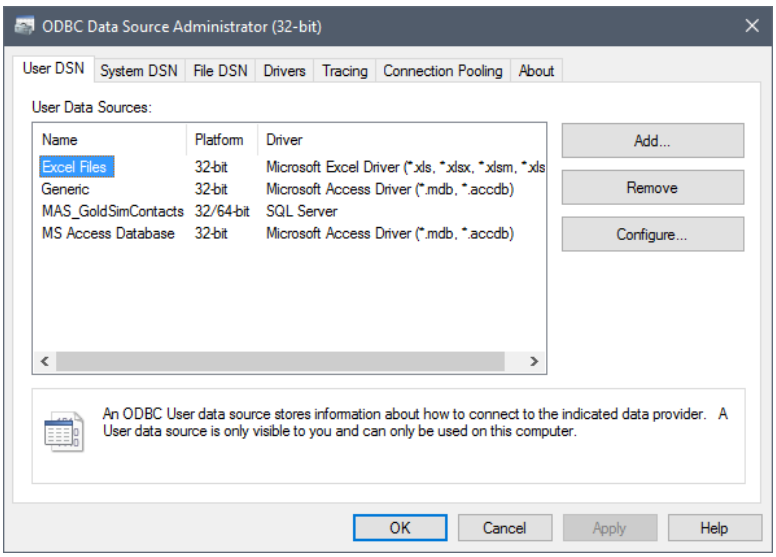
For details in adding and configuring data sources, you should refer to your Microsoft Windows documentation. A brief overview is presented below.

To add a data source to your computer, do the following (the instructions here are for Windows 10; they may differ slightly for other Windows versions):

1. From the Windows Control Panel, select under System and Security / Administrative Tools, you will find and option to **Set up ODBC data sources (32-bit)**.

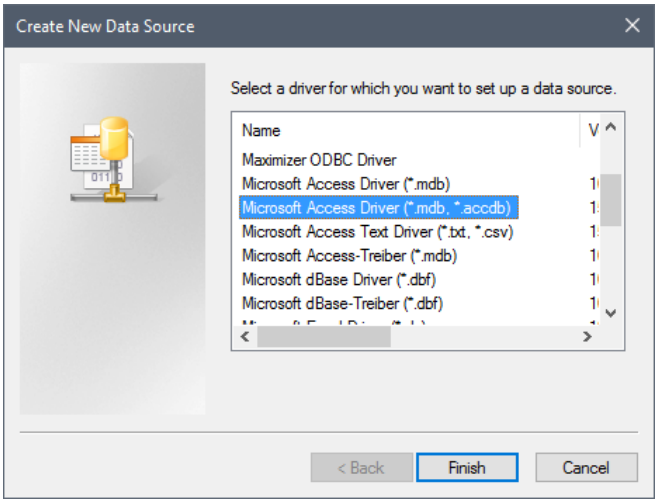
Warning: There will also be an option for 64-bit. It is important that you select the 32-bit option.

2. If your select that option, a dialog similar to the one shown below will be displayed:



You can define your database(s) as either 'User DSN' or 'System DSN', depending whether you want it to be private or public, respectively.

3. Add a data source by pressing the **Add…** button., which will display a dialog like this:



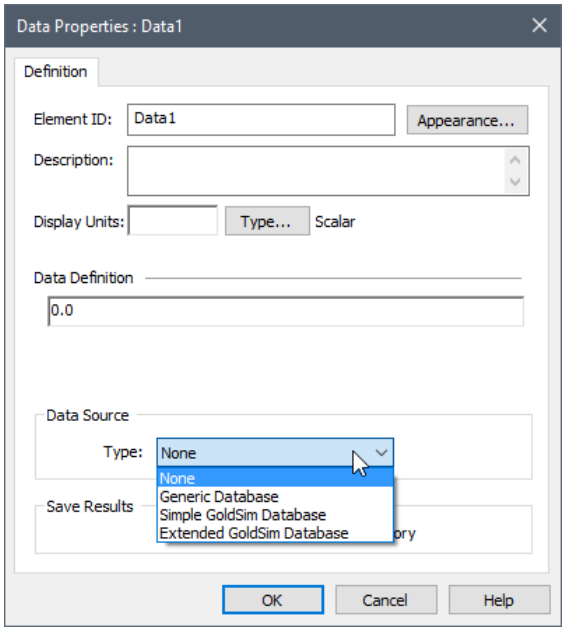
4. Select a driver with the same file extension as your database and press **Finish** (the driver selected above is for Microsoft Access). A dialog is displayed (the dialog will differ for each driver). You will be prompted to assign a name to the data source, and select the specific file (i.e., a database file).

Once you have created the data source, you can reference it from within GoldSim.

Downloading Element Definitions from a Database

After defining the database and creating the data source, you must then link the database to specific elements and download the data.

In order to link a specific element to the database, you first select a database option from the **Data Source** field in the properties dialog for the element. This is typically found toward the bottom of the dialog:



You can also right-click on the element in the graphics pane or browser, and select **Connect to DataSource…**, which will display a menu for selecting the Data Source.

By default, the Data Source is "None" (i.e., the element is not linked to a database). To link to a database, you must select one of the database types from the drop-down list.

Note: Not all three database options are available in the drop-down list for all elements. For example, since a Stochastic cannot be linked to a Generic database, this option is not available for Stochastics in the **Database** tab.

When you do so, a **Database** tab is added to the element.

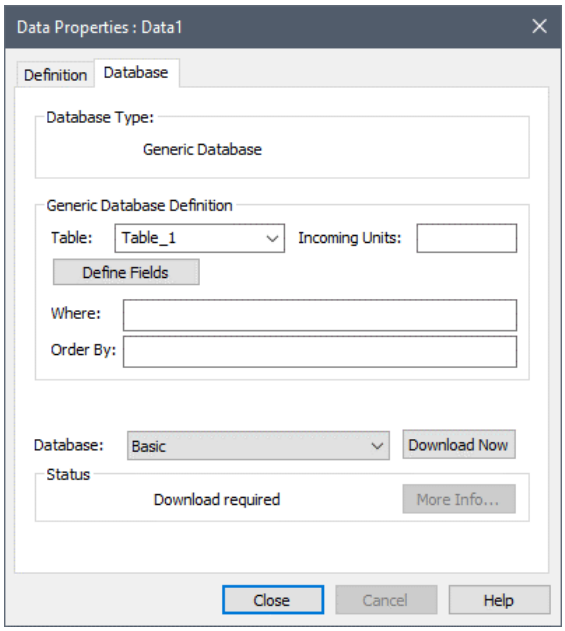
Three sample GoldSim files (GenericDatabase.gsm, SimpleDatabase.gsm, and Extended_Database.gsm) which illustrates the use of all three database types, are included in the General Examples/Database folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu). This folder also includes three sample databases referenced by these files (GenericDatabase.accdb, SimpleDatabase. accdb, and ExtendedDatabase. accdb). In order to use the GoldSim files, you will need to add the databases as data sources to your computer.

Read more: Adding Data Sources to Your Computer (page 1109).

Note: If you open a file which has elements linked to a database which GoldSim cannot find on your machine, it will prompt you to select from a list of databases that are registered on your machine. If none of these databases is appropriate, you must add a new data source to your computer. If you want GoldSim to check to see if it can find all of the databases referenced by elements in your model, press **Model | Database | Validate Databases**.

Downloading from a Generic Database

The following dialog is displayed when you specify a "Generic Database" for the **Data Source** for an element and click on the **Database** tab in the properties dialog for a Data element (the only element for which this type of data source can be specified):



As described in Appendix E, the Generic database format is very simple, and consists of a single table. To link to the database, you must specifically indicate the record and field you wish to access.

You link and download from a Generic database as follows:

1. Select the appropriate data source from the **Database** drop-down list (all defined data sources will be listed).
2. Select the appropriate table from the database from the **Table** drop-down list.
3. Press the **Define Fields** button in order to access a dialog for specifying which field(s) in the table contain the data. For scalar data, you will need to enter a single field (and this will be indicated at the top of the dialog). Vector and matrix data require multiple fields to be specified.
4. Specify which record (or for matrix data, records) in the table contain the data by specifying an appropriate condition in the **Where** input field.
5. Specify the incoming units of the data in the **Incoming Units** input field (using the appropriate GoldSim abbreviations for the units).
6. Press the **Download Now** button to download the data.

GoldSim notes whether the download was successful (and, if successful, displays the date and time of the download).

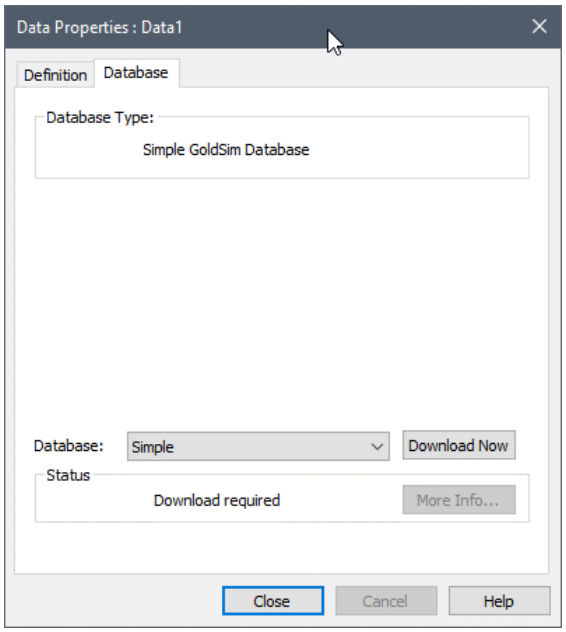
If you wish to download a vector, you must specify one record for each item in the vector. You identify the items of the vector using the **Where** input field. You must sort the records in the appropriate order using the **Order By** input field.

If you wish to download a matrix, you must specify one data field for each columns of the matrix (using the Define Fields dialog) and one record for each row of the matrix using the **Where** input field. The order of the fields (i.e., the columns of the matrix) is the order shown in the Define Fields dialog. You can use the **Move Up** button to modify the order. You must sort the records (i.e., the rows of the matrix) in the appropriate order using the **Order By** input field.

The file GenericDatabase.gsm in the General Examples/Database folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) includes examples of how to download a vector and a matrix from a Generic database.

Downloading from a Simple GoldSim Database

The following dialog is displayed when you specify a "Simple GoldSim Database" for the **Data Source** for an element and click on the **Database** tab in the properties dialog for a Data or Stochastic element (the two elements for which this type of data source can be specified):



As described in Appendix E, the Simple GoldSim database has a specific structure in which a string in a field in one of the database tables must uniquely match the ID of the element you wish to link to.

When you link an element to a Simple GoldSim database, GoldSim locates the data to download within the database by using the element's ID and path. Unlike a Generic database, you do not need to manually indicate the record and field you wish to access from within GoldSim.

In addition, the units of data being downloaded are specified directly in the database, and need not be identified on the **Database** tab (although they must be consistent with the specified dimensions for the element as defined on the **Definition** tab).

Note: Particular care must be taken when importing Stochastics from a database, as different Stochastics could have different dimensions (e.g., a Binomial is always dimensionless; a Boolean is always a condition). If a Stochastic is defined in your model as a particular type of distribution whose output is inconsistent with that of the distribution that you are trying to import from the database, GoldSim will display an error.

Note: Care must also be taken when importing Stochastics that represent temperatures. This is because temperatures have an absolute reference (i.e., absolute zero). *Differences* between temperatures are expressed in 'deg' units (Cdeg, Fdeg). This can lead to errors when importing Stochastics, since GoldSim assumes a single unit for the distribution parameters, while some types of distributions would require two different types of units. For example, a Normal distribution representing a temperature would require the Mean to be specified in absolute units (e.g., C) and the Standard Deviation to be specified in difference units (e.g., Cdeg). If faced with this problem, there are several approaches for addressing this: 1) Use a distribution type where all parameters have the same units (e.g., triangular, uniform, cumulative); or 2) Specify and import the distributions as dimensionless and then apply a unit to the sampled value using an Expression element.

Read more: Dealing with Temperature Units (page 92).

Because a Simple GoldSim database is so highly structured, if the database is properly defined, linking and downloading from it requires only two steps:

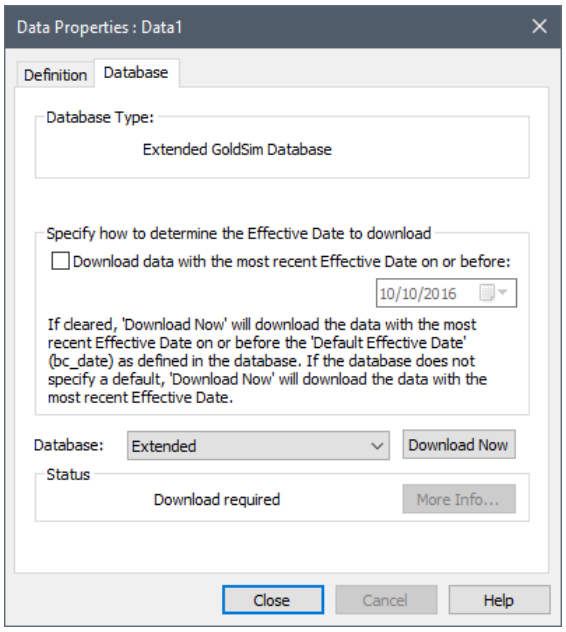
1. Select the appropriate data source from the **Database** drop-down list (all defined data sources will be listed).
2. Press the **Download Now** button to download the data.

GoldSim notes whether the download was successful (and, if successful, displays the date and time of the download).

The file SimpleDatabase.gsm in the General Examples/Database folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) includes examples of how to download data from a Simple GoldSim database.

Downloading from an Extended GoldSim Database

The following dialog is displayed when you specify an "Extended GoldSim Database" for the **Data Source** for an element and click on the **Database** tab in the properties dialog for Data, Stochastic or Lookup Table element (the three elements for which this type of data source can be specified):



As described in Appendix E, like the Simple GoldSim database, the Extended GoldSim database has a specific structure in which a string in a field in one of the database tables must uniquely match the ID of the element you wish to link to.

That is, when you link an element to an Extended GoldSim database, GoldSim locates the data to download within the database by using the element's ID. Unlike a Generic database, you do not need to manually indicate the record and field you wish to access from within GoldSim.

In addition, the units of data being downloaded are specified directly in the database, and need not be identified on the **Database** tab (although they must be consistent with the specified dimensions for the element as defined on the **Definition** tab).

Note: Particular care must be taken when importing Stochastics from a database, as different Stochastics could have different dimensions (e.g., a Binomial is always dimensionless; a Boolean is always a condition). If a Stochastic is defined in your model as a particular type of distribution whose output is inconsistent with that of the distribution that you are trying to import from the database, GoldSim will display an error.

Note: Care must also be taken when importing Stochastics that represent temperatures. This is because temperatures have an absolute reference (i.e., absolute zero). *Differences* between temperatures are expressed in 'deg' units (Cdeg, Fdeg). This can lead to errors when importing Stochastics, since GoldSim assumes a single unit for the distribution parameters, while some types of distributions would require two different types of units. For example, a Normal distribution representing a temperature would require the Mean to be specified in absolute units (e.g., C) and the Standard Deviation to be specified in difference units (e.g., Cdeg). If faced with this problem, there are several approaches for addressing this: 1) Use a distribution type where all parameters have the same units (e.g., triangular, uniform, cumulative); or 2) Specify and import the distributions as dimensionless and then apply a unit to the sampled value using an Expression element.

Read more: Dealing with Temperature Units (page 92).

Because an Extended GoldSim database is so highly structured, if the database is properly defined, linking and downloading from it requires only two steps:

1. Select the appropriate data source from the **Database** drop-down list (all defined data sources will be listed).
2. Press the **Download Now** button to download the data.

GoldSim notes whether the download was successful (and, if successful, displays the date and time of the download).

The **More info…** button provides some additional information regarding a successful download (the effective date and the Run Log strings associated with the data).

As discussed in detail in Appendix E, for an Extended GoldSim database, you can create multiple records for a particular item of data, each with a different "Effective Date". This allows you to keep a record of how particular inputs to your model have been modified.

The checkbox allows you to download data associated with a specific Effective Date:

- If checked, you must specify a date, and **Download Now** will download the data with the most recent Effective Date on or before the specified date.
- If cleared, **Download Now** will download the data with the most recent Effective Date on or before the default Effective Date for the element, as specified in the GS_Parameter table of the database (described in Appendix E).
- If cleared and no default Effective Date is specified in the database for the element, **Download Now** will download the data with the most recent Effective Date

Note: As pointed out above, when you link an element to an Extended GoldSim database, GoldSim locates the data to download by using the element's ID alone (no path is specified in the database). Hence, in order for GoldSim to download the element's definition from the database, a record in the Element ID field of the database must match the GoldSim element ID exactly (although the comparison is not case-sensitive). This implies that you cannot have multiple elements with identical names (e.g. , in two localized containers) which are both being linked to an Extended GoldSim database.

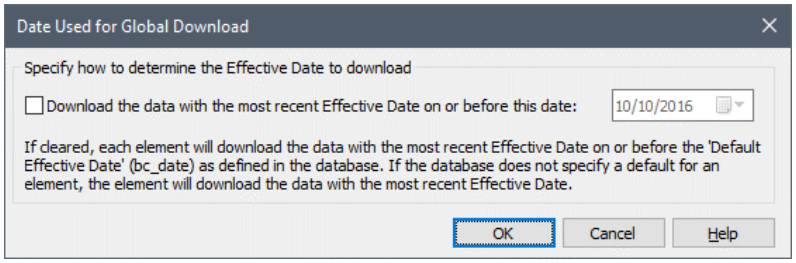
The file ExtendedDatabase.gsm in the General Examples/Database folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) includes examples of how to download data from an Extended GoldSim database.

Globally Downloading Elements from a Database

In addition to downloading each element's definition individually from a database, you can also globally download all element definitions by pressing the Database Download button from the Standard toolbar:

Yo can also select **Model | Database | Database Download** from the main menu.

If any of your elements are linked to an Extended GoldSim database, you are prompted to specify which Effective Date should be used for each of those elements:



The checkbox activates a Date field:

- If checked, you must specify a date, and each element will download the data with the most recent Effective Date on or before the specified date.
- If cleared, each element will download the data with the most recent Effective Date on or before the default Effective Date for the element, as specified in the GS_Parameter table of the database (described in Appendix E).
- If cleared and no default Effective Date is specified in the database for an element, each element will download the data with the most recent Effective Date.

If one or more of the downloads fail, a dialog will appear summarizing the elements for which the download failed.

Modifying Downloaded Data

While an element is linked to a database, you cannot access or edit the data. After you have downloaded data, however, you can choose to "uncouple" the element from the database by selecting the “No Database” option in the

Database tab. When you do this, you will be able to view and edit the values downloaded from the database.

References

Embrechts, Paul., Lindskog, Filip and Alexander McNeil, 2001, "Modelling Dependence with Copulas and Applications to Risk Management," Department of Mathematics, Swiss Federal Institute of Technology, Zurich (http://www.defaultrisk.com/pp_corr_19.htm).

Dorey, Martyn, 2006, "Why Aren't Copulas Far More Popular?", Professional Investor, February 2006 (http://www.psolve.com/news/200602_Martyn%20Dorey%20article.pdf).

Appendix A: Introduction to Probabilistic Simulation

> Our knowledge of the way things work, in society or in nature, comes trailing clouds of vagueness. Vast ills have followed a belief in certainty.
>
> Kenneth Arrow, *I Know a Hawk from a Handsaw*

Appendix Overview

This appendix provides a very brief introduction to probabilistic simulation (the quantification and propagation of uncertainty). Because detailed discussion of this topic is well beyond the scope of this appendix, readers who are unfamiliar with this field are strongly encouraged to consult additional literature. A good introduction to the representation of uncertainty is provided by Finkel (1990) and a more detailed treatment is provided by Morgan and Henrion (1990). The basic elements of probability theory are discussed in Harr (1987) and more detailed discussions can be found in Benjamin and Cornell (1970) and Ang and Tang (1984).

In this Appendix

This appendix discusses the following:

- Types of Uncertainty
- Quantifying Uncertainty
- Propagating Uncertainty
- A Comparison of Probabilistic and Deterministic Analyses
- References

Types of Uncertainty

Many of the features, events and processes which control the behavior of a complex system will not be known or understood with certainty. Although there are a variety of ways to categorize the sources of this uncertainty, for the purpose of this discussion it is convenient to consider the following four types:

- Value (parameter) uncertainty: The uncertainty in the value of a particular parameter (e.g., a geotechnical property, or the development cost of a new product);
- Uncertainty regarding future events: The uncertainty in the ability to predict future perturbations of the system (e.g., a strike, an accident, or an earthquake).
- Conceptual model uncertainty: The uncertainty regarding the detailed understanding and representation of the processes controlling a particular system (e.g., the complex interactions controlling the flow rate in a river); and
- Numerical model uncertainty: The uncertainty introduced by approximations in the computational tool used to evaluate the system.

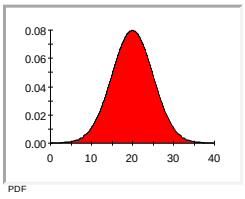
Incorporating these uncertainties into the predictions of system behavior is called *probabilistic analysis* or in some applications, *probabilistic performance assessment*. Probabilistic analysis consists of explicitly representing the uncertainty in the parameters, processes and events controlling the system and propagating this uncertainty through the system such that the uncertainty in the results (i.e., predicted future performance) can be quantified.

Quantifying Uncertainty

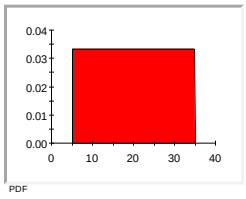
Understanding Probability Distributions

When uncertainty is quantified, it is expressed in terms of ***probability distributions***. A probability distribution is a mathematical representation of the relative likelihood of an uncertain variable having certain specific values.

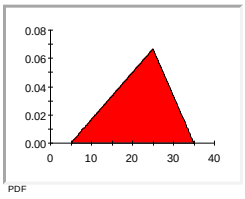
There are many types of probability distributions. Common distributions include the normal, uniform and triangular distributions, illustrated below:



Normal Distribution



Uniform Distribution



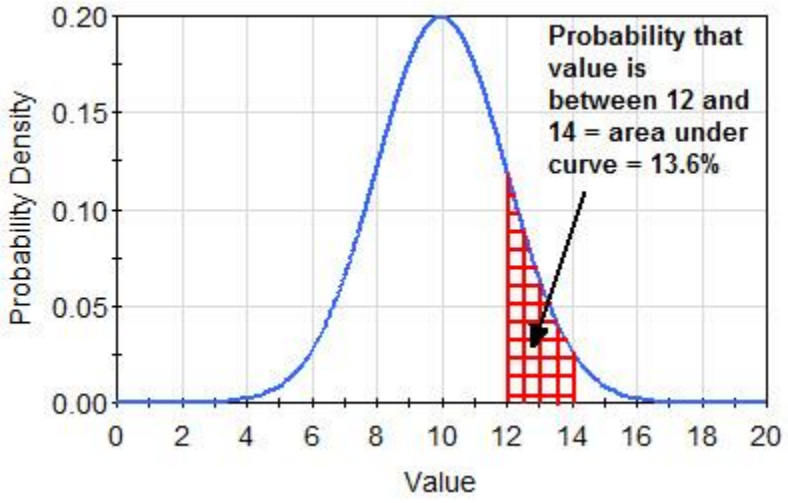
Triangular Distribution

All distribution types use a set of *arguments* to specify the relative likelihood for each possible value. For example, the normal distribution uses a ***mean*** and a ***standard deviation*** as its arguments. The mean defines the value around which the bell curve will be centered, and the standard deviation defines the spread of values around the mean. The arguments for a uniform distribution are a minimum and a maximum value. The arguments for a triangular distribution are a minimum value, a most likely value, and a maximum value.

The nature of an uncertain parameter, and hence the form of the associated probability distribution, can be either *discrete* or *continuous*. Discrete distributions have a limited (discrete) number of possible values (e.g., 0 or 1; yes

or no; 10, 20, or 30). Continuous distributions have an infinite number of possible values (e.g., the normal, uniform and triangular distributions shown above are continuous). Good overviews of commonly applied probability distributions are provided by Morgan and Henrion (1990) and Stephens et al. (1993).

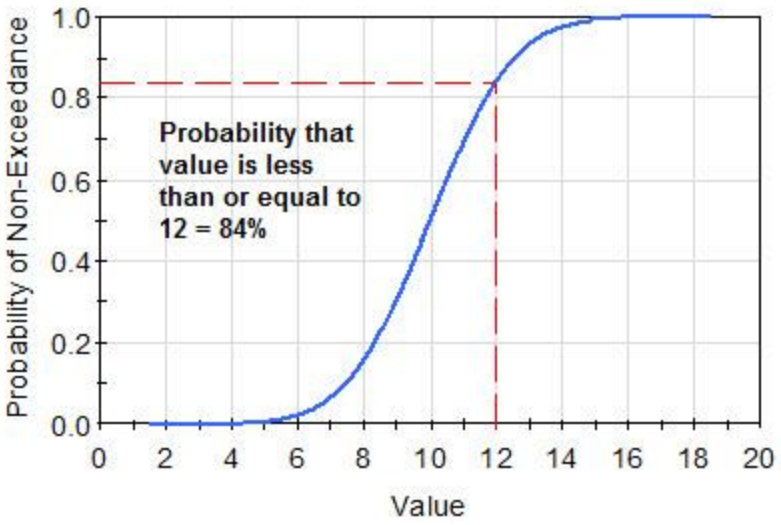
There are a number of ways in which probability distributions can be graphically displayed. The simplest way is to express the distribution in terms of a ***probability density function*** (PDF), which is how the three distributions shown above are displayed. In simple terms, this plots the relative likelihood of the various possible values, and is illustrated schematically below:



Note that the "height" of the PDF for any given value is *not* a direct measurement of the probability. Rather, it represents the *probability density*, such that integrating under the PDF between any two points results in the probability of the actual value being between those two points.

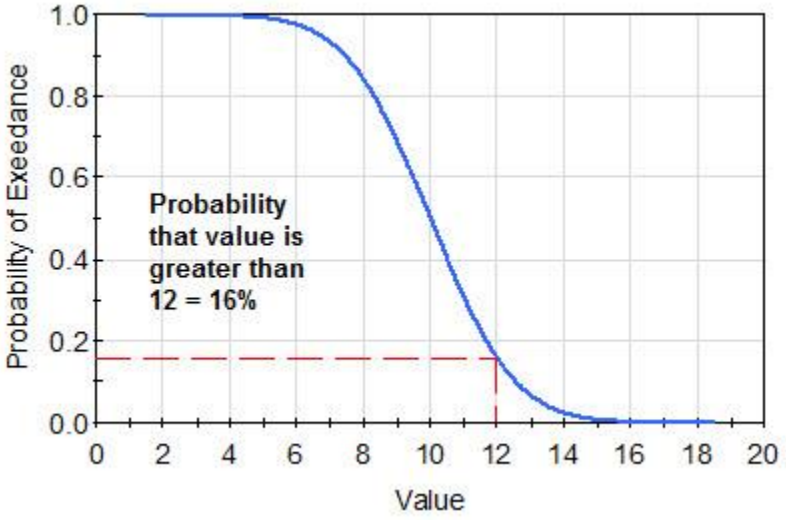
Note: Discrete distributions are described mathematically using probability mass functions (pmf), rather than probability density functions. Probability mass functions specify actual probabilities for given values, rather than probability densities.

An alternative manner of representing the same information contained in a PDF is the ***cumulative distribution function*** (CDF). This is formed by integrating over the PDF (such that the slope of the CDF at any point equals the height of the PDF at that point). For any value on the horizontal axis, the CDF shows the cumulative probability that the variable will be less than or equal to that value. That is, as shown below, a particular point, say [12, 0.84], on the CDF is interpreted as follows: the probability that the value is less than or equal to 12 is equal to 0.84 (84%).



By definition, the total area under the PDF must integrate to 1.0, and the CDF therefore ranges from 0.0 to 1.0.

A third manner of presenting this information is the ***complementary cumulative distribution function*** (CCDF). The CCDF is illustrated schematically below:



A particular point, say [12, 0.16], on the CCDF is interpreted as follows: the probability that the value is greater than 12 is 0.16 (16%). Note that the CCDF is simply the complement of the CDF; that is, in this example 0.84 is equal to 1 – 0.16.

Probability distributions are often described using *quantiles* or *percentiles* of the CDF. Percentiles of a distribution divide the total frequency of occurrence into hundredths. For example, the 90th percentile is that value of the parameter below which 90% of the distribution lies. The 50th percentile is referred to as the ***median***.

Characterizing Distributions

Probability distributions can be characterized by their *moments*. The first moment is referred to as the ***mean*** or ***expected value***, and is typically denoted as μ. For a continuous distribution, it is computed as follows:

$$\mu = \int x\, f(x)\, dx$$

where f(x) is the probability density function (PDF) of the variable. For a discrete distribution, it is computed as:

$$\mu = \sum_{i=1}^{N} x_i p(x_i)$$

in which $p(x_i)$ is the probability of x_i, and N is the total number of discrete values in the distribution.

Additional moments of a distribution can also be computed. The nth moment of a continuous distribution is computed as follows:

$$\mu_n = \int (x - \mu)^n f(x)\, dx$$

For a discrete distribution, the nth moment is computed as:

$$\mu_n = \sum_{i=1}^{N} (x_i - \mu)^n p(x_i)$$

The second moment is referred to as the ***variance***, and is typically denoted as σ^2. The square root of the variance, σ, is referred to as the ***standard deviation***. The variance and the standard deviation reflect the amount of spread or dispersion in the distribution. The ratio of the standard deviation to the mean provides a dimensionless measure of the spread, and is referred to as the ***coefficient of variation***.

The ***skewness*** is a dimensionless number computed based on the third moment:

$$\text{skewness} = \frac{\mu_3}{\sigma^3}$$

The skewness indicates the symmetry of the distribution. A normal distribution (which is perfectly symmetric) has a skewness of zero. A positive skewness indicates a shift to the right (and example is the log-normal distribution). A negative skewness indicates a shift to the left.

The ***kurtosis*** is a dimensionless number computed based on the fourth moment:

$$\text{kurtosis} = \frac{\mu_4}{\sigma^4}$$

The kurtosis is a measure of how "fat" a distribution is, measured relative to a normal distribution with the same standard deviation. A normal distribution has a kurtosis of zero. A positive kurtosis indicates that the distribution is more "peaky" than a normal distribution. A negative kurtosis indicates that the distribution is "flatter" than a normal distribution.

Specifying Probability Distributions

Given the fact that probability distributions represent the means by which uncertainty can be quantified, the task of quantifying uncertainty then becomes a matter of assigning the appropriate distributional forms and arguments to the uncertain aspects of the system. Occasionally, probability distributions can be defined by fitting distributions to data collected from experiments or other data collection efforts. For example, if one could determine that the uncertainty in a particular parameter was due primarily to random measurement errors, one might simply attempt to fit an appropriate distribution to the available data.

Most frequently, however, such an approach is not possible, and probability distributions must be based on *subjective assessments* (Bonano et al., 1989; Roberds, 1990; Kotra et al., 1996). Subjective assessments are opinions and judgments about probabilities, based on experience and/or knowledge in a

specific area, which are consistent with available information. The process of developing these assessments is sometimes referred to as *expert elicitation*. Subjectively derived probability distributions can represent the opinions of individuals or of groups. There are a variety of methods for developing subjective probability assessments, ranging from simple informal techniques to complex and time-consuming formal methods. It is beyond the scope of this document to discuss these methods. Roberds (1990), however, provides an overview, and includes a list of references. Morgan and Henrion (1990) also provide a good discussion on the topic.

A key part of all of the various approaches for developing subjective probability assessments is a methodology for developing (and justifying) an appropriate probability distribution for a parameter in a manner that is logically and mathematically consistent with the level of available information. Discussions on the applicability of various distribution types are provided by Harr (1987, Section 2.5), Stephens et al. (1993), and Seiler and Alvarez (1996). Note that methodologies (Bayesian updating) also exist for updating an existing probability distribution when new information becomes available (e.g., Dakins, et al., 1996).

Correlated Distributions

Frequently, parameters describing a system will be *correlated* (inter-dependent) to some extent. For example, if one were to plot frequency distributions of the height and the weight of the people in an office, there would likely be some degree of positive correlation between the two: taller people would generally also be heavier (although this correlation would not be perfect).

The degree of correlation can be measured using a ***correlation coefficient***, which varies between 1 and -1. A correlation coefficient of 1 or -1 indicates perfect positive or negative correlation, respectively. A positive correlation indicates that the parameters increase or decrease together. A negative correlation indicates that increasing one parameter decreases the other. A correlation coefficient of 0 indicates no correlation (the parameters are apparently independent of each other). Correlation coefficients can be computed based on the actual values of the parameters (which measures linear relationships) or the rank-order of the values of the parameters (which can be used to measure non-linear relationships).

One way to express correlations in a system is to directly specify the correlation coefficients between various model parameters. In practice, however, assessing and quantifying correlations in this manner is difficult. Oftentimes, a more practical way of representing correlations is to explicitly model the cause of the dependency. That is, the analyst adds detail to the model such that the underlying functional relationship causing the correlation is directly represented.

For example, one might be uncertain regarding the solubility of two contaminants in water, while knowing that the solubilities tend to be correlated. If the main source of this uncertainty was actually uncertainty in pH conditions, and the solubility of each contaminant was expressed as a function of pH, the distributions of the two solubilities would then be explicitly correlated. If both solubilities increased or decreased with increasing pH, the correlation would be positive. If one decreased while one increased, the correlation would be negative.

Ignoring correlations, particularly if they are very strong (i.e., the absolute value of the correlation coefficient is close to 1) can lead to physically unrealistic simulations. In the above example, if the solubilities of the two contaminants were positively correlated (e.g., due to a pH dependence), it would be physically inconsistent for one contaminant's solubility to be selected from the high end of its possible range while the other's was selected from the low end of its possible

range. Hence, when defining probability distributions, it is critical that the analyst determine whether correlations need to be represented.

Variability and Ignorance

When quantifying the uncertainty in a system, there are two fundamental causes of uncertainty which are important to distinguish: 1) that due to inherent variability; and 2) that due to ignorance or lack of knowledge. IAEA (1989) refers to the former as "Type A uncertainty" and the latter as "Type B uncertainty". These are also sometimes referred to as *aleatory* and *epistemic* uncertainty, respectively.

Aleatory uncertainty results from the fact that many parameters are inherently variable (random or noisy) over time such that their behavior can only be described statistically. Examples include the flow rate in a river, the price of a stock or the temperature at a particular location.

Variability in a parameter can be expressed using *frequency distributions*. A frequency distribution displays the relative frequency of a particular value versus the value. For example, one could sample the flow rate of a river once an hour for a week, and plot a frequency distribution of the hourly flow rate (the x-axis being the flow rate, and the y-axis being the frequency of the observation over the week).

Other parameters are not inherently variable over time, but cannot be specified precisely due to epistemic uncertainty: we lack sufficient information or knowledge to specify their value with certainty. Examples include the strength of a particular material, the mass of a planet, or the efficacy of a new drug.

A fundamental difference between these two types of uncertainty is that epistemic uncertainty (i.e., resulting from lack of knowledge) can theoretically be reduced by studying the parameter or system. That is, since the variability is due to a lack of knowledge, theoretically that knowledge could be improved by carrying out experiments, collecting data or doing research. Aleatory uncertainty, on the other hand, is inherently irreducible. If the parameter itself is inherently variable, studying the parameter further will certainly not do anything to change that variability. This is important because one of the key purposes of probabilistic simulation modeling is not just to make predictions, but to identify those parameters that are contributing the most to the uncertainty in results. If the uncertainty in the results is due primarily to epistemic parameters, we know that we could (at least theoretically) reduce our uncertainty in our results by gaining more information about those parameters.

It should be noted that parameters which have both kinds of uncertainty are not uncommon in simulation models. For example, in considering the flow rate in a river, we know that it will be temporally variable (inherently random in time so it can only be described statistically), but in the absence of adequate data, we will have uncertainty about the statistical measures (e.g., mean, standard deviation) describing that variability. By taking measurements, we can reduce our uncertainty in these statistical measures (i.e., what is the mean flow rate?), but we will not be able to reduce the inherent variability in the flow.

Note that some quantities are variable not over time, but over space or within a collection of items or instances. An example is the age of population. If you had a group of 1000 individuals, you could obtain the age of each individual and create a frequency distribution of the age of the group. This kind of distribution is similar to the example of the flow rate in a river discussed above in that both are described using frequency distributions (one showing a frequency in time, and one showing a frequency of occurrence within a group). The age example, however, is fundamentally different from an inherently random parameter. Whereas a distribution representing an inherently random parameter truly is

describing uncertainty (we cannot predict the value at any given time), a distibution representing the age distribution is not describing uncertainty at all. It is simply describing a variability within the group that we could actually measure and define very precisely.

It is critical not to combine variability like this with uncertainty and represent both using a single distribution. For example, suppose that you needed to represent the efficacy of a new drug. The efficacy is different for different age groups. Moreover, for each age group, there is scientific uncertainty regarding its efficacy. A common mistake would be to define a single probability distribution that represents both the variability due to age and the uncertainty due to lack of knowledge. Not only would it be difficult to define the shape of such a distribution in the first place, this would produce simulation results that would be difficult, if not impossible, to interpret in a meaningful way. The correct way to handle such a situation would be to disaggregate the problem (by explicitly modeling each age group separately) and then define different probability distributions for each age group (with each distribution representing only the scientific uncertainty in the efficacy for that age group).

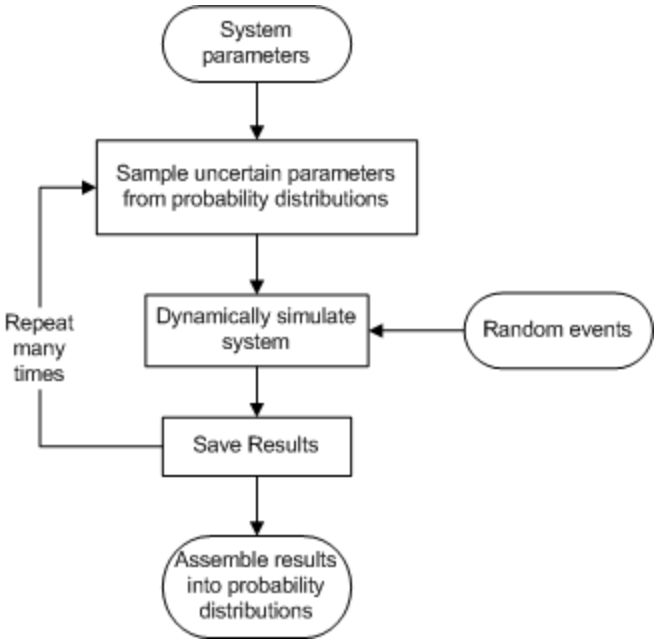
Propagating Uncertainty

If the inputs describing a system are uncertain, the prediction of the future performance of the system is necessarily uncertain. That is, the result of any analysis based on inputs represented by probability distributions is itself a probability distribution.

In order to compute the probability distribution of predicted performance, it is necessary to *propagate* (translate) the input uncertainties into uncertainties in the results. A variety of methods exist for propagating uncertainty. Morgan and Henrion (1990) provide a relatively detailed discussion on the various methods.

One common technique for propagating the uncertainty in the various aspects of a system to the predicted performance (and the one used by GoldSim) is ***Monte Carlo simulation***. In Monte Carlo simulation, the entire system is simulated a large number (e.g., 1000) of times. Each simulation is equally likely, and is referred to as a ***realization*** of the system. For each realization, all of the uncertain parameters are sampled (i.e., a single random value is selected from the specified distribution describing each parameter). The system is then simulated through time (given the particular set of input parameters) such that the performance of the system can be computed.

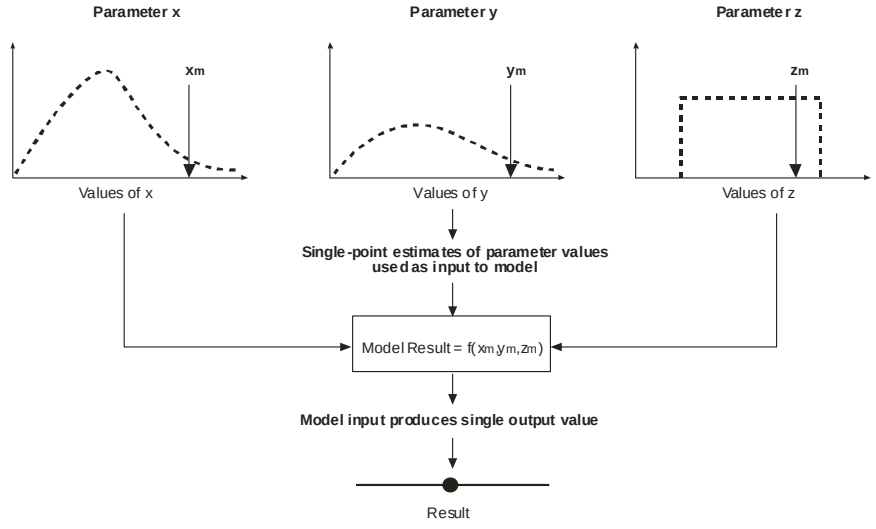
This results in a large number of separate and independent results, each representing a possible "future" for the system (i.e., one possible path the system may follow through time). The results of the independent system realizations are assembled into probability distributions of possible outcomes. A schematic of the Monte Carlo method is shown below:



A Comparison of Probabilistic and Deterministic Simulation Approaches

Having described the basics of probabilistic analysis, it is worthwhile to conclude this appendix with a comparison of probabilistic and ***deterministic*** approaches to simulation, and a discussion of why GoldSim was designed to specifically facilitate both of these approaches.

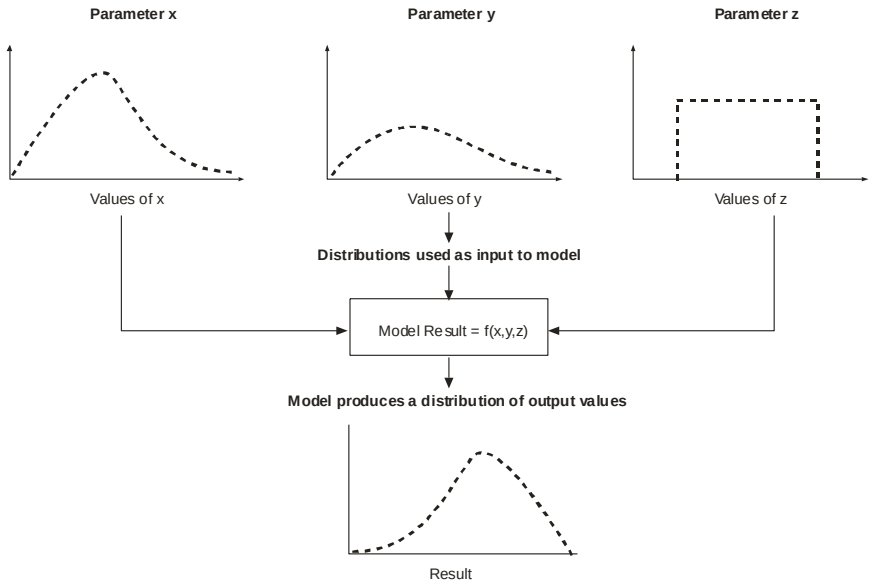
The figure below shows a schematic representation of a deterministic modeling approach:



In the deterministic approach, the analyst, although he/she may implicitly recognize the uncertainty in the various input parameters, selects single values

for each parameter. Typically, these are selected to be "best estimates" or sometimes "worst case estimates". These inputs are evaluated using a simulation model, which then outputs a single result, which presumably represents a "best estimate" or "worst case estimate".

The figure below shows a similar schematic representation of a probabilistic modeling approach:



In this case the analyst explicitly represents the input parameters as probability distributions, and propagates the uncertainty through to the result (e.g., using the Monte Carlo method), such that the result itself is also a probability distribution.

One advantage to deterministic analyses is that they can typically incorporate more detailed components than probabilistic analyses due to computational considerations (since complex probabilistic analyses generally require time-consuming simulation of multiple realizations of the system).

Deterministic analyses, however, have a number of disadvantages:

- *"Worst case" deterministic simulations can be extremely misleading*. Worst case simulations of a system may be grossly conservative and therefore completely unrealistic (i.e., they typically have an extremely low probability of actually representing the future behavior of the system). Moreover, it is not possible in a deterministic simulation to quantify how conservative a "worst case" simulation actually is. Using a highly improbable simulation to guide policy making (e.g., "is the design safe?") is likely to result in poor decisions.
- *"Best estimate" deterministic simulations are often difficult to defend*. Because of the inherent uncertainty in most input parameters, defending "best estimate" parameters is often very difficult. In a confrontational environment, "best estimate" analyses will typically evolve into "worst case" analyses.
- *Deterministic analyses do not lend themselves directly to detailed uncertainty and sensitivity studies*. In order to carry out uncertainty and

sensitivity analysis of deterministic simulations, it is usually necessary to carry out a series of separate simulations in which various parameters are varied. This is time-consuming and typically results only in a limited analysis of sensitivity and uncertainty.

These disadvantages do not exist for probabilistic analyses. Rather than facing the difficulties of defining worst case or best estimate inputs, probabilistic analyses attempt to explicitly represent the full range of possible values. The probabilistic approach embodied within GoldSim acknowledges the fact that for many complex systems, predictions are inherently uncertain and should always be presented as such. Probabilistic analysis provides a means to present this uncertainty in a quantitative manner.

Moreover, the output of probabilistic analyses can be used to directly determine parameter sensitivity. Because the output of probabilistic simulations consists of multiple sets of input parameters and corresponding results, the sensitivity of results to various input parameters can be directly determined. The fact that probabilistic analyses lend themselves directly to evaluation of parameter sensitivity is one of the most powerful aspects of this approach, allowing such tools to be used to aid decision-making.

There are, however, some potential disadvantages to probabilistic analyses that should also be noted:

- *Probabilistic analyses may be perceived as unnecessarily complex, or unrealistic.* Although this sentiment is gradually becoming less prevalent as probabilistic analyses become more common, it cannot be ignored. It is therefore important to develop and present probabilistic analyses in a manner that is straightforward and transparent. In fact, GoldSim was specifically intended to minimize this concern.

- *The process of developing input for a probabilistic analysis can sometimes degenerate into futile debates about the "true" probability distributions.* This concern can typically be addressed by simply repeating the probabilistic analysis using alternative distributions. If the results are similar, then there is not necessity to pursue the "true" distributions further.

- *The public (courts, media, etc.) typically does not fully understand probabilistic analyses and may be suspicious of it*. This may improve as such analyses become more prevalent and the public is educated, but is always likely to be a problem. As a result, complementary deterministic simulations will always be required in order to illustrate the performance of the system under a specific set of conditions (e.g., "expected" or "most likely" conditions).

As this last point illustrates, it is important to understand that use of a probabilistic analysis does not preclude the use of deterministic analysis. In fact, deterministic analyses of various system components are often essential in order to provide input to probabilistic analyses. The key point is that for many systems, deterministic analyses *alone* can have significant disadvantages and in these cases, they should be complemented by probabilistic analyses.

References

The references cited in this appendix are listed below.

Ang, A. H-S. and W.H. Tang, 1984, Probability Concepts in Engineering Planning and Design, Volume II: Decision, Risk, and Reliability, John Wiley & Sons, New York.

Bonano, E.J., S.C. Hora, R.L. Keaney and C. von Winterfeldt, 1989, Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories, Sandia Report SAND89-1821, Sandia National Laboratories.

Benjamin, J.R. and C.A. Cornell, 1970, Probability, Statistics, and Decision for Civil Engineers, McGraw-Hill, New York.

Dakins, M.E., J.E. Toll, M.J. Small and K.P. Brand, 1996, *Risk-Based Environmental Remediation: Bayesian Monte Carlo Analysis and the Expected Value of Sample Information*, Risk Analysis, Vol. 16, No. 1, pp. 67-79.

Finkel, A., 1990, Confronting Uncertainty in Risk Management: A Guide for Decision-Makers, Center for Risk Management, Resources for the Future, Washington, D.C.

Harr, M.E., 1987, Reliability-Based Design in Civil Engineering, McGraw-Hill, New York.

IAEA, 1989, Evaluating the Reliability of Predictions Made Using Environmental Transfer Models, IAEA Safety Series No. 100, International Atomic Energy Agency, Vienna.

Kotra, J.P., M.P. Lee, N.A. Eisenberg, and A.R. DeWispelare, 1996, *Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program*, Draft manuscript, February 1996, U.S. Nuclear Regulatory Commission.

Morgan, M.G. and M. Henrion, 1990, Uncertainty, Cambridge University Press, New York.

Roberds, W.J., 1990, *Methods for Developing Defensible Subjective Probability Assessments*, Transportation Research Record, No. 1288, Transportation Research Board, National Research Council, Washington, D.C., January 1990.

Seiler, F.A and J.L. Alvarez, 1996, *On the Selection of Distributions for Stochastic Variables*, Risk Analysis, Vol. 16, No. 1, pp. 5-18.

Stephens, M.E., B.W. Goodwin and T.H. Andres, 1993, *Deriving Parameter Probability Density Functions*, Reliability Engineering and System Safety, Vol. 42, pp. 271-291.

Appendix B: Probabilistic Simulation Details

Clever liars give details, but the cleverest don't.

Anonymous

Appendix Overview

This appendix provides the mathematical details of how GoldSim represents and propagates uncertainty, and the manner in which it constructs and displays probability distributions of computed results. While someone who is not familiar with the mathematics of probabilistic simulation should find this appendix informative and occasionally useful, most users need not be concerned with these details. Hence, this appendix is primarily intended for the serious analyst who is quite familiar with the mathematics of probabilistic simulation and wishes to understand the specific algorithms employed by GoldSim.

In this Appendix

This appendix discusses the following:

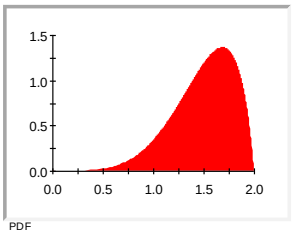
- Mathematical Representation of Probability Distributions
- Correlation Algorithms
- Sampling Techniques
- Representing Random (Poisson) Events
- Computing and Displaying Result Distributions
- Computing Sensitivity Analysis Measures
- References

Mathematical Representation of Probability Distributions

Distributional Forms

The arguments, probability density (or mass) function (pdf or pmf), cumulative distribution function (cdf), and the mean and variance for each of the probability distributions available within GoldSim are presented below.

Beta Distribution



The beta distribution for a parameter is specified by a minimum value (a), a maximum value (b), and two shape parameters denoted S and T. The beta distribution represents the distribution of the underlying probability of success for a binomial sample, where S represents the observed number of successes in a binomial trial of T total draws.

Alternative formulations of the beta distribution use parameters α and β, or α_1 and α_2, where S = α = α_1 and (T-S) = β = α_2.

Frequently the Beta distribution is also defined in terms of a minimum, maximum, mean, and standard deviation. The shape parameters are then computed from these statistics.

The beta distribution has many variations controlled by the shape parameters. It is always limited to the interval (a,b). Within (a,b), however, a variety of distribution forms are possible (e.g., the distribution can be configured to behave exponentially, positively or negatively skewed, and symmetrically). The distribution form obtained by different S and T values is predictable for a skilled user.

pdf: $$f(x) = \frac{1}{B(b-a)^{T-1}}(x-a)^{S-1}(b-x)^{T-S-1}$$

where: $$B = \frac{\Gamma(S)\Gamma(T-S)}{\Gamma(T)}$$

$$\Gamma(k) = \int_0^\infty e^{-u}u^{k-1}du$$

cdf: No closed form

mean: $$\mu = a + \frac{S}{T}(b-a)$$

variance: $$\sigma^2 = (b-a)^2\frac{S(T-S)}{T^2(T+1)}$$

Note that within GoldSim, there are three ways to define a Beta distribution. You can choose to specify S and T (Beta Distribution). Alternatively, you can specify a mean, standard deviation, minimum and maximum, as defined above (Generalized Beta Distribution). In this case, GoldSim limits the standard deviations that can be specified as follows:

$$\sigma^* <= 0.6\sqrt{\mu^*(1-\mu^*)}$$

where $\mu^* = \frac{\mu - a}{b - a}$, $\sigma^* = \frac{\sigma}{b - a}$

This constraint ensures that the distribution has a single peak and that it does not have a discrete probability mass at either end of its range.

Finally, you can specify a minimum (a), maximum (b) and most likely value (c) (BetaPERT distribution). In this case, GoldSim assumes shape parameters are as follows:

$$\alpha = 1 + 4c_n$$

$$\beta = 5 - 4c_n$$

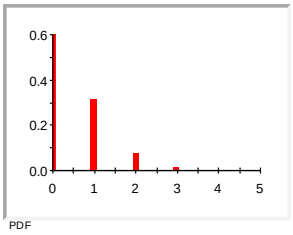
where

$$c_n = \frac{c - a}{b - a}$$

Note that in this case, the most likely value specified by the user is not mathematically the most likely value (but is a very close approximation to it).

Note that if the BetaPert is defined using the 10th and 90th percentile (instead of a minimum and a maximum) the minimum and maximum are estimated through iteration.

Binomial Distribution



The binomial distribution is a discrete distribution specified by a batch size (n) and a probability of occurrence (p). This distribution can be used to model the number of parts that failed from a given set of parts, where n is the number of parts and p is the probability of the part failing.

pmf: $$P(x) = \binom{n}{x} p^x (1-p)^{n-x} \qquad x = 0, 1, 2, 3...$$

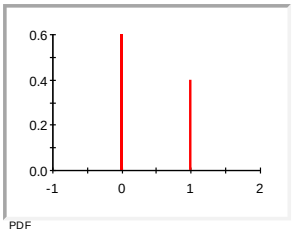
where: $$\binom{n}{x} = \frac{n!}{x!\,(n-x)!}$$

cdf: $$F(x) = \sum_{i=0}^{x} \binom{n}{i} p^i (1-p)^{n-i}$$

mean: np

variance: $np(1-p)$

Boolean Distribution



The Boolean (or logical) distribution requires a single input: the probability of being true, p. The distribution takes on one of two values: False (0) or True (1).

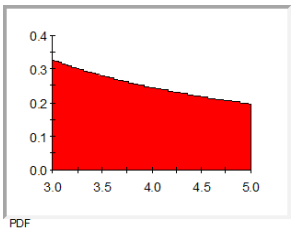
pmf: $P(x) = 1-p$ x=0; p x=1

cdf: $F(x) = 1-p$ x=0; 1 x=1

mean: $\mu = p$

variance: $\sigma^2 = p(1 - p)$

Cumulative Distribution



The cumulative distribution enables the user to input a piece-wise linear cumulative distribution function by simply specifying value (x_i) and cumulative probability (p_i) pairs.

GoldSim allows input of an unlimited number of pairs, x_i, p_i. In order to conform to a cumulative distribution function, it is a requirement that the first probability equal 0 and the last equal 1. The associated values, denoted x_0 and x_n, respectively, define the minimum value and maximum value of the distribution.

pdf:

$$f(x) = \begin{cases} 0 & x \le x_0 \text{ or } x \ge x_n \\ \dfrac{p_{i+1} - p_i}{x_{i+1} - x_i} & x_i \le x \le x_{i+1} \end{cases}$$

cdf:

$$F(x) = \begin{cases} 0 & x \le x_0 \\ p_i + (p_{i+1} - p_i)\dfrac{x - x_i}{x_{i+1} - x_i} & x_i \le x \le x_{i+1} \\ 1 & x \ge x_n \end{cases}$$

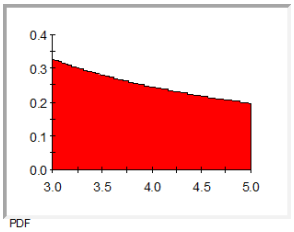
mean:

$$\mu \cong \sum_{i=1}^{n} x_i f(x_i)$$

variance:

$$\sigma^2 \cong \sum_{i=1}^{n} x_i^2 f(x_i) - \mu^2$$

Log- Cumulative Distribution



The log-cumulative distribution enables the user to input a piece-wise logarithmic cumulative distribution function by simply specifying value (x_i) and cumulative probability (p_i) pairs. Whereas in a cumulative distribution, the density between values is constant (i.e., the distribution between values is uniform), in a log-cumulative, the density of the *log* of the value is constant (i.e., the distribution between values is log-uniform).

GoldSim allows input of an unlimited number of pairs, x_i, p_i. In order to conform to a cumulative distribution function, it is a requirement that the first probability equal 0 and the last equal 1. The associated values, denoted x_0 and x_n, respectively, define the minimum value and maximum value of the distribution. Also, all values must be positive.

pdf:

$$f(x) = \begin{cases} 0 & x \le x_0 \text{ or } x \ge x_n \\ \dfrac{p_{i+1} - p_i}{x \ln(x_{i+1} / x_i)} & x_i \le x \le x_{i+1} \end{cases}$$

cdf:

$$F(x) = \begin{cases} 0 & x \le x_0 \\ p_i \dfrac{\ln(x_{i+1} / x)}{\ln(x_{i+1} / x_i)} + p_{i+1} \dfrac{\ln(x / x_i)}{\ln(x_{i+1} / x_i)} & x_i \le x \le x_{i+1} \\ 1 & x \ge x_n \end{cases}$$

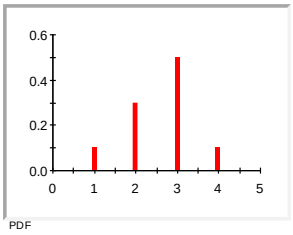
mean:

$$\mu \cong \sum_{i=1}^{n} \frac{(p_{i+1} - p_i)(x_{i+1} - x_i)}{\ln(x_{i+1} / x_i)}$$

variance:

$$\sigma^2 \cong \sum_{i=1}^{n} \frac{(p_{i+1} - p_i)(x_{i+1}^{\ 2} - x_i^{\ 2})}{2\ln(x_{i+1} / x_i)}$$

Discrete Distribution



The discrete distribution enables the user to directly input a probability mass function for a discrete parameter. Each discrete value, x_i, that may be assigned to the parameter, has an associated probability, p_i, indicating its likelihood to occur. To conform to the requirements of a probability mass function, the sum of the probabilities, p_i, must equal 1. The discrete distribution is commonly used for situations with a small number of possible outcomes, such as "flag" variables used to indicate the occurrence of certain conditions.

pmf:

$$P(x_i) = p_i \qquad x = x_i$$

cdf:

$$F(x_i) = \sum_{j=1}^{i \ge j} p_j$$

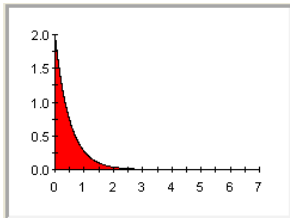
mean:

$$\mu \cong \sum_{i=1}^{n} x_i p_i$$

variance:

$$\sigma^2 \cong \sum_{i=1}^{n} x_i^2 p_i - \mu^2$$

Exponential Distribution



The Exponential distribution is a continuous distribution specified by a mean value (μ) which must be positive. This distribution is typically used to model the time required to complete a task or achieve a milestone.

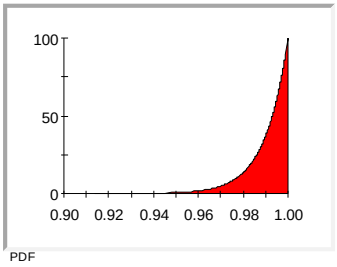
pdf: $$f(x)=\begin{cases}\frac{1}{\mu}e^{-\frac{x}{\mu}} & if \quad x \geq 0 \\ 0 & otherwise\end{cases}$$

cdf: $$F(x)=\begin{cases}1-e^{-\frac{x}{\mu}} & if \quad x \geq 0 \\ 0 & otherwise\end{cases}$$

mean: μ

variance: μ^2

Extreme Probabilty Distribution



The Extreme Probability distribution provides the expected extreme probability level of a uniform distribution given a specific number of samples. Both the Minimum and Maximum Extreme Probability Distributions are equivalent to the Beta distribution with the following parameters:

	Maximum	Minimum
S	Number of samples	1
(T-S)	1	Number of Samples

pdf: $$f(x) = \frac{1}{B(b-a)^{T-1}}(x-a)^{S-1}(b-x)^{T-S-1}$$

where: $$B = \frac{\Gamma(S)\Gamma(T-S)}{\Gamma(T)}$$

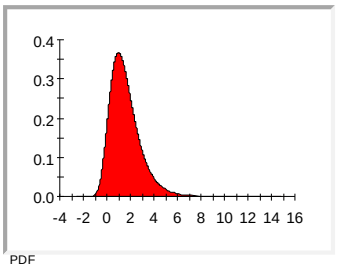
$$\Gamma(k) = \int_0^\infty e^{-u}u^{k-1}du$$

cdf: No closed form

mean: $$\mu = a + \frac{S}{T}(b-a)$$

variance: $$\sigma^2 = (b-a)^2\,\frac{S(T-S)}{T^2(T+1)}$$

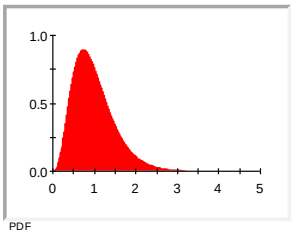
Extreme Value Distribution



The Extreme Value distribution (also known as the Gumbel distribution) is used to represent the maximum or minimum expected value of a variable. It is specified with the mode (m) and a scale parameter (s) that must be positive.

	Maximum	Minimum
pdf	$f(x) = \frac{z}{s}e^{-z}$ where $z = e^{\frac{-(x-m)}{s}}$	$f(x) = \frac{z}{s}e^{-z}$ where $z = e^{\frac{(x-m)}{s}}$
cdf	$F(x) = e^{-z}$	$F(x) = 1-e^{-z}$
mean	$\mu = m + 0.57722s$	$\mu = m - 0.57722s$
Variance	$\sigma^2 = \frac{(s\pi)^2}{6}$	$\sigma^2 = \frac{(s\pi)^2}{6}$

Gamma Distribution



The gamma distribution is most commonly used to model the time to the k^{th} event, when such an event is modeled by a Poisson process with rate parameter λ. Whereas the Poisson distribution is typically used to model the *number of events* in a period of given length, the gamma distribution models the *time to the k^{th} event* (or alternatively the time separating the k^{th} and $k^{th}+1$ events).

The gamma distribution is specified by the Poisson rate variable, λ , and the event number, k. The random variable, denoted as x, is the time period to the k^{th} event. Within GoldSim, the gamma distribution is specified by the mean and the standard deviation, which can be computed as a function of λ and k.

pdf: $$f(x)=\frac{\lambda(\lambda x)^{k-1}e^{-\lambda x}}{\Gamma(k)}$$

cdf: $$F(x)=\frac{\Gamma(k,\lambda x)}{\Gamma(k)}$$

where: $$\Gamma(k)=\int_0^\infty e^{-u}u^{k-1}du \qquad \text{(gamma function)}$$

$$\Gamma(k,x)=\int_0^x e^{-u}u^{k-1}du \qquad \text{(incomplete gamma function)}$$

$$k=\frac{\mu^2}{\sigma^2}$$

$$\lambda=\frac{\mu}{\sigma^2}$$

mean: μ

variance: σ^2

Note that

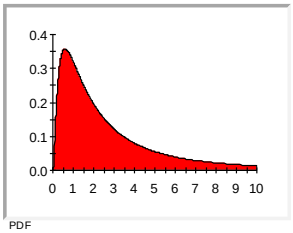
mean: k/λ

variance: k/λ^2

If k is near zero, the distribution is highly skewed. For k=1, the gamma distribution reduces to an exponential distribution with mean of 1/λ. If k=n/2 and λ= ½, the distribution is known as a chi-squared distribution with n degrees of freedom.

Note: If the mean value (in terms of SI units) is less than 1E-13 or the ratio of the standard deviation to the mean is less than 0.1, the gamma is approximated as a normal distribution (truncated such that it is never less than 0).

Log-Normal Distribution



The log-normal distribution is used when the *logarithm* of the random variable is described by a normal distribution. The log-normal distribution is often used to describe environmental variables that must be positive and are positively skewed.

In GoldSim, the log-normal distribution may be based on either the true mean and standard deviation, or on the geometric mean (identical to the median) and the geometric standard deviation. Thus, if the variable x is distributed log-normally, the mean and standard deviation of log x may be used to characterize the log-normal distribution. (Note that either *base 10* or *base e* logarithms may be used).

pdf: $$f(x) = \frac{1}{\zeta x \sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln(x)-\lambda}{\zeta}\right)^2}$$

where:

$$\zeta^2 = \ln\left[1+\left(\frac{\sigma}{\mu}\right)^2\right]$$ (variance of ln x);

ζ is referred to as the shape factor; and

$$\lambda = \ln(\mu) - \frac{1}{2}\zeta^2$$ (expected value of ln x)

cdf: No closed form solution

mean (arithmetic): $$\mu = \exp\left[\lambda + \frac{1}{2}\zeta^2\right]$$

The mean computed by the above formula is the expected value of the log-normally distributed variable x and is a function of the mean and standard deviation of lnx. The mean value can be estimated by the arithmetic mean of a sample data set.

variance (arithmetic): $$\sigma^2 = \mu^2\left[\exp\left(\zeta^2\right)-1\right]$$

The variance computed by the above formula is the variance of the log-normally distributed variable x. It is a function of the mean of x and the standard deviation of lnx. The variance of x can be estimated by the sample variance computed arithmetically.

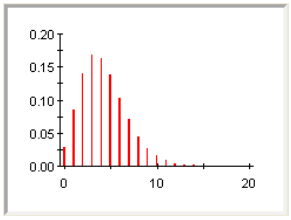
Other useful formulas:

Geometric mean = e^{λ}

Geometric standard deviation = e^{ζ}

A commonly used descriptor for a log-normal distribution is its Error Factor (EF), where the EF is defined as (geometric standard deviation) ^ 1.645. 90% of the distribution lies between Median/EF and Median*EF.

Negative Binomial Distribution



The negative binomial distribution is a discrete distribution specified by a number of successes (n), which can be fractional, and a probability of success (p). This distribution can be used to model the number of failures that occur when trying to achieve a given number of successes, and is used frequently in actuarial models.

pmf: $P(x)=\binom{x+n-1}{x} p^n(1-p)^x$ x = 0, 1, 2, 3...

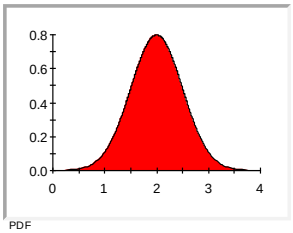
where: $\binom{x+n-1}{x}=\frac{(x+n-1)!}{x!(n-1)!}$

cdf: $F(x)= p^n \sum_{i=0}^{x}\binom{i+n-1}{i}(1-p)^i$

mean: $\frac{n(1-p)}{p}$

variance: $\frac{n(1-p)}{p^2}$

Normal Distribution



The normal distribution is specified by a mean (μ) and a standard deviation (σ). The linear normal distribution is a bell shaped curve centered about the mean value with a half-width of about four standard deviations. Error or uncertainty that can be higher or lower than the mean with equal probability may be satisfactorily represented with a normal distribution. The uncertainty of average values, such as a mean value, is often well represented by a normal distribution, and this relation is further supported by the *Central Limit Theorem* for large sample sizes.

pdf: $f(x)=\frac{1}{\sqrt{2\pi\sigma^2}}\ e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$

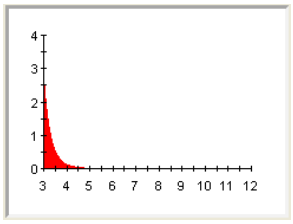
cdf: No closed form solution

mean: μ

variance: σ^2

Pareto Distribution

The Pareto distribution is a continuous, long-tailed distribution specified by a shape parameter (a) and a scale parameter (b). The shape parameter and the scale parameter must be greater than zero. This distribution can be used to model things like network traffic in a telecommunications system or income levels in a particular country.



pdf: $f(x)=\begin{cases}\dfrac{ab^a}{x^{a+1}} & if \quad x \geq b \\ 0 & otherwise\end{cases}$

cdf: $F(x)=\begin{cases}1-\left(\dfrac{b}{x}\right)^a & if \quad x \geq b \\ 0 & otherwise\end{cases}$

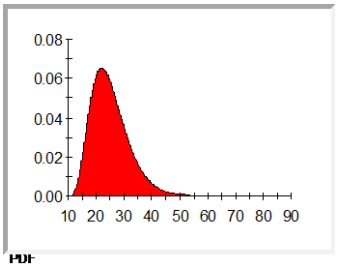
mean: $\dfrac{ab}{a-1}$

variance: $\dfrac{ab^2}{(a-1)^2(a-2)}$

Pearson Type III Distribution

Often used in financial and environmental modeling, the Pearson Type III distribution is a continuous distribution specified by location (α), scale (β) and shape (p) parameters. Both the scale and shape parameters must be positive.

Note that the Pearson Type III distribution is equivalent to a gamma distribution if the location parameter is set to zero.



pdf: $f(x)= \dfrac{1}{\beta\Gamma(p)}\left(\dfrac{x-\alpha}{\beta}\right)^{p-1} e^{-\left(\frac{x-\alpha}{\beta}\right)}$ if $x \geq \alpha$

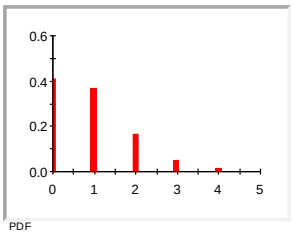
0 if $x < \alpha$

cdf: $F(x) = \dfrac{\Gamma\left(p, \dfrac{x-a}{\beta}\right)}{\Gamma(p)}$

mean: $\mu = \alpha + p\beta$

variance: $\sigma^2 = p\beta^2$

Poisson Distribution



The Poisson distribution is a discrete distribution specified by a mean value, μ. The Poisson distribution is most often used to determine the probability for one or more events occurring in a given period of time. In this type of application, the mean is equal to the product of a rate parameter, λ, and a period of time, ω. For example, the Poisson distribution could be used to estimate probabilities for numbers of earthquakes occurring in a 100 year period. A rate parameter characterizing the number of earthquakes per year would be needed for input to the distribution. The time period would simply be equal to 100 years.

pdf: $f(x)=\frac{e^{-\mu}\mu^{x}}{x!}$ x = 0, 1, 2, 3...

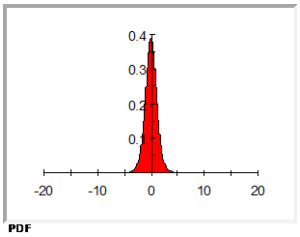
cdf: $F(x) = e^{-\mu}\sum_{i=0}^{x}\frac{\mu^{i}}{i!}$

mean: $\mu = \lambda\omega$

variance: $\sigma^2 = \mu$

where λ and ω are the "rate" and "time period" parameters, respectively. Note that quotations are used because the terminology rate and time period applies to only one application of the Poisson distribution.

Student's t Distribution



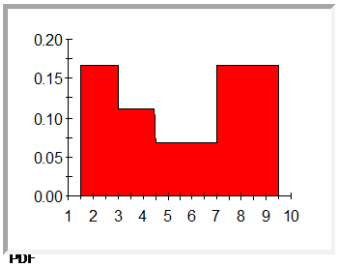
The Student's t distribution requires a single input: the number of degrees of freedom, which equals the number of samples minus one.

mean: 0

variance: $\frac{\nu}{\nu-2}$

where ν is the number of degrees of freedom

Sampled Result Distribution

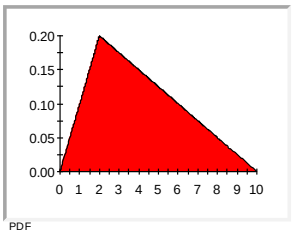


The sampled result distribution allows you to construct a distribution using observed results. GoldSim generates a CDF by sorting the observations and assuming that a cumulative probability of 1/(Number of Observations) exists between each data point. If there are multiple data points at the same value, a discrete probability equal to (N)/(Number of Observations) is applied at the value, where N is equal to the number of identical observations.

If the Extrapolation option is cleared, a discrete probability of 0.5/(Number of observations) is assigned to the minimum and maximum values. When the extrapolation option is selected, GoldSim extends the generated CDF to cumulative probability levels of 0 and 1 using the slope between the two smallest and two largest unique observations.

Triangular Distribution

The triangular distribution is specified by a minimum value (a), a most likely value (b), and a maximum value (c).



pdf:

$$f(x) = \begin{cases} \dfrac{2(x-a)}{(b-a)(c-a)} & a \le x \le b \\ \dfrac{2(c-x)}{(c-b)(c-a)} & b \le x \le c \\ 0 & x < a \text{ or } x > c \end{cases}$$

cdf:

$$F(x) = \begin{cases} 0 & x < a \\ \dfrac{(x-a)^2}{(b-a)(c-a)} & a \le x \le b \\ 1 - \dfrac{(c-x)^2}{(c-b)(c-a)} & b < x < c \\ 1 & x \ge c \end{cases}$$

mean:

$$\mu = \frac{a+b+c}{3}$$

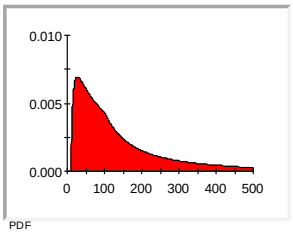
variance:

$$\sigma^2 = \frac{a^2+b^2+c^2-ab-ac-bc}{18}$$

Note that if the triangular is defined using the 10th and 90th percentile (instead of a minimum and a maximum) the minimum and maximum are estimated through iteration.

Log-Triangular Distribution

The log-triangular distribution is used when the *logarithm* of the random variable is described by a triangular distribution. The minimum (a), most likely (b), and maximum (c) values are specified in linear space.



pdf:

$$f(x) = \begin{cases} \dfrac{2\left[\ln\left(\frac{x}{a}\right)\right]\left(\frac{1}{x}\right)}{\ln\left(\frac{b}{a}\right)\ln\left(\frac{c}{a}\right)} & a \le x \le b \\ \dfrac{2\left[\ln\left(\frac{c}{x}\right)\right]\left(\frac{1}{x}\right)}{\ln\left(\frac{c}{a}\right)\ln\left(\frac{c}{b}\right)} & b \le x \le c \\ 0 & \text{otherwise} \end{cases}$$

cdf:

$$F(x) = \begin{cases} 0 & x<a \\ \dfrac{\left[\ln\left(\frac{x}{a}\right)\right]^2}{\ln\left(\frac{b}{a}\right)\ln\left(\frac{c}{a}\right)} & a \le x \le b \end{cases}$$

$$1 - \frac{\left[\ln\left(\frac{c}{x}\right)\right]^2}{\ln\left(\frac{c}{a}\right)\ln\left(\frac{c}{b}\right)} \qquad b < x \le c$$

$$1 \qquad x > c$$

mean: $$\mu = \frac{2}{d_1}\left\{a + b\left[\ln\left(\frac{b}{a}\right) - 1\right]\right\} + \frac{2}{d_2}\left\{c + b\left[\ln\left(\frac{b}{c}\right) - 1\right]\right\}$$

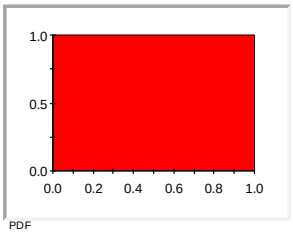
variance: $$\sigma^2 = \frac{2}{d_1}\left\{\frac{a^2}{4} + \frac{b^2}{2}\left[\ln\left(\frac{b}{a}\right) - \frac{1}{2}\right]\right\} + \frac{2}{d_2}\left\{\frac{c^2}{4} + \frac{b^2}{2}\left[\ln\left(\frac{b}{c}\right) - \frac{1}{2}\right]\right\} - \mu^2$$

where: $$d_1 = \ln\left(\frac{c}{a}\right)\ln\left(\frac{b}{a}\right) \text{ and}$$

$$d_2 = \ln\left(\frac{c}{a}\right)\ln\left(\frac{c}{b}\right)$$

Note that if the log-triangular is defined using the 10th and 90th percentile (instead of a minimum and a maximum) the minimum and maximum are estimated through iteration.

Uniform Distribution



The uniform distribution is specified by a minimum value (a) and a maximum value (b). Each interval between the endpoints has equal probability of occurrence. This distribution is used when a quantity varies uniformly between two values, or when only the endpoints of a quantity are known.

pdf: $$f(x) = \frac{1}{b-a} \qquad a \le x \le b$$

$$0 \qquad \text{otherwise}$$

cdf: $$F(x) = 0 \qquad x < a$$

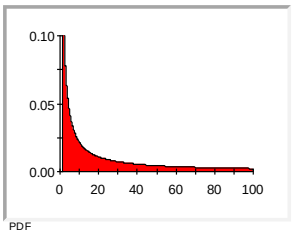
$$\frac{x-a}{b-a} \qquad a \le x \le b$$

$$1 \qquad x > b$$

mean: $$\mu = \frac{b+a}{2}$$

variance: $$\sigma^2 = \frac{(b-a)^2}{12}$$

Log-Uniform Distribution



The log-uniform distribution is used when the *logarithm* of the random variable is described by a uniform distribution. Log-uniform is the distribution of choice for many environmental parameters that may range in value over two or more log-cycles and for which only a minimum value and a maximum value can be reasonably estimated. The log-uniform distribution has the effect of assigning equal probability to the occurrence of intervals within each of the log-cycles. In contrast, if a linear uniform distribution were used, only the intervals in the upper log-cycle would be represented uniformly.

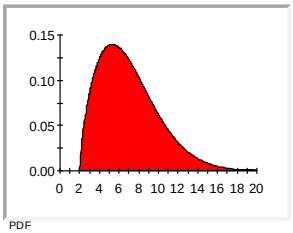
pdf: $f(x) = \begin{cases} \dfrac{1}{x(\ln b - \ln a)} & a \le x \le b \\ 0 & x \le a \text{ or } x \ge b \end{cases}$

cdf: $F(x) = \begin{cases} 0 & x \le a \\ \dfrac{\ln x - \ln a}{\ln b - \ln a} & a \le x \le b \\ 1 & x > b \end{cases}$

mean: $\mu = \dfrac{b-a}{(\ln b - \ln a)}$

variance: $\sigma^2 = \dfrac{b^2 - a^2}{2(\ln b - \ln a)} - \left(\dfrac{b-a}{(\ln b - \ln a)}\right)^2$

Weibull Distribution



The Weibull distribution is typically specified by a minimum value (ε), a scale parameter (β), and a slope or shape parameter (α). The random variable must be greater than 0 and also greater than the minimum value, ε.

The Weibull distribution is often used to characterize failure times in reliability models. However, it can be used to model many other environmental parameters that must be positive. There are a variety of distribution forms that can be developed using different values of the distribution parameters.

pdf: $f(x) = \dfrac{\alpha}{\beta - \varepsilon}\left(\dfrac{x - \varepsilon}{\beta - \varepsilon}\right)^{\alpha-1} e^{-\left(\frac{x-\varepsilon}{\beta-\varepsilon}\right)^{\alpha}}$

cdf: $F(x) = 1 - e^{-\left(\frac{x-\varepsilon}{\beta-\varepsilon}\right)^{\alpha}}$

mean: $\mu = \varepsilon + (\beta - \varepsilon)\Gamma\left(1 + \dfrac{1}{\alpha}\right)$

variance: $\sigma^2 = (\beta - \varepsilon)^2\left[\Gamma\left(1 + \dfrac{2}{\alpha}\right) - \Gamma^2\left(1 + \dfrac{1}{\alpha}\right)\right]$

The Weibull distribution is sometimes specified using a *shape parameter*, which is simply β - ε. Within GoldSim, the Weibull is defined by ε, α, and the mean-ε. As shown above, the mean can be readily computed as a function of ε, α, and β.

In practice, the Weibull distribution parameters are moderately difficult to determine from sample data. The easiest approach utilizes the cdf, fitting a regression through the sample data to estimate α (regression slope) and the difference quantity, $\beta - \varepsilon$.

Representing Truncated Distributions

Several distributions in GoldSim can be truncated at the ends (normal, log-normal, Gamma, and Weibull). That is, by specifying a lower bound and/or an upper bound, you can restrict the sampled values to lie within a portion of the full distribution's range.

The manner in which truncated distributions are sampled is straightforward. Because each point in a full distribution corresponds to a specific cumulative probability level between 0 and 1, it is possible to identify the cumulative probability levels of the truncation points. These then define a scaling function which allows sampled values to be mapped into the truncated range.

In particular, suppose the cumulative probability levels for the lower bound and upper bound were L and U, respectively. Any sampled random number R (representing a cumulative probability level between 0 and 1) would then be scaled as follows:

$L + R(U-L)$

This resulting "scaled" cumulative probability level would then be used to compute the sampled value for the distribution. The scaling operation ensures that it falls within the truncated range.

Correlation Algorithms

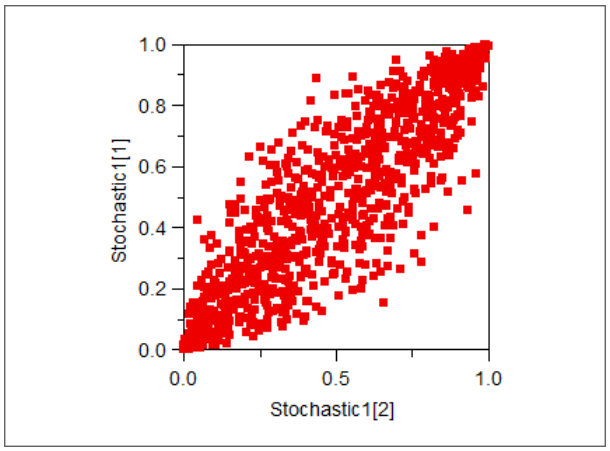
Several GoldSim elements that are used to represent uncertainty or stochastic behavior in models permit the user to define correlations between elements or amongst the items of a vector-type element.

To generate sampled values that reflect the specified correlations GoldSim uses copulas and the Iman and Conover methodology.

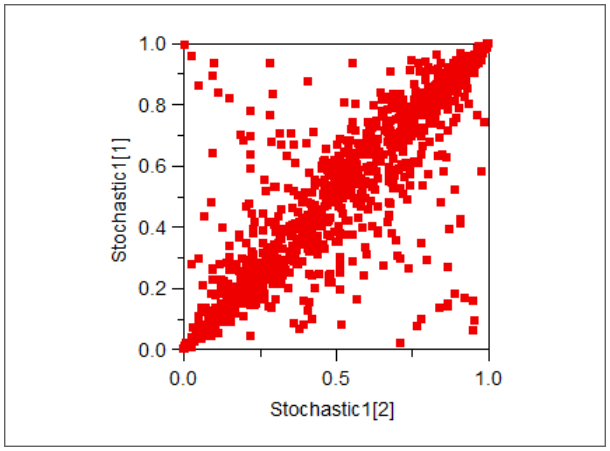
A copula is a function that joins two or more univariate distributions to form a multivariate distribution. As such, it provides a method for specifiying the correlation between two variables. Copulas are described in general terms by Dorey (2006) and in detail by Embrechts, Lindskog and McNeil (2001).

GoldSim uses two different copulas to generate correlated values: the Gaussian copula and the t-distribution copula. When a Stochastic element is correlated to itself, or to another Stochastic element, GoldSim uses the Gaussian copula to generate the correlated value. A vector-type Stochastic or History Generator can use either the Gaussian copula or a t-distribution copula to generate correlated values.

The Gaussian copula produces values where the correlation between variables is stronger towards the middle of the distributions than it is at the tails. The plot below shows the values for two variables (uniform distributions between 0 and 1) generated using the Gaussian copula with a correlation coefficient of 0.9:



A t-distribution copula produces a correlation that is stronger at the tails than in the middle. The plot below shows the values for the two variables generated using the t-distribution copula for the same variables with a correlation coefficient of 0.9 and the **Degrees of Freedom** setting in the copula of 1):



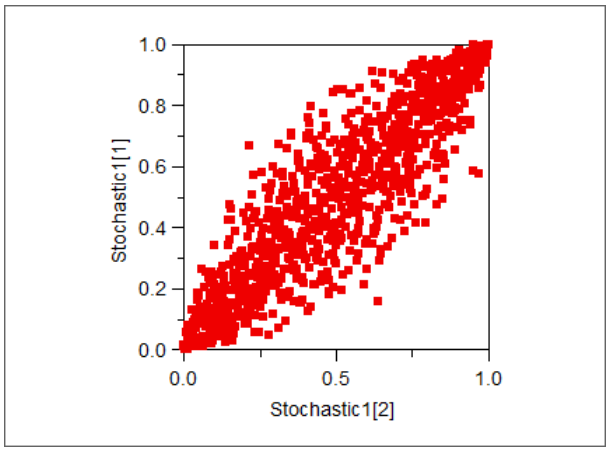
The t-distribution's form is often what is observed in the real world: correlations at the extremes (e.g. representing a rare, but significant event such as a war) tend to be higher than correlations in the middle (representing the higher variability in more common occurrences).

The **Degrees of Freedom** setting controls the tail dependency in the copula. A low value produces stronger dependence in the tails, while higher values produce stronger correlations in the middle of the distributions. This means that a t-distribution copula with a high number of Degrees of Freedom will begin to behave like a Gaussian copula.

One of the weaknesses of the copula approach to generating correlated samples is that it does not respect Latin Hypercube Sampling (with the exception of the first item in a vector-type stochastic where the Gaussian copula is used to generate sampled values).

The Iman and Conover approach is designed to produce a set of correlated items that each respect Latin Hypercube sampling. Complete details on the algorithm's methodology can be found in Iman and Conover (1982).

Its behavior is similar, but not identical, to a Gaussian for the first sample:



However, if the element is resampled during a realization, elements that use the Iman and Conover approach will use the Gaussian copula to generate the second and subsequent sets of sampled data.

Sampling Techniques

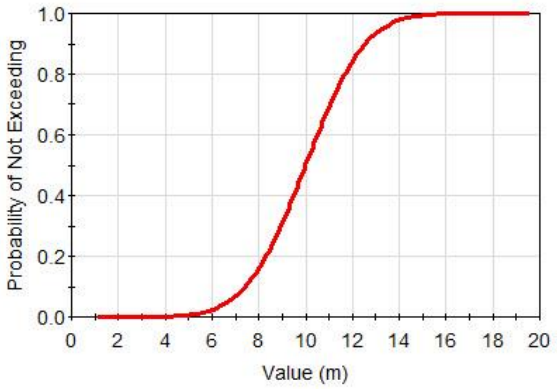
This section discusses the techniques used by GoldSim to sample elements with random behavior. These include the following GoldSim elements:

- Stochastic
- Random Choice
- Timed Event Generator
- Event Delay
- Discrete Change Delay
- History Generator
- Source (in the Radionuclide Transport Module)
- Action element (in the Reliability module)
- Function element (in the Reliability module)

After first discussing how GoldSim generates random numbers in order to sample these elements, two enhanced sampling techniques provided by GoldSim (Latin Hypercube sampling and importance sampling) are discussed.

Generating Random Numbers to Sample Elements

In order to sample an element (we will simplify the discussion here by using a Stochastic element as an example rather than one of the other types of elements), GoldSim starts with the CDF of the distribution that we want to sample. Below is a CDF for a Normal distribution with a mean of 10m and a standard deviation of 2m:



To randomly sample this distribution, we simply need to do the following:

1. Obtain a random number (i.e., a number between 0 and 1).
2. Use the CDF to map that random number to the corresponding sampled value.

So, for example, in the CDF above, a random number of about 0.2 would correspond to a sampled value of about 8.3m.

As can be seen, this sampling process itself is conceptually very simple. The more complicated part involves obtaining the random number needed to sample the element. That is, in order to carry out Monte Carlo simulation, GoldSim (and any Monte Carlo simulator) needs to consistently generate a series of random numbers.

In GoldSim, the process consists of the following components:

- Several different types of **random number seeds**. You can simply think of a random number seed as an integer number. It actually consists of a pair of long (32-bit) integers, but that is not important to the discussion that follows.
- **Random numbers**. A random number, as used here, has a specific definition: it is a real number between 0 and 1.
- A **seed generator**. This is an algorithm that takes as input one random number seed and randomly generates a new random number seed. A particular value for the input seed always generates the same output seed, but different input seeds generate different output seeds.
- A **random number generator**. This is another algortihm. It takes as input one random number seed and generates a random number. A particular value for the random number seed always generates the same random number, but different random number seeds generate different random numbers.

Within GoldSim, there are several types of random number seeds:

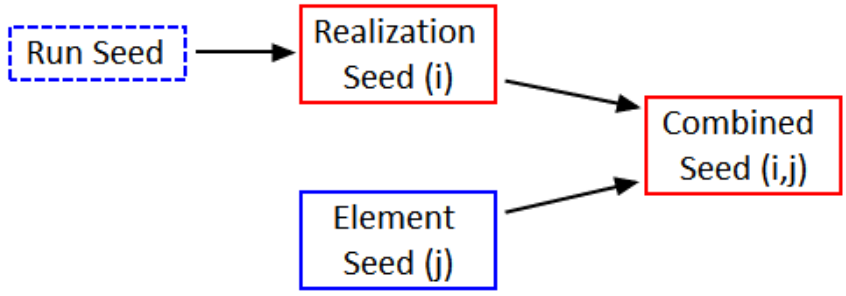
- The model itself (as well as any SubModel) has a ***run seed***. If you choose to **Repeat Sampling Sequences** (an option on the Monte Carlo tab of the Simulation Settings dialog), this seed is (reproducibly) created based on an integer number that can be edited by the user. If you do not **Repeat Sampling Sequences**, it is randomly created based on the computer's system clock.

- The ***realization seed*** is a mutable seed that is initialized with the ***run seed*** and then updated for each realization.
- Each Stochastic element (as well as other elements that behave probabilistically) has its own random number seed. This is referred to as the ***element seed***. This seed is created (in a random manner, based on the system clock) when the element is first created.

Note: No two elements in a GoldSim model can have the same **element seed**. This means that if an element is copied and pasted into a model where no elements have the same seed value, its seed will be unchanged. However, if it is pasted into the same model, or into a model where another element already has that seed value, one of the elements with the same seed value will be given a new unique seed. (Element seeds can be displayed by selecting the element in the graphics pane and pressing **Ctrl-Alt-Shift-F12**).

- For every element that behaves probabilistically), the realization seed and the element seed are combined together to create a **combined seed** for that element. It is this combined seed that is used to generate a random number using a random number generator.

This random number seed structure is illustrated below:



The ***run seed*** and ***element seeds*** are constant during a simulation (they never change). The run seed is marked using a dashed line to indicate that although it is constant during a simulation, it can be changed by the user. The element seed (which is different for each element j) is created when the element is created and cannot be changed. As we shall see below, however, the ***realization seeds*** and ***combined seeds*** are not constant during a simulation but change as the simulation proceeds.

So given all of this information, let's describe how GoldSim carries out a Monte Carlo simulation by considering a very simple model consisting of a single Stochastic element that is resampled every day, with the model being run for multiple realizations:

1. At the beginning of the simulation, GoldSim has a value for the run seed, and a single element seed.
2. At the beginning of the simulation (assuming we are repeating sampling sequences), the run seed is used to initialize a realization seed.
3. At the beginning of each realization, we do the following:
    a. The current realization seed is input int the seed generator to generate a new realization seed for this realization.

b. The realization seed is combined with the element seed to create a combined seed for the element.

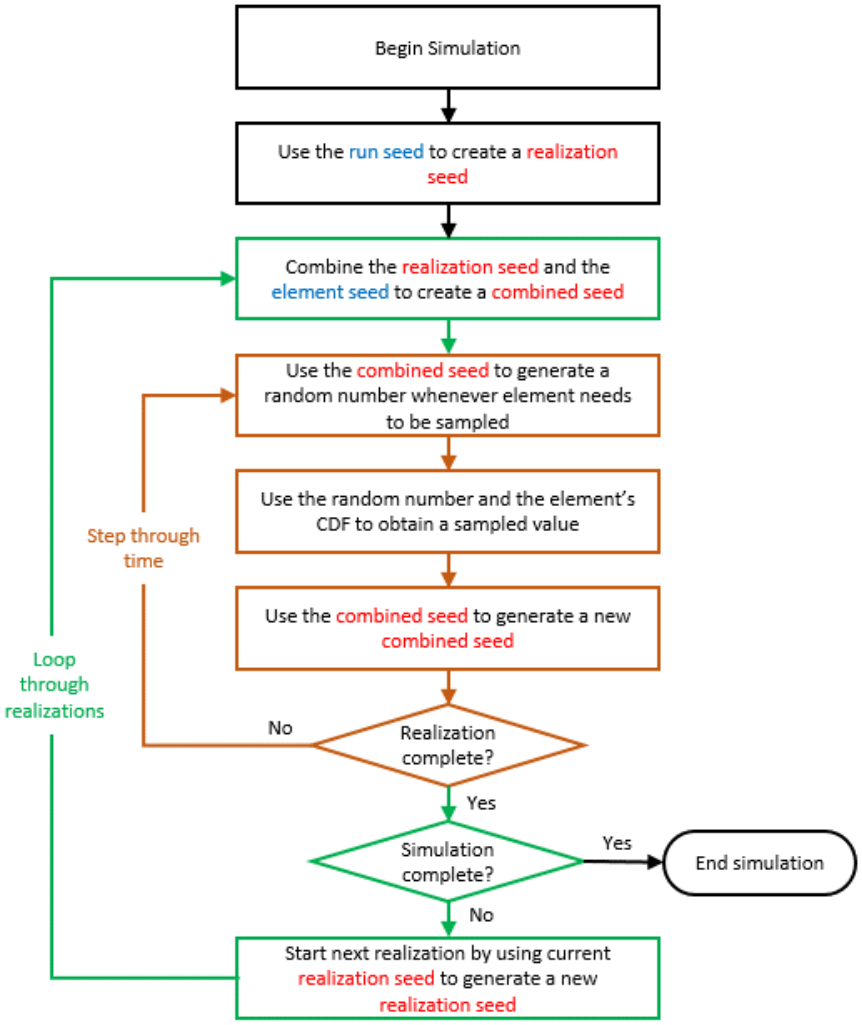
c. Now that we have the combined seed, two things happen:

   i. The combined seed is input into the random number generator to generate a random number for the element. This random number is then mapped to the CDF to obtain a sampled value for the element.

   ii. The combined seed is input into the seed generator to generate a new combined seed that we will use the next time we need a random number.

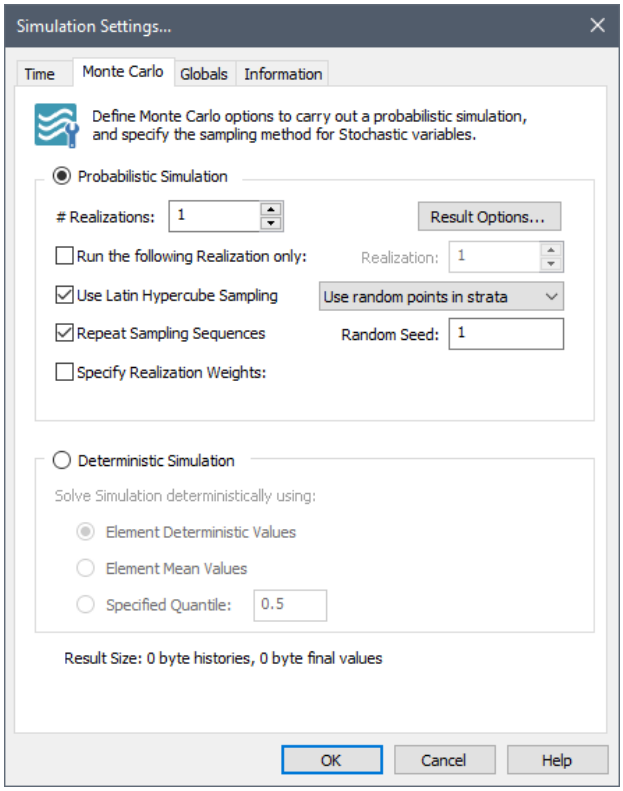
d. Whenever we need to resample the element during the realization (in this case every day), we need a new random number. To do so, every day we repeat steps i and ii above.

This same logic is shown schematically below:



Note: GoldSim's random number generation process is based on a method presented by L'Ecuyer (1988). As pointed out above, each seed actually consists of two long (32-bit) integers. When random numbers are generated, each of the integers cycles through a standard linear congruential sequence, with different constants used for the two sequences (so that their repeat-cycles are different). The random numbers that are generated are a function of the combination of the two seeds, so that the length of their repeat period is extremely long.

Now let's consider the various options on the **Monte Carlo** tab of the Simulation Settings dialog:



In particular, we will focus on just two fields: **Repeat Sampling Sequences** and **Random Seed**. These two fields impact the ***run seed*** in the following ways:

- If **Repeat Sampling Sequences** in checked, you can specify a **Random Seed**. The **Random Seed** is used to create the ***run seed***.
- If **Repeat Sampling Sequences** is cleared, the ***run seed*** is created "on the fly" using the system clock. As a result, it is different every time the model is run.

These facts, combined with the logic outlined above, can be used to describe exactly how elements will be sampled in various models under any set of circumstances. In particular:

- If **Repeat Sampling Sequences** is checked (the default), as long as you do not modify the model, you will get the same results (i.e., the same random numbers will be used) if you run the model today, and then run it again tomorrow. This is because the ***run seed*** is unchanged.

- Similarly, if **Repeat Sampling Sequences** is checked and you copy a model to someone else (and they do not make any changes), they will get the same results as you.
- If **Repeat Sampling Sequences** is checked, but the **Random Seed** is changed (e.g., from 1 to 2), you will get different results (i.e., different random numbers will be used). This is because the ***run seed*** is different. If you then change the **Random Seed** back to the original value, you will reproduce the original results.
- If **Repeat Sampling Sequences** is cleared, every time you run the model you will get different results (i.e., different random numbers will be used). This is because the ***run seed*** is different
- If two people simultaneously build the same simple model with the exact same inputs (including the same **Random Seed**), the results will still be different (i.e., different random numbers will be used). This is because the ***element seeds*** will be different.
- If the user selects the option to **Run the following Realization only**, such as realization 16, GoldSim simply iterates through the process the necessary number of times prior to starting the specified realization.

Latin Hypercube Sampling

GoldSim provides an option to implement a Latin Hypercube sampling (LHS) scheme (in fact, it is the default when a new GoldSim file is created). The LHS option results in forced sampling from each "stratum" of each parameter.

The following elements use LHS sampling:

- Stochastic
- Random Choice
- Timed Event Generator
- Time Series (when time shifting using a random starting point)
- Action (in the Reliability Module)
- Function (in the Reliability Module)

Each element's probability distribution (0 to 1) is divided into up to 10000 equally likely strata or slices (actually, the lesser of the number of realizations and 10000). The strata are then "shuffled" into a random sequence, and a random value is then picked from each stratum in turn. This approach ensures that a uniform spanning sampling is achieved.

Note: If possible, GoldSim will attempt to create LHS sequences where subsets are also complete LHS sequences. This means that if the total number of realizations is an even number, the first half and second half of the realizations are complete LHS sequences. If the total number of realizations is divisible by 4 or 8, that fraction of the total number of realizations, run in sequence, will be complete LHS sequences. This property of GoldSim's LHS sequences is sometimes useful for statistical purposes and also permits a user to extract a valid LHS sequence from a partially completed simulation by screening realizations. The details of this approach are discussed below ("Latin Hypercube Subsets").

Note that each element has an independent sequence of shuffled strata that are a function of the element's internal random number seed and the number of realizations in the simulation. If the number of realizations exceeds 10,000, then at the 10,001st realization each element makes a random jump to a new position in its strata sequence. A random jump is repeated every 10,000 realizations.

If you select "Use mid-points of strata" in the Simulation Settings dialog in models with less than 10,000 realizations, GoldSim will use the expected value of the strata selected for that realization. (Even if this option is selected, in simulations with greater than 10,000 realizations, the 10,001 and subsequent realizations will use random values from within the strata selected for that realization.) Using mid-points provides a slightly better representation of the distribution, but without the full randomness of the original definition of Latin Hypercube sampling (as described by McKay, Conover and Beckman, 1979).

If you select "Use random points in strata" in the Simulation Settings dialog, GoldSim also picks a random value from each stratum.

Note: LHS is only applied to the first sampled random value in each realization. Subsequent samples will not use LHS.

LHS appears to have a significant benefit only for problems involving a few independent stochastic parameters, and with moderate numbers of realizations. In no case does it perform worse than true random sampling, and accordingly LHS sampling is the default for GoldSim.

Note that the binary subdivision approach (described in more detail below) and the use of mid-stratum values are GoldSim-specific modifications to the original description of Latin Hypercube Sampling, as described in McKay, Conover and Beckman (1979).

Latin Hypercube Subsets

In order to allow users to do convergence tests, GoldSim's LHS sampling automatically organizes the LHS strata for each random variable so that binary subsets of the overall number of realizations each represent an independent LHS sample over the full range of probabilities.

For example, if the user does 1,000 realizations, GoldSim will generate strata such that:

- Realizations 1-125 represent a full LHS sample with 125 strata. Realizations 126-250, 251-375, etc. through 876-1000 also represent full LHS samples with 125 strata each.
- Also, realizations 1-250, 251-500, 501-750, and 751-1000 represent full LHS samples with 250 strata each.
- And, realizations 1-500 and 501-1000 represent full LHS samples with 500 strata each.

The generation of binary subsets is automatic, and is carried out whenever the total number of realizations is an even number. Up to 16 binary subsets will be generated, if the number of realizations can be subdivided evenly four times. For example, if the total number of realizations was 100 then GoldSim would generate 2 subsets of 50 strata each and 4 subsets of 25 strata. If the total number of realizations was 400 then GoldSim would generate 2 subsets of 200 strata, 4 subsets of 100 strata, 8 subsets of 50 strata, and 16 subsets of 25 strata.

The primary purpose of this sampling approach is to use the subsets to carry out statistical tests of convergence. For example, the mean of each of the subsets of

results could be evaluated and a t-test used to estimate statistics of the population mean, as described in Iman (1982). Rather than carrying out a set of independent LHS simulations using different random seeds, this approach allows the user to run a single larger simulation, with the benefits of a better overall representation of the system's result distribution, while still being able to test for convergence and to generate confidence bounds on the results. (A secondary benefit of the binary sampling approach is that if a simulation is terminated partway through it should have a slightly greater likelihood of having uniform sampling over the completed realizations than normal Latin Hypercube sampling would.)

The algorithm for assigning strata to the binary subsets is quite simple. For each pair of strata (e.g., 1st and 2nd; 3rd and 4th), the first member of the pair is randomly assigned to one of two "piles" ("left" or "right"), and the second member is assigned to the opposite pile. That is, conceptually, it can be imagined that the full set of strata is sent one at a time to a 'flipper' that randomly chooses 'left' or 'right' on its first, third, fifth etc. activations, and on its second, fourth, sixth etc. activations chooses the opposite of the previous value.

For the case of one binary subdivision of a total of N_s strata, the algorithm goes through the strata sequentially from lowest to highest, and passes them to a flipper that generates two 'piles' of strata. Each pile will therefore randomly contain one of the first two strata, one of the second two, and so on. Thus, each pile will contain one sample from each of the strata that would have been generated if only N_s /2 total samples were to be taken. The full sampling sequence is generated by randomly shuffling each pile and then concatenating the two sequences.

For four binary subdivisions the same approach is extended, with the first flipper passing its 'left' and 'right' outputs to two lower-level flippers. This results in four 'piles' of strata, which again are just randomly shuffled and then concatenated. The same approach is simply extended to generate eight or sixteen strata where possible.

Importance Sampling

For risk analyses, it is frequently necessary to evaluate the low-probability, high-consequence end of the distribution of the performance of the system. Because the models for such systems are often complex (and hence need significant computer time to simulate), and it can be difficult to use the conventional Monte Carlo approach to evaluate these low-probability, high-consequence outcomes, as this may require excessive numbers of realizations.

To facilitate these type of analyses, GoldSim allows you to utilize an ***importance sampling*** algorithm to modify the conventional Monte Carlo approach so that the high-consequence, low-probability outcomes are sampled with an enhanced frequency. During the analysis of the results which are generated, the biasing effects of the importance sampling are reversed. The result is high-resolution development of the high-consequence, low-probability "tails" of the consequences, without paying a high computational price.

The following elements permit importance sampling:

- Stochastic
- Random Choice
- Timed Event Generator
- Action (in the Reliability Module)
- Function (in the Reliability Module)

Note: Importance sampling is only applied to the first sampled random value in each realization for elements with importance sampling enabled. Subsequent samples will use random sampling.

Note: In addition to the importance sampling method described here (in which you can choose to force importance sampling on either the low end or high end of a Stochastic element's range), GoldSim also provides an advanced feature that supports custom importance sampling that can be applied over user-defined regions of the Stochastic element's range.

Read more: Customized Importance Sampling Using User-Defined Realization Weights (page 1089).

Warning: Importance sampling affects the basic Monte Carlo mechanism, and it should be used with great care and only by expert users. In general, it is recommended that only one or at most a very few parameters should use importance sampling, and these should be selected based on sensitivity analyses using normal Monte Carlo sampling. **Importance sampling should only be used for elements whose distribution tails will *not* be adequately sampled by the selected number of realizations.**

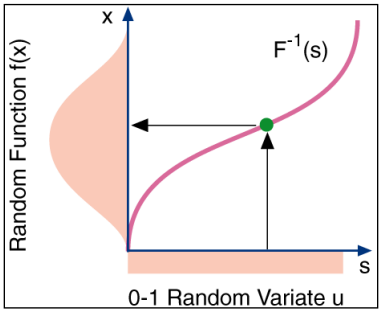
How Importance Sampling Works

Importance sampling is a general approach to selectively enhance sampling of important outcomes for a model. In principle, the approach is simple:

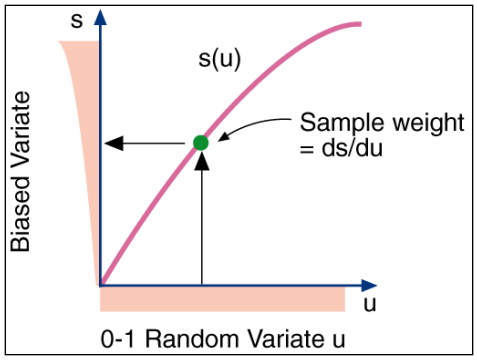
1. Identify an important subset of the sampling space;
2. Sample that subset at an enhanced rate; and
3. When analyzing results, assign each sample a weight inversely proportional to its enhancement-factor.

In conventional Monte Carlo sampling (with or without Latin Hypercube), each realization is assumed equally probable. It is straightforward, however, to incorporate a weight associated with each sample in order to represent the relative probability of the sample compared to the others.

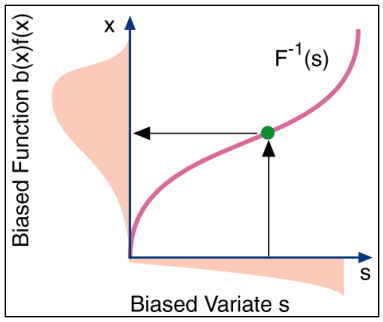
The conventional Monte Carlo approach is as shown below. A uniform 0 – 1 random variable **u** is sampled, and its value is then used as input to the inverse cumulative distribution function of the random variable:



In order to do importance sampling, the original uniformly-distributed random numbers are first mapped onto a non-uniform 'biased' sampling function **s**:



The biased variate **s** is then used to generate the random function. Since the input random numbers are no longer uniformly distributed, the resulting sample set is selectively enriched in high-consequence results:



In general, any continuous monotonic biasing function **s** which spans the range 0-1, and has **s**(0) = 0 and **s**(1) = 1 can be used to generate the set of input random numbers. The weight associated with each sampled realization is d**s**/d**u**, the slope of the biasing function **s** at the sampled point.

When a number of independent random variables are involved in a model, then the weight associated with a given realization is simply equal to the product of the weights of all parameters.

Biasing (Enhancement) Functions

GoldSim uses simple functions to selectively enhance either the upper or the lower end of an element's probability distribution.

The biasing function for enhancing the lower end of a distribution is:

$$s = u - \frac{u}{1+au} + \frac{u^2}{1+a}$$

where *a* is a function of the number of elements that are using importance sampling. This is equal to zero if only one element uses importance sampling, and is equal to ten times the number of importance sampled elements in all other cases. The effect of increasing *a* is to restrict the importance sampling to a smaller subset of the full range of the random value, which reduces the negative impacts of importance sampling numerous variables in the same model.

The sample weight is given by:

$$w = \frac{ds}{du} = 1 - \frac{1}{(1+au)^2} + \frac{2u}{1+a}$$

Note: For the first 10,000 realizations where GoldSim uses the expected values of the LHS strata the weight given to each sample is equal to the integral of s over the stratum divided by the corresponding integral of u over the strata. For the 10,001st and subsequent realizations GoldSim will calculate s and w for the sampled point.

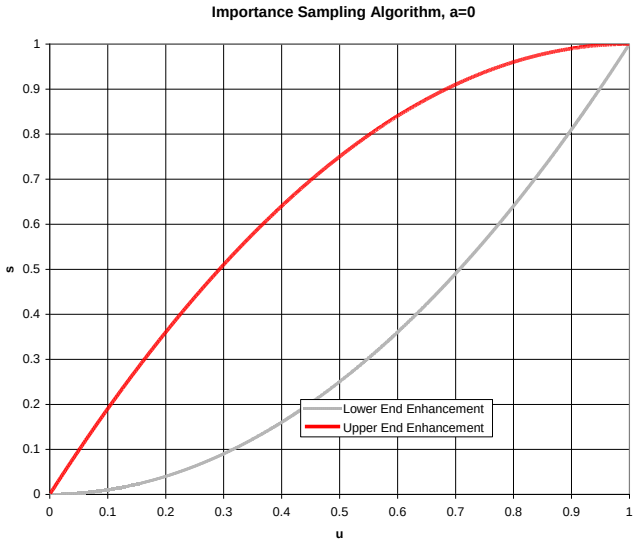
The biasing function for enhancing the upper end is:

$$s_{upper} = 1 - s_{lower}(1-u) = 1 - \left((1-u) - \frac{(1-u)}{1+a(1-u)} + \frac{(1+u)^2}{1+a} \right)$$

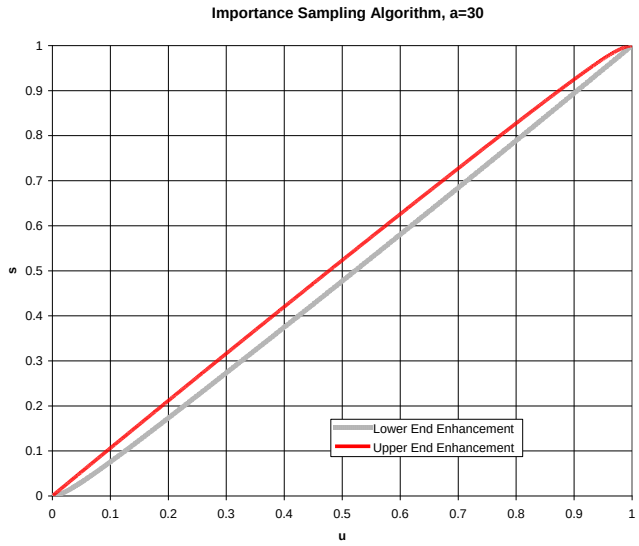
and the corresponding sample weight is given by:

$$w_{upper} = w_{lower}(1-u) = 1 - \frac{1}{(1+a(1-u))^2} + \frac{2(1-u)}{1+a}$$

The following plot shows the upper and lower biasing function when a single element utilizes importance sampling (an *a* value of zero):



The following figure shows the bias function when three elements are importance sampled (an *a* value of 30):



Note the less prominent bias as the number of importance sampled elements increases.

Behavior of Elements with Importance Sampling Enabled

The Stochastic element provides the option to choose between upper and lower end enhancement when importance sampling is enabled. However, the other elements that utilize importance sampling (the Timed Event element, the Reliability elements and the Random Choice element) importance sample only one end of the distribution.

Timed Events will use lower end importance sampling on the time to event distribution specified by the user. The Random Choice element has a slightly different behavior. When importance sampling is enabed, the Random Choice element sorts the probability of each outcome from lowest probability to highest probability and assigns them to sections of a uniform distribution. This uniform distribution is then importance sampled at the lower end, so that the least probable outcomes are enhanced.

The Reliability elements will use a combination of these approaches. Time based failure modes behave in a similar manner to the timed event elements. Modes with a "probability of failure" perform importance sampling to enhance the number of failure outcomes.

It is important to note that only the first sampled value utilizes importance sampling. This means that only the first event from a Timed Event, the first Random Choice and the first occurrence of each Failure Mode will use importance sampling.

Representing Random (Poisson) Events

Timed Event elements can be specified to produce discrete event signals *regularly* or *randomly*.

Read more: Timed Event Elements (page 379).

Random events are simulated as occurring according to a Poisson process with a specified *rate of occurrence*. If an event occurs according to a Poisson process,

the probability that N events will occur during a time interval T is described by the following expression (Cox and Miller, 1965):

$$P(N) = \frac{e^{-\lambda T}(\lambda T)^N}{N!}$$

where:

P(N) is the probability of N occurrences of the event within the time interval T;

T is the time interval of interest;

λ is the annual rate of occurrence; and

N is the number of occurrences of the event within the time interval T.

The expected (mean) number of occurrences during the time interval is equal to λT.

The Poisson distribution also has the property that the intervals between events are exponentially distributed (Benjamin and Cornell, 1970):

$$F(t) = 1 - e^{-\lambda t}$$

where F(t) is the probability that the time to the next event will be less than or equal to t.

If you indicate that the event can only occur once, GoldSim simulates the first occurrence according to the above equations, but does not allow the event to occur again.

Note that the rate of occurrence can be specified to be a function of time (i.e., the event process can be non-stationary).

Computing and Displaying Result Distributions

Displaying a CDF

Probabilistic results may be viewed in the form of a CDF (or a CCDF). This section describes how the values realized during the simulations are used to generate the CDF (or CCDF) seen by the user.

Creating the Results Array

Within GoldSim Monte Carlo results are stored in a particular data structure, referred to here as the *results array*. As the simulation progresses, each specific Monte Carlo realization result is added to the results array as a pair of values; the value realized and the weight given by GoldSim to the value. The array is filled "on the fly", as each new realization is generated. Theoretically, each separate realization would represent a separate entry in the results array (consisting of a value and a weight). If unbiased sampling were carried out each separate entry would have equal weight.

As implemented in GoldSim, however, the number of data pairs in the results array may be less than the number of realizations: There are two reasons why this may be the case:

- If multiple results have identical values, there is no need to have identical data pairs in the results array: the weight associated with the particular value is simply adjusted (e.g., if the value occurred twice, its weight would be doubled).
- For computational reasons, the results array has a maximum number of unique results which it can store. The maximum number for post-

processing GoldSim simulation results is 25,000. If the number of realizations exceeds these limits, results are "merged" in a self-consistent manner. The process of merging results when the number of realizations exceeds 25,000 is discussed below.

To merge a new result with the existing results (in cases where the number of realizations exceeds one of the maxima specified above), GoldSim carries out the following operations:

- GoldSim finds the surrounding pair of existing results, and selects one of them to merge with. GoldSim selects this result based on the ratio of the distance to the result to the weight of the result (i.e., the program preferentially merges with closer, lower weight results).
- After selecting the result to merge with, GoldSim replaces its value with the weighted average of its existing value and the new value; it then replaces its weight with the sum of the existing and new weights.

There is one important exception to the merging algorithm discussed above: If the new result will be an extremum (i.e., a highest or a lowest), GoldSim replaces the existing extremum with the new one, and then merges the existing result instead. This means that GoldSim never merges data with an extremum.

Plotting a CDF

Plotting the CDF from the results array is straightforward. The basic algorithm assumes that the probability distribution between each adjacent pair of result values is uniform, with a total probability equal to half the sum of the weights of the values. One implication of this assumption is that for a continuous distribution the probability of being less than the smallest value is simply equal to half the weight of the lowest value and the probability of being greater than the highest value is half the weight of the highest value.

For example, if we have ten equally weighted results in a continuous distribution, there is a uniform probability, equal to 0.1, of being between any two values. The probability of being below the lowest value or above the highest value would be 0.05. GoldSim extrapolates the value at a probability level of 0 using the slope between the first two observations. Similarly the slope between the last two observations is used to estimate the value at a probability level of 1.

Note: Extrapolation is not carried out for Milestone result distributions, Reliability element failure and repair time distributions, Decision Analysis results, and for Sampled Stochastic distributions if the option to extrapolate is not checked.

In certain circumstances there are several minor variations to the basic algorithm discussed above:

- If a large number of results are identical, GoldSim assumes the entire distribution is discrete (rather than continuous), and lumps the probabilities at the actual values sampled. In particular, if more than 50% of the realization results were identical to an existing result (and there are less than 1000 results), GoldSim presumes the distribution is discrete and plots it accordingly. The user can observe this by sampling from a binomial distribution.
- GoldSim uses a heuristic algorithm to decide if each specific result represents a discrete value: if any result is repeated, GoldSim treats the result as a discrete value and does not ‘smear’ it. For example, suppose the result is 0.0 30% of the time, and normal (mean=10, s.d.=2) the rest

of the time. The first result value would be 0.0, with a weight of about 0.3. The second value would be close to 8, with a weight of 1/# realizations. We would not want to smear half of the 0 result over the range from 0 to 8!

When the user selects the confidence bounds options (discussed below), a different algorithm is used to display and plot CDF values. In particular, the displayed value is simply the calculated median (50th percentile) in the probability distribution for the "true" value of the desired quantile.

Displaying a PDF

Displaying PDFs is much more difficult than CDFs, as unless a large number of realizations are run, PDFs tend to be "noisy" even if the corresponding CDF appears smooth (small changes in the slope of the CDF are typically not noticeable to the eye, but these can translate into very noticeable "spikes" in the PDF).

To display a PDF, GoldSim creates a series of equally-spaced bins, with a constant density value within each bin. The density within each bin is the average slope of the CDF over the bin. The number of bins automatically increases with the number of realizations. In particular, the number of bins is equal to the square root of the number of results being considered. The maximum number of bins used is 1000 (and the minimum is 1).

Computing and Displaying Confidence Bounds on the Mean

GoldSim is able to perform a statistical analysis of Monte Carlo results to produce confidence bounds on the mean of a probabilistic result. These bounds reflect uncertainty in the probability distribution due to the finite number of Monte Carlo realizations - as the number of realizations is increased, the limits become narrower. The confidence bounds on the mean are displayed in the Statistics section of the Distribution Summary dialog when viewing Distribution Results if the **Confidence Bounds** checkbox is checked.

Read more: Viewing a Distribution Summary (page 666).

This approach to compute the confidence bounds uses the t distribution, which is strictly valid only if the underlying distribution is normal. The 5% and 95% confidence bounds on the population mean are calculated as defined below:

$$P\{\overline{X} + t_{0.05}\frac{s_x}{\sqrt{n}}\} < \mu = 0.05$$

and $$P\{\overline{X} + t_{0.95}\frac{s_x}{\sqrt{n}}\} \geq \mu = 0.05$$

where:

$\overline{X}$	is the sample mean
$t_{0.05}$	is the 5% value of the t distribution for n-1 degrees of freedom
$t_{0.95}$	is the 95% value, = $-t_{0.05}$.
s_x	is the sample standard deviation
μ	is the true mean of the population, and
n	is the number of samples (realizations).

As the number of realizations, n, becomes large, the Central Limit theorem becomes effective, the t distribution approaches the normal distribution, and the assumption of normality is no longer required. This may generally be assumed

to occur for n in the order of 30 to 100 realizations even for results of highly-skewed distributions.

Computing and Displaying Confidence Bounds on CDFs and CCDFs

GoldSim is able to perform a statistical analysis of Monte Carlo results to produce confidence bounds on the resulting probability distribution curves. These bounds reflect uncertainty in the probability distribution due to the finite number of Monte Carlo realizations - as the number of realizations is increased, the limits become narrower. The confidence bounds are displayed when viewing Distribution Results if the **Show Confidence Bounds** button in the Distribution display window is pressed.

The confidence bounds appear as different-colored curves on the probability plots produced by the GoldSim user interface. The bounds represent 5% and 95% confidence limits on the distribution value at each probability level. Confidence bounds cannot be displayed for PDFs..

The theory used to produce the confidence bounds has several limitations:

- The bounds on distributions can only be calculated for cases where all realizations have equal weights. If importance sampling is used for any parameter is used, GoldSim will not display confidence bounds.
- The confidence bounds cannot be calculated for values less than the smallest result, or greater than the largest result. As a result of this, the confidence-bound curves do not generally reach all of the way to the tails of the result plots.

In cases with relatively few stochastic parameters, Latin Hypercube sampling can increase the accuracy of the probability distributions. The confidence bounds are not able to reflect this improvement, and as a result will be conservatively wide in such cases.

Theory: Bounds on Cumulative Probability

Suppose we have calculated and sorted in ascending order n random results r_i from a distribution. What can we say about the q^{th} quantile x_q (e.g., q=0.9) of the underlying distribution?

Each random result had a probability of q that its value would be less than or equal to the actual q^{th} quantile x_q. The total number of results less than x_q was therefore random and binomially distributed, with the likelihood of exactly i results <= x_q being:

$$P(i) = P(r_i \le x_q \le r_{i+1}) = \binom{n}{i} q'(1-q)^{n-i} = \frac{n!}{i!(n-i)!} q'(1-q)^{n-i}$$

Note that there may be a finite probability that the value of x_q is less than the first or greater than the largest result: for example, if 100 realizations r_i were sampled, there would be a probability of 0.366 that the 0.99 quantile exceeded the largest result. The 100 realization probability distribution for $x_{0.99}$ is as follows:

Between Results	Probability	Cumulative Probability
<94	0.0000	0.0000
94 and 95	0.0005	0.0005
95 and 96	0.003	0.0035
96 and 97	0.015	0.0185
97 and 98	0.061	0.0795

Between Results	Probability	Cumulative Probability
98 and 99	0.1849	0.2644
99 and 100	0.370	0.6344
>100	0.366	1.

GoldSim assumes that the probability defined by the equation presented above is uniformly distributed over the range from r_i to r_{i+1} , and interpolates into the Monte Carlo results-list to find the 5% and 95% cumulative probability levels for x_q. For example, for 100 realizations, the 5% confidence bound on the 0.9 quantile is 0.31 of the distance from result 85 to result 86, and the 95% confidence bound is 0.22 of the distance from result 95 to result 96.

Between Results	Probability	Cumulative Probability
<85	-	0.040
85 and 86	.033	0.073
86 and 87	0.051	0.124
87 and 88	0.074	0.198
88 and 89	0.099	0.297
89 and 90	0.120	0.417
90 and 91	0.132	0.549
91 and 92	0.130	0.679
92 and 93	0.115	0.794
93 and 94	0.089	0.883
94 and 95	0.060	0.942
95 and 96	0.034	0.976
96 and 97	0.016	0.992
97 and 98	0.006	0.998
98 and 99	0.0016	1.000
99 and 100	0.000	1.000
>100	0.000	1.000

Using the above probability distribution, it is also possible to calculate the expected value of x_q,. This approach appears (by experimentation) to provide a slightly more reliable estimate of x_q than the conventional Monte Carlo approach of directly interpolating into the results-list. The expected value of x_q is calculated by summing the product of the probability of x_q lying between each pair of results and the average of the corresponding pair of result-values, i.e.,

$$\bar{x}_q = \sum_{i=1}^{n} P(i) \frac{[r_{i+1} + r_i]}{2}$$

When using this equation to estimate a very high or low quantile, a problem arises when the probability level, q, is near to 0 or 1, as there can be a significant probability that x_q lies outside the range of results. In the first table presented above, for example, there is a 0.366 chance of $q_{0.99}$ exceeding the largest result. In such cases, an estimate of the expected value of x_q can be found by

extrapolating from the probabilities within the range of the results. Obviously, however there are limits to extrapolation and without knowledge of the actual distributional form no extrapolation would produce a reliable estimate of (say) the 0.9999 quantile if only 100 realizations had been performed.

In evaluating the binomial distribution for large values of n, large numbers can be generated which can cause numerical difficulties. To avoid these difficulties, when the number of realizations (n) is greater than 100, GoldSim uses either the normal or Poisson approximations to the binomial distribution. The Poisson approximation is used when i or (n-i) is less than 20 and the normal distribution is used otherwise. These approximations are described in any introductory statistics text.

Computing the Conditional Tail Expectation

The Conditional Tail Expectation (CTE) is the expected value of the result given that it lies above a specified value or quantile (Hardy, 2006). The CTE is displayed in the 'Calculator' portions of the Stochastic and Result Distribution elements, and is an optional output type for a Monte Carlo SubModel element.

Read more: Specifying the Distribution for a Stochastic Element (page 160); Viewing a Distribution Summary (page 666); Creating the Output Interface to a SubModel (page 1059).

For a tail starting at value k, the CTE is defined as:

$$CTE_k = \frac{1}{1-F(k)} \int_k^\infty x \cdot f(x) \cdot dx$$

where:

F(k) is the cumulative probability of value k

f(x) is the probability density at value x

The CTE is related to another statistical measure of a distribution, the partial expectation (PE). The PE is defined as:

$$PE_k = \int_k^\infty (x-k) \cdot f(x) \cdot dx$$

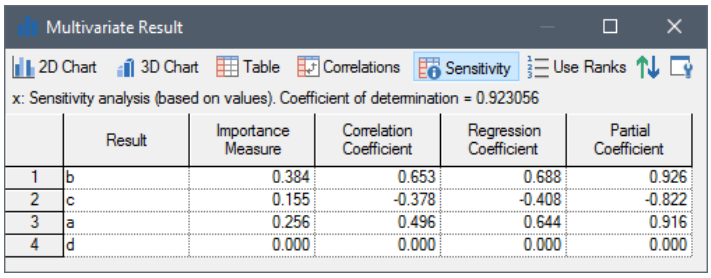
The CTE and PE are related as follows:

$$PE_k = \left(1-F(k)\right)\left[CTE_k - k\right]$$

$$CTE_k = \frac{PE_k}{\left(1-F(k)\right)} + k$$

Computing Sensitivity Analysis Measures

GoldSim provides a number of statistical sensitivity analyses through the multi-variate result display option. If you press the **Sensitivity Analysis…** button from the Multi-Variate Result dialog, a table such as this is displayed:



	Result	Importance Measure	Correlation Coefficient	Regression Coefficient	Partial Coefficient
1	b	0.384	0.653	0.688	0.926
2	c	0.155	-0.378	-0.408	-0.822
3	a	0.256	0.496	0.644	0.916
4	d	0.000	0.000	0.000	0.000

This table displays measures of the sensitivity of the selected result (the output from which you selected **Multi-Variate Result…**) to the selected input variables.

Note: You can control whether the sensitivity analyses are based on the values or the ranks of the variables and the result via the **Use Ranks** button at the top of the display.

The measures that GoldSim computes are:

- Coefficient of determination;
- Correlation coefficient;
- Standardized regression coefficient (SRC);
- Partial correlation coefficient; and
- Importance measure.

The manner in which each of these measures is computed is described below.

Read more: Viewing a Sensitivity Analysis Table (page 746).

Computing the Coefficient of Determination

The coefficient of determination represents the fraction of the total variance in the result that can be explained based on a linear (regression) relationship to the input variables (i.e., Result = aX + bY + cZ + …). The closer this value is to 1, the better that the relationship between the result and the variables can be explained with a linear model.

The formulation for the coefficient of determination (R^2) can be found in Iman (1985). Note that if all of the variables on uncorrelated, then:

$$R^2 = \sum_i C_i$$

Where C_i is the correlation coefficient for variable i.

Computing Correlation Coefficients

Rank (Spearman) or value (Pearson) correlation coefficients range between -1 and +1, and express the extent to which there is a linear relationship between the selected result and an input variable.

The value correlation coefficient is computed as follows:

$$C_{rp} = \frac{\sum_{i=1}^{n}(p_i - m_p)(r_i - m_r)}{\sqrt{\sum_{i=1}^{n}(p_i - m_p)^2 \sum_{i=1}^{n}(r_i - m_r)^2}}$$

where:

C_{rp}= the value correlation coefficient;

n = the number of selected data points (realizations);

p_i = value of output p for realization i;

ri = value of output r for realization i;

m_p = mean value of output p; and

m_r = mean value of output r.

Note that the value correlation coefficient as defined here provides a measure of the *linear* relationship between two variables.

Furthermore, it may be affected by a few aberrant pairs (i.e., a good alignment of a few extreme pairs can dramatically improve an otherwise poor correlation coefficient; likewise, an otherwise good correlation could be ruined by the poor alignment of a few extreme pairs).

To overcome these problems, the value correlation coefficient can be supplemented by the rank correlation coefficient.

The rank correlation coefficient (also referred to as the *Spearman rank correlation coefficient*) is computed using the same equation as that of the value correlation coefficient with the *ranks* of the data values being used rather than the actual values:

$$C_{rp,rank} = \frac{\sum_{i=1}^{n}(Rp_i - m_{Rp})(Rr_i - m_{Rr})}{\sqrt{\sum_{i=1}^{n}(Rp_i - m_{Rp})^2 \sum_{i=1}^{n}(Rr_i - m_{Rr})^2}}$$

where:

$C_{rp,rank}$ = the rank correlation coefficient;

n = the number of selected data points (realizations);

Rp_i = the rank (from 1 to n) of output p for realization I;

Rr_i = the rank (from 1 to n)of output p for realization I;

m_{Rp} = mean value of the rank of output p; and

m_{Rr} = mean value of the rank of output r.

In GoldSim, the ranks of equal values are the same. For example, if the lowest two realizations of an output were the same, their ranks would both be 1.5 (the mean of 1 and 2), with the third lowest value being assigned a rank of 3.

Note: A correlation coefficient cannot be computed for a pair of outputs if one of the outputs has a standard deviation of zero (i.e., is constant). In this case, GoldSim sets the correlation coefficient to zero.

Computing Standardized Regression Coefficients (SRC)

Standardized regression coefficients range between -1 and +1and provide a normalized measure of the linear relationship between variables and the result. They are the regression coefficients found when all of the variables (and the result) are transformed and expressed in terms of the number of standard deviations away from their mean. GoldSim's formulation is based on Iman et al (1985).

The use of standardized regression coefficients to identify the importance of correlated input variables is described in Iman et al (1985) and Mishra (2004). In this approach the correlation matrix C for the input variables is augmented, with an additional row/column assigned for the result (GoldSim uses the first row/column for this purpose).

The standardized regression coefficients are based on the inverse of the augmented correlation matrix, and are found by dividing the terms in the augmented column of the matrix by the negative of the augmented diagonal term:

$$SRC_{y,i} = \frac{-c_{iy}}{c_{yy}}$$

where:

$SRC_{y,i}$ = the standardized regression coefficient of the result (Y) with respect to input variable X_i;

c_{iy} = the off-diagonal term in the inverted correlation matrix for row i, column y; and

c_{yy} = the diagonal term in the inverted correlation matrix corresponding to the result y.

Computing Partial Correlation Coefficients

Partial correlation coefficients reflect the extent to which there is a linear relationship between the selected result and an input variable, after removing the effects of any linear relationships between the other input variables and both the result and the input variable in question. For systems where some of the input variables may be correlated, the partial correlation coefficients represent the "unique" contribution of each input to the result. GoldSim's formulation is based on Iman et al (1985).

The partial correlation coefficient $P_{y,i}$ is calculated as:

$$P_{y,i} = \frac{-c_{iy}}{\sqrt{c_{ii}c_{yy}}}$$

where:

$P_{y,I}$ = the partial correlation coefficient of the result (Y) to input variable X_i;

c_{iy} = the off-diagonal term in the inverted correlation matrix for row i, column y; and

c_{ii}, c_{yy} = the diagonal terms in the inverted correlation matrix corresponding to the input variable and the result, respectively.

Note that if any two or more of the input variables are linearly dependent, for example if they are perfectly correlated, then the correlation matrix becomes singular and cannot be inverted. GoldSim, which uses Choleski decomposition to compute the inverse, will automatically adjust the correlation matrix if necessary in order to compute the partial correlation coefficients. This adjustment, which takes the form of 'weakening' of the off-diagonal terms, does not affect the displayed correlation coefficients.

Computing Importance Measures

If there is a nonlinear, non-monotonic relationship between an input variable and the result, conventional correlation coefficients may not reveal the relationship. The Importance Measure computed by GoldSim is a normalized version of the measure $E[V(Y|X_i)]$ discussed in Saltelli and Tarantola (2002). The Saltelli and

Tarantola measure represents the expected value of the variance if the input variable X_i was not uncertain. Thus, the smaller this value, the more the input variable controls the result.

The GoldSim version of this measure is normalized as follows:

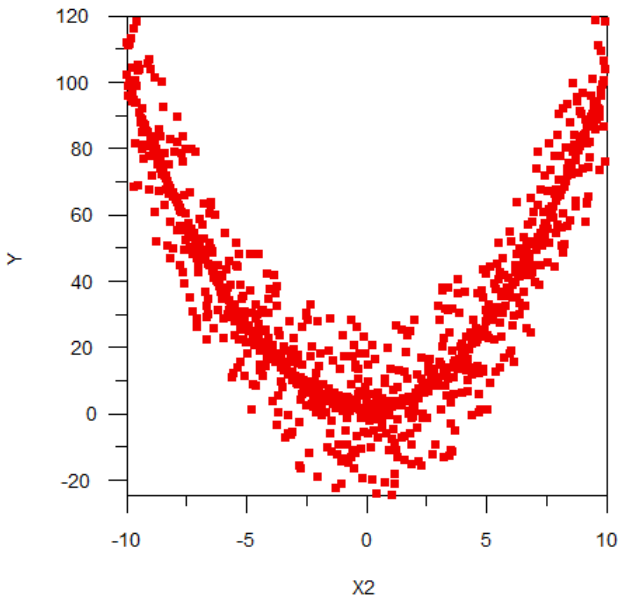
$$M_{y,i} = 1 - \frac{E\left[V_y\left(Y \mid X_i\right)\right]}{V_y}$$

where:

M_y =	the GoldSim importance measure for the sensitivity of the result (Y) to input variable X_i;
V_y =	the current variance in the result Y; and
$E[V_y (Y\|X_i)]$ =	the expected value of V_y if the input variable X_i was perfectly known.

Thus, GoldSim's Importance Measure $M_{y,i}$ represents the fraction of the result variance that is explained by X_i. Note that, like the correlation coefficients and scatter-plots, the importance measure can be calculated using either values or ranks, as specified in the main property window for the multivariate element.

GoldSim calculates $M_{y,i}$ numerically, using the following method. Construct a 2-d scatter plot of the results, with the X_i values on the horizontal axis and the result on the vertical axis. If X_i is very important to the result, then this plot will show a clustering around a central line or curve:



Subdivide the plot into N_s vertical segments based on the ranks of the X_i-values, where N_s equals the square root of the number of model realizations. For each of the segments, estimate the variance of Y within that segment by using a weighting function that assigns decreasing weights to the results as their distance from the center of the segment increases. Then compute the average value of the variance over all of the segments, i.e. $E[V_y (Y|X_i)]$. For the weighting function, GoldSim uses the density of a beta distribution having a mean equal to the X-value at the center of the segment, a standard deviation equal to the segment width, and upper and lower bounds corresponding to the range of X-values.

The example plot above is based on calculating:

$$Y = X_1 + X_2^{\,2} + X_3^{\,3}$$

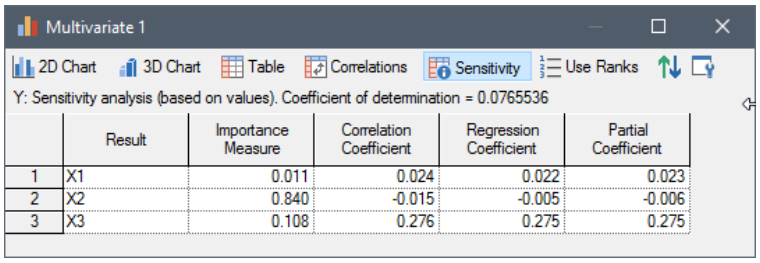
where:

X_1 = a random variable with a U(1,2) distribution;

X_2 = a random variable with a U(-10,10) distribution; and

X_3 = a random variable with a U(-3,3) distribution.

The plot shown above, plotting Y vs X_2, clearly reveals the importance of X_2 in this model. Conventional correlation analysis is completely unable to recognize this sensitivity, as indicated by the correlation coefficient of effectively zero (-0.015) in the screen-shot below. However, the importance measure is sensitive to it, and identifies X_2 as the most importance variable:



	Result	Importance Measure	Correlation Coefficient	Regression Coefficient	Partial Coefficient
1	X1	0.011	0.024	0.022	0.023
2	X2	0.840	-0.015	-0.005	-0.006
3	X3	0.108	0.276	0.275	0.275

References

The references cited in this appendix are listed below.

Cox, D.R. and H.D. Miller, 1965. The Theory of Stochastic Processes, Chapman and Hall, New York.

Benjamin, J.R. and C.A. Cornell, 1970. Probability, Statistics, and Decision for Civil Engineers, McGraw-Hill, New York.

Hardy, Mary, 2006. *Simulating VaR and CTE*, Financial Engineering News, http://www.fenews.com/fen47/topics_act_analysis/topics-act-analysis.htm.

Iman, R.L. 1982. *Statistical Methods for Including Uncertainties Associated with the Geologic Isolation of Radioactive Waste Which Allow for a Comparison with Licensing Criteria*. Proceedings of the Symposium on Uncertainties Associated with the Regulation of the Geologic Disposal of High-Level Radioactive Waste, Gatlinburg, Tennessee, March 9-13, 1981. Kocher, D.C., ed. NUREG/CP-0022. 145-157. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 213069.

Iman, R.L. and W.J. Conover, 1982. *A Distribution-Free Approach to Inducing Rank Correlation Among Input Variables*, Communications in Statistics: Simulation and Computation, 11(3), pp 311-334,

Iman, R.L. et al., 1985. *A FORTRAN Program and User's Guide for the Calculation of Partial Correlation and Standardized Regression Coefficients*, NUREG/CR-4122, SAND85-0044.

L'Ecuyer, P., 1988, *Communications of the ACM*, vol. 31, pp. 742-744.

McKay, M.D., Conover, W. J., and Beckman, R. J., 1979. *A Comparison of Three Methods for Selecting Values of Input Variables*

in the Analysis of Output from a Computer Code, Technometrics, 21, 239-245.

Mishra, Srikanta, 2004. *Sensitivity Analysis with Correlated Inputs – an Environmental Risk Assessment Example*. Proceedings of the 2004 Crystal Ball User Conference, http://www.decisioneering.com/cbuc/2004/papers/CBUC04-Mishra.pdf.

Saltelli, A. and S. Tarantola, 2002. *On the Relative Importance of Input Factors in Mathematical Models: Safety Assessment for Nuclear Waste Disposal*, J. Am. Stat. Ass., Vol. 97, No. 459.

Appendix C: Implementing External (DLL) Elements

> **Begin at the beginning and go on till you come to the end; then stop.**
>
> **Lewis Carroll, *Alice in Wonderland***

Appendix Overview

GoldSim allows you to develop separate program modules (written in C, C++, Pascal, FORTRAN or other compatible programming languages) which can then be directly coupled with the main GoldSim algorithms. These user-defined modules are referred to as *external functions*, and are linked into GoldSim as DLLs (Dynamic Link Libraries) at run time. GoldSim interfaces with the DLL via an *External element*.

Read more: External (DLL) Elements (page 1004).

Integrating your external program module into GoldSim requires that you develop a "wrapper" or "shell" around the function and compile it into a DLL. This appendix discusses the details of how external functions must be coded and compiled.

In this Appendix

This appendix discusses the following:

- Understanding External (DLL) Elements
- Implementing an External Function
- External Function Examples
- External Function Calling Sequence
- DLL Calling Details

Understanding External (DLL) Elements

External functions work with External elements to do calculations or other manipulations that are not included in the standard capabilities of GoldSim. The external function facility allows special purpose calculations or manipulations to be accomplished with more flexibility, speed or complexity than with the standard GoldSim element types.

The external functions are bound to the GoldSim executable code at run time using DLL technology. The DLL files should be present in the same folder as the GoldSim .gsm file, in the same folder as the GoldSim executable file, or elsewhere in the user's path.

Note that these functions are external to GoldSim and are not covered by the standard GoldSim verification process. The user is responsible for any necessary testing of external functions.

Every external function is called by GoldSim with specific requests. The requests include initialization, returning the function version number, performing a normal calculation, and "cleaning up" after a simulation. The function name and argument list (the set of input and output data for the function) are specified by the GoldSim user when setting up the External element.

External functions should provide their own error handling, message handling, file management and memory management if required. It is essential that when it receives a "clean up" request, an external function should release any dynamically acquired memory and close any open files.

Note: In the case of an error condition, the external function should always return an error code to GoldSim, so that the user can be informed about the problem and the simulation can be terminated cleanly with no memory leaks.

Implementing an External Function

Important Restrictions

The implementation of the external function is left to the programmer, but several restrictions apply so that the functions can be correctly called by GoldSim. They are:

- The function return value is ignored. For example, use *void* functions in C/C++, or subroutines in FORTRAN.
- Data are passed from GoldSim to the external function and back again to GoldSim via arrays of double precision floating point input and output arguments.
- Input arguments ***must not*** be modified by the external function. Doing so may cause memory corruption in the DLL and/or GoldSim.
- Each function must manage its own initialization and memory allocation, and its own messages to the user (if any).
- Unique external function (or subroutine) names must be defined in each DLL. In C++, function names are case-sensitive, while in FORTRAN, the case of the external subroutine name is determined from the DLL

build options. In all instances, the function name specified in GoldSim is case-sensitive, and must agree with the case specified in the DLL.

- All files required to run your specific DLL must be properly installed on the machine where GoldSim is running. This includes any additional runtime libraries required by your DLL.
- Most development environments allow both ***static*** and ***dynamic*** binding of runtime libraries to DLLs. DLLs built with static binding are stand-alone, with all run-time library references included in the DLL file. However, if a DLL is built with dynamic binding, the runtime libraries are ***not included***. For a DLL with dynamic binding, the runtime libraries (e. g. **msvcrt.dll** for Visual C++ or **libifcoremd.dll** for Intel Visual Fortran) must be present and in the environment PATH variable on the machine where GoldSim is running.

External Function Format

When calling methods from the DLL, GoldSim always expects the following C/C++ function signature:

```
extern "C" void __declspec(dllexport)
MyExternalFcn(int     XFMethod,
int*    XFState,
double* inargs,
double* outargs)
```

The extern "C" specifies C language style linkage between GoldSim and the DLL, and __declspec(dllexport) makes the function visible outside the DLL.

For Intel Visual Fortran, the following subroutine signature can be used:

```
subroutine my_external_fcn(xfmethod, xfstate, inargs,
outargs)
    !DEC$ ATTRIBUTES dllexport,c :: add_mult_scalars
    !DEC$ ATTRIBUTES value       :: nmethod
    !DEC$ ATTRIBUTES reference   :: nstatus
    !DEC$ ATTRIBUTES reference   :: dinputs
    !DEC$ ATTRIBUTES reference   :: doutputs
```

Other FORTRAN development environments may require different attributes for the proper linkage to GoldSim.

Note: Arrays in C/C++ start at zero, rather than one (the default for FORTRAN). Array indices in this section use the C/C++ convention.

The arguments are :

```
int      XFmethod;   // Action that the external function
                     // must perform  (see table below)
int*     XFState;    // Returned value success 0 or fatal 1
double* inargs;      // Array of input arguments
double* outargs;     // This array returns different
                     // information when different XFmethod
                     // values are passed to the external
```

```
// function.
```

The values for `XFmethod are`:

0	XF_INITIALIZE	Initialize (called at the beginning of each realization). No arguments are passed on this call.
1	XF_CALCULATION	Normal calculation. Total number of output arguments are returned on this call. outargs[0] = 1st result from the function outargs[1] = 2nd result from the function etc.
2	XF_REP_VERSION	External functions report their versions. No input arguments are passed on this call. outargs[0] = external function version, e.g. 1.23
3	XF_REP_ARGUMENTS	External functions report the # of input and output arguments. No input arguments are passed on this call. outargs[0] = # of input arguments. outargs[1] = # of output arguments.
99	XF_CLEANUP	Close any open files, and optionally release dynamic memory at the end of a simulation. No arguments are passed on this call.

The returned values for XFState are:

0	OK, continue GoldSim
>0 and < 99	terminate GoldSim
99	OK, unload the DLL

The following two return codes may only be used for an XF_CALCULATION call:

-1	Fatal error, error message pointer returned
-2	More result memory required; the total amount (in doubles) required is returned in outargs[0]. This may be required of the external function is returning a table or time series definition. (Note that the additional memory is retained until the end of the simulation.)

The memory for the inargs and outargs arrays is allocated by GoldSim at the start of the simulation, based upon the inputs and outputs specified in the Interface tab of the External element properties dialog. The number of input and output arguments is verified during the XF_REP_ARGUMENTS request. GoldSim counts up the number of input and output arguments it expects, and compares it to the numbers for each reported by the DLL.

Warning: It is the responsibility of the external function to ensure that it ***does not*** write to any output arguments beyond the number reported for XF_REP_ARGUMENTS. Doing so may cause memory corruption in GoldSim.

Argument Checking

GoldSim calculates the total number of input and output arguments by summing over the the inputs and outputs specified on the Interface tab of the External element properties dialog. Note that each scalar input or output counts as one argument, while array inputs or outputs count as the size of the array (rows * columns). The calculated totals are then compared to the external function's reported number of input and output arguments. If the number of arguments defined by GoldSim does not agree with the number reported by the external function, GoldSim terminates with an error message.

However, note the following exceptions:

- If outargs[0] is returned as -1, the number of input arguments is not tested. This allows for functions where the DLL does not know in advance the number of input argument that it will receive.
- If the external function will be returning definitions for one or more Tables or Time Series (see below), GoldSim will not know in advance how long the Table definitions will be. In this case, the external function should specify a value for outargs[1] greater than or equal to the actual total number of arguments that may be returned. GoldSim will allocate this amount of memory for outargs. Note that this can be reset during the simulation by returning XFState=-2.

The Input and Output Argument Arrays

The content of input and output argument arrays is determined from the Interface tab of the External element properties dialog.

The following points should be noted:

- Input or outputs are processed in the order specified in the interface. All data from one input or output is contiguous, followed by the data from the next input or output.
- Scalar inputs and outputs are mapped to a single array argument.
- Vector input and output items are specified in order, one argument per item, according to the order specified in the array label.
- Matrix input and output items are specified item-by-item, with all items in one row together, followed by all items in the next row, and so on.
- Lookup Table definitions can be specified in the output interface, via a special format.
- Time Series definitions can be specified as inputs or outputs, also via a special format.

Lookup Table Definitions

External functions can also return Table definition elements to GoldSim. A table definition requires a specific sequence of values, depending whether it is a 1-D, 2-D, or 3-D table.

The sequence for a 1-D table is as follows:

- number of dimensions (in this case, 1)

- the number of rows
- row value1, row value 2, …, row value n
- dependent value 1, dependent value 2, …, dependent value n

The sequence for a 2-D table is as follows:

- number of dimensions (in this case, 2)
- the number of rows, the number of columns
- row value1, row value 2, …, row value n
- column value 1, column value 2, …, column value n
- dependent(row 1, column 1), …, dependent(row 1,column n)
- dependent(row 2, column 1), …, dependent(row 2,column n)
- …
- dependent(row n, column 1), …, dependent(row n, column n)

Warning: This is different than the sequence used to read in an ASCII text file for a 2-D table.

The sequence for a 3-D table is as follows:

- number of dimensions (must be 3)
- the number of rows, the number of columns, the number of layers
- row value1, row value 2, …, row value y
- column value 1, column value 2, …, column value x
- layer value1, layer value 2, …, layer value z
- dependent(row 1, column 1, layer 1), …, dependent(row 1,column x, layer 1)
- dependent(row 2, column 1, layer 1), …, dependent(row 2,column x, layer 1)
- …
- dependent(row y, column 1, layer 1), …, dependent(row y, column x, layer 1)
- .
  .
  .
- dependent(row 1, column 1, layer z), …, dependent(row 1,column x, layer z)
- dependent(row 2, column 1, layer z), …, dependent(row 2,column x, layer z)
- …
- dependent(row y, column 1, layer 1), …, dependent(row y, column x, layer z)

Warning: This is different than the sequence used to read in an ASCII text file for a 3-D table.

Time Series Definitions

External functions can also read and return Time Series Definition. A Time Series Definition consists of the following specific sequence of values.

1. The number 20 (this informs GoldSim that this is a Time Series)
2. The number -3 (this is a format number that infoms GoldSim what version of the time series format is expected)
3. Calendar-baed index: 0 if elapsed time; 1 if dates
4. An index (0,1,2,3) indicating what the data represents (0=instantaneous value, 1=constant value over the next time interval, 2=change over the next time interval, 3=discrete change)
5. The number of rows (0 for scalar time series)
6. The number of columns (0 for scalar and vector time series)
7. Number of series
8. For each series, the following is repeated:
   - The total number of time points in the series
   - Time point 1, Time point 2, …, Time point n

   The structure of the remainder of the file depends on whether the Time Series Definition represents a scalar, a vector, or a matrix.

   For a scalar, the next sequence of values is as follows:

   - Value 1[time point 1], Value 2[time point 2], …, Value[time point n]

   For a vector, the next sequence of values is as follows:

   - Value[row1, time point 1], Value[row1, time point 2], …, Value[row1, time point n]
   - Value[row2, time point 1], Value[row2, time point 2], …, Value[row2, time point n]
   - …
   - Value[row*r*, time point 1], Value[row*r*, time point 2], …, Value[row*r*, time point n]

   For a matrix, the next sequence of values is as follows:

   - Value[row1, column1, time point 1], Value[row1, column1, time point 2], …, Value[row1, column1, time point n]
   - Value[row1, column2, time point 1], Value[row1, column2, time point 2], …, Value[row1, column2, time point n]
   - …
   - Value[row1, column*c*, time point 1], Value[row1, column*c*, time point 2], …, Value[row1, column*c*, time point n]
   - .

- .
- .
- Value[row*r*, column1, time point 1], Value[row*r*, column1, time point 2], …, Value[row*r*, column1, time point n]
- Value[row*r*, column2, time point 1], Value[row*r*, column2, time point 2], …, Value[row*r*, column2, time point n]
- …
- Value[row*r*, column*c*, time point 1], Value[row*r*, column*c*, time point 2], …, Value[row*r*, column*c*, time point n]

External Function Examples

The following is a simple example implementation of DLL code that will work with an External element. This code takes two scalar elements as input, and returns the sum and product to GoldSim. For simplicity, this code is written in C, implemented with Visual C++. This external function can be used with the External.gsm example which can be found in the External subfolder of the the General Examples folder in your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu).

```
// Global enumerations, useful for C-style implementations
//
// XFMethodID identifies the method types, used to identify the phase of
the simulation
// that is currently in progress.
//
//    XF_INITIALIZE    - Called after DLL is loaded and before each
realization.
//    XF_CALCULATE     - Called during the simulation, each time the
inputs change.
//    XF_REP_VERSION   - Called after DLL load to report the external fcn
version number.
//    XF_REP_ARGUMENTS - Called after DLL load to report the number of
input and output //                          arguments.
//    XF_CLEANUP       - Called before the DLL is unloaded.
//
enum XFMethodID
{
    XF_INITIALIZE = 0, XF_CALCULATE = 1, XF_REP_VERSION = 2,
XF_REP_ARGUMENTS = 3,
    XF_CLEANUP = 99
};

// XFStatusID identifies the return codes for external functions.
//
//     XF_SUCCESS          - Call completed successfully.
//     XF_CLEANUP_NOW      - Call was successful, but GoldSim should
clean up
//                           and unload the DLL immediately.
//     XF_FAILURE          - Failure (no error information returned).
//     XF_FAILURE_WITH_MSG - Failure, with DLL-supplied error message
available.
//                           Address of error message is returned in the
first element
//                           of the output arguments array.
//     XF_INCREASE_MEMORY  - Failed because the memory allocated for
output arguments
```

```
//                            is too small.  GoldSim will increase the
size of the
//                            output argument array and try again.
//
enum XFStatusID
{
    XF_SUCCESS = 0, XF_FAILURE = 1, XF_CLEANUP_NOW = 99,
XF_FAILURE_WITH_MSG = -1,
    XF_INCREASE_MEMORY   = -2
};

////////////////////////////////////////////////////////////////////////
//////
// AddMultScalarsInC
//     Adds and multiplies two input scalar values (C Language
implementation).
//------------------------------------------------------------------------
------
extern "C" void __declspec(dllexport) AddMultScalarsInC(int     methodID,
                                                         int*    status,
                                                         double* inargs,
                                                         double* outargs)
{
    *status = XF_SUCCESS;
    switch ( methodID )
    {
    case  XF_INITIALIZE:
        break;                                  // nothing required

    case  XF_REP_VERSION:
        outargs[0] = 1.03;
        break;

    case  XF_REP_ARGUMENTS:
        outargs[0] = 2.0;                       // 2 scalar inputs expected
        outargs[1] = 2.0;                       // 2 scalar outputs
returned
        break;

    case  XF_CALCULATE:
        outargs[0] = inargs[0] + inargs[1];   // return the sum
         outargs[1] = inargs[0]*inargs[1];     // return the product
        break;

    case  XF_CLEANUP:
        break;                                  // No clean-up required

    default:
        *status = XF_FAILURE;
        break;
    }
}
```

The following code is the same algorithm, implemented in Intel Visual Fortran.

```
! Utility module to specify the GoldSim parameter constants
module gs_parameters
    implicit none
```

```
    ! Parameters to identify the method types, which indicate the phase
of the
    ! simulation that is currently in progress.
    !
    ! INITIALIZE       - Called after DLL is loaded and before each
realization.
    ! CALCULATE        - Called during the simulation, each time the
inputs change.
    ! REPORT_VERSION   - Called after DLL load to report the external fcn
version number.
    ! REPORT_ARGUMENTS - Called after DLL load to report the number of
input and output
    !                    arguments.
    ! CLEANUP          - Called before the DLL is unloaded.

    integer(4), parameter :: INITIALIZE       =  0
    integer(4), parameter :: CALCULATE        =  1
    integer(4), parameter :: REPORT_VERSION   =  2
    integer(4), parameter :: REPORT_ARGUMENTS =  3
    integer(4), parameter :: CLEANUP          = 99

    ! Parameters to identify the return codes for external functions.
    !
    ! SUCCESS          - Call completed successfully.
    ! CLEANUP_NOW      - Call was successful, but GoldSim should clean up
    !                    and unload the DLL immediately.
    ! FAILURE          - Failure (no error information returned).
    ! FAILURE_WITH_MSG - Failure, with DLL-supplied error message
available.
    !                    Address of error message is returned in the
first element
    !                    of the output arguments array.
    ! INCREASE_MEMORY  - Failed because the memory allocated for output
arguments
    !                    is too small.  GoldSim will increase the size of
the
                         output argument array and try again.

    integer(4), parameter :: SUCCESS          =  0
    integer(4), parameter :: FAILURE          =  1
    integer(4), parameter :: CLEANUP_NOW      = 99
    integer(4), parameter :: FAILURE_WITH_MSG = -1
    integer(4), parameter :: INCREASE_MEMORY  = -2

end module gs_parameters


!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!
! add_mult_scalars
!     Adds and multiplies two input scalar values.
!-----------------------------------------------------------------------
subroutine add_mult_scalars(method_id, status, inargs, outargs)
    !DEC$ ATTRIBUTES dllexport,c :: add_mult_scalars
    !DEC$ ATTRIBUTES value       :: method_id
    !DEC$ ATTRIBUTES reference   :: status
    !DEC$ ATTRIBUTES reference   :: inargs
    !DEC$ ATTRIBUTES reference   :: outargs

    use gs_parameters
    implicit none
    real(8),    parameter :: VERSION  = 1.03
    integer(4), parameter :: NINPUTS  = 2 ! Two scalar inputs expected
```

```
    integer(4), parameter :: NOUTPUTS = 2 ! Two scalar outputs returned
    integer(4) method_id, status
    real(8)    inargs(*), outargs(*)

    select case (method_id)
    case (INITIALIZE)
        status = SUCCESS
    case (REPORT_VERSION)
        outargs(1) = VERSION
        status = SUCCESS
    case (REPORT_ARGUMENTS)
        outargs(1) = NINPUTS
        outargs(2) = NOUTPUTS
        status = SUCCESS
    case (CALCULATE)
        outargs(1) = inargs(1) + inargs(2)      ! return the sum
        outargs(2) = inargs(1)*inargs(2)        ! return the product
        status = SUCCESS
    case (CLEANUP)
        status = SUCCESS
    case default
        status = FAILURE
    end select

end subroutine add_mult_scalars
```

Additional DLL code examples can be found (including examples for arrays, Lookup Tables, and Time Series Elements) can be found in the GoldSim install directory. In addition to the source files, example solution and project files for Microsoft Visual C++ and Intel Visual Fortran are also included (under General Examples/External).

External Function Calling Sequence

GoldSim makes calls to the DLL external function at different times during the course of a GoldSim simulation:

- Before the simulation starts (while checking model integrity).
- The first time that the External element values are calculated.
- Every time that the input values of the External element change.
- Before each (subsequent) realization.
- After each realization (Cleanup After Realization option only).
- After the simulation finishes.
- If any DLL external function call returns a value of 99.

GoldSim users can control when the DLL is unloaded via the Unload After Each Use and Cleanup After Realization options. These options are selected via checkboxes in the External element properties dialog ("Unload DLL after each use" and "Run Cleanup after each realization"). As the name implies, Unload After Each Use will clean up (XFMethod = XF_CLEANUP) and unload the DLL after each calculation call (XFMethod = XFCalculate). Similarly, Cleanup After Realization will clean up and unload the DLL at the end of each realization (if the DLL is loaded).

The DLL external function code can also control when the DLL is unloaded. If any call to a DLL external function returns a status of 99, GoldSim will treat the call as a success, but will clean up and unload the DLL immediately after processing the returned data.

Before the Simulation

GoldSim calls the DLL external function before the simulation starts, as part of the process to check the validity of the model. The main reason is to get the number of input and output arguments, to insure that they are consistent with what is specified in the Interface tab. The call sequence is as follows:

1. Load the DLL and check for the existence of the external function
2. Ask for the version number (XFMethod = XF_REP_VERSION).
3. Ask for the number of input and output arguments (XFMethod = XF_REP_ARGUMENTS), and compare to the values determined from the External element interface.
4. Clean up (XFMethod = XF_CLEANUP) and unload the DLL.

If any of these calls fail, or if the number of input or output arguments in step 3 are inconsistent, GoldSim will display an error message and return to the previous state (Edit or Ready mode).

During Each Realization

During each realization, GoldSim will call the DLL external function when the corresponding External element needs to be updated. This happens the first time that the Element is referenced, and every subsequent time-step or event update where an input to the Element changes. In this case, the following call sequence is used:

1. Check to see if the DLL is loaded. If so, skip to step 6.
2. Load the DLL and check for the existence of the external function
3. Ask for the version number (XFMethod = XF_REP_VERSION), and write it to the log file.
4. Ask for the number of input and output arguments (XFMethod = XF_REP_ARGUMENTS).
5. Initialize the DLL (XFMethod = XF_INITIALIZE).
6. Calculate (XFMethod = XF_CALCULATE)
7. If Unload After Each Use is specified, clean up (XFMethod = XF_CALCULATE) and unload the DLL.

Before Each Realization

Before each realization, GoldSim will check to see if the DLL is loaded for each External element. If the DLL is loaded, GoldSim will reinitialize the DLL (XFMethod = XF_INITIALIZE).

After Each Realization

If the Cleanup After Realization option is specified, and the DLL is loaded, GoldSim will clean up (XFMethod = XF_CLEANUP) and unload the DLL after each realization.

After the Simulation

After the simulation completes (either successfully or after a fatal error), GoldSim will clean up (XFMethod = XF_CLEANUP) and unload the DLL if it is still loaded.

DLL Calling Details

GoldSim can call DLL external functions by two different mechanisms, depending upon the Separate Process Space option. For each External element, the GoldSim user can select this option in the properties dialog, via the "Run in separate process space" checkbox. If this option is not selected, the DLL will be

loaded with the Win32 LoadLibrary function. As a result, this DLL will share the same memory address space as the GoldSim process, and any memory used in the DLL will be charged to the GoldSim process. By default, External elements are created without the Separate Process Space option enabled.

If the Separate Process Space option is selected, GoldSim will call the DLL using a Component Object Model (COM) interface. The interface is implemented as a COM LocalServer executable, which is started when GoldSim first requests to load the DLL. Once the LocalServer is started, it loads the DLL into its own memory address space (separate from GoldSim), and acts a proxy between GoldSim and the DLL for all external function requests. After the DLL is unloaded, GoldSim frees the COM interface and the LocalServer executable terminates. Because this option loads the DLL into a separate memory space, it may be a better option for DLLs with a large memory footprint.

64-Bit DLL Support

GoldSim also supports loading of external DLLs that are built as 64-bit libraries. The main advantage for a 64-bit DLL is a significant increase in the amount of virtual memory available (from 4GB to 8TB). Migrating DLL code from 32-bit to 64-bit requires minimal (if any) changes; just install the 64-bit compilers for Visual C++ or Visual Fortran and build with a 64-bit target. No change is GoldSim model configuration is required to use 64-bit DLLs, since GoldSim will automatically determine the type of DLL and call the appropriate interface. However, the following caveats do apply when using 64-bit DLLs in GoldSim:

- 64-bit DLLs can only be run on a computer with a 64-bit Windows operating system. If a DLL needs to run on both 32-bit and 64-bit Windows, it should be a 32-bit DLL (which will run on both 64-bit and 32-bit OS).
- 64-bit DLLs must run in a separate process space.
- For Distributed Processing runs, models that contain 64-bit DLLs can only be launched from a 64-bit Windows operating system. GoldSim will inspect the model to see if it contains a 64-bit DLL, and will disconnect all slaves that are running a 32-bit Windows OS.

Returning Error Messages from External Functions

To help GoldSim users debug problems with DLL external functions, GoldSim lets users send an error message from the DLL back to GoldSim through the External element interface when the call to an external function fails. The error message is then displayed to the user in a pop-up dialog.

The DLL external function signals the presence of an error message by returning a status value of -2. When GoldSim processes the results of the DLL external function call, it will interpret the first element of the output arguments arrray (outargs in our source-code example) as a **pointer** to a memory location where the error string can be found. The memory containing the string must have **static** scope, so that it will still be available when GoldSim retrieves the string. The string must also be NULL-terminated, even when returning from a FORTRAN DLL. If either of these recommendations are not followed, GoldSim will likely crash when it tries to display the error message.

The following code is an example of a C language function that will properly handle passing a message from a DLL external function to GoldSim. The ULONG_PTR is cast to different types on 64-bit (unsigned long) and 32-bit (unsigned __int64), so that it will work for building both 32-bit and 64-bit binaries.

```
// Utility method used to simplify sending an error message to GoldSim
void CopyMsgToOutputs(const char* sMsg, double* outargs)
```

```
{
    // Static character array used to hold the error message.
    // For the current incarnation of GoldSim, this is OK.
    // However, it will not be threadsafe if GoldSim simulations
    // become multithreaded.
    static char sBuffer[81];
    // Clear out any old data from the buffer
    memset(sBuffer, 0, sizeof(sBuffer));

    // Cast the first output array element as a pointer.
    // ULONG_PTR is used because it will work for both
      // 32-bit and 64-bit DLLs
    ULONG_PTR* pAddr = (ULONG_PTR*) outargs;

    // Copy the string data supplied into the static buffer.
    strncpy(sBuffer, sMsg, sizeof(sBuffer) - 1);

    // Copy the static buffer pointer to the first output array
    // element.
  *pAddr = (ULONG_PTR) sBuffer;
```

For FORTRAN DLLs, the following code performs the same function:

```
! Utility subroutine to simplify sending an error message to GoldSim
subroutine copy_msg_to_outputs(smsg, outargs)
    implicit none
    character(*) smsg
    real(8) outargs(*)
    ! "Static" character buffer, used to store the error message so
    ! that it can be returned to GoldSim.
    character(80), save :: sbuffer

    ! Create a shared memory variable that can be interpreted either as
    ! integer or real.
    integer(8) ioutput1
    real(8)    doutput1
    equivalence(ioutput1, doutput1)

    ! Copy the message into the buffer.  Truncate it if it is too long
    ! Make sure that it is null terminated!
    if (len(smsg) .lt. 80) then
        sbuffer = smsg // char(0)
    else
        sbuffer = smsg(1:79) // char(0)
    end if

    ! Since we are sending back to C++, we need an actual address.
    ! The "loc" function is not standard, but it is supported by all
    ! compilers that we checked.
    ioutput1 = loc(sbuffer)
    outargs(1) = doutput1
end subroutine copy_msg_to_outputs
```

Appendix D: GoldSim Units Database

364.4 Smoots plus 1 ear.

Official length of the Harvard Bridge

Appendix Overview

One of the more powerful features of GoldSim is that it is *dimensionally-aware*. You enable this capability by assigning dimensions to the outputs (and hence to the inputs) of the elements in your model. GoldSim has an extensive internal database of units and conversion factors. This appendix lists all of the units and conversion factors that are built into GoldSim.

Built-in Units and Conversion Factors

All units in GoldSim are defined relative to the following basic units:

- meter (m)
- kilogram (kg)
- second (s)
- Kelvin temperature (K)
- ampere (amp)
- radian (rad)
- Candela (cd)

The following table summarizes all of the built-in units and conversion factors within GoldSim, organized by category:

Unit	Abbreviation	Definition
Acceleration		
Mean Acceleration of earth's gravity	gee	9.80665 m/s2
Angle		
Degree of Arc	°	0.017453293 rad
One cycle/revolution	cycle	6.2831853 rad
Degree of arc	deg	0.017453293 rad
Minute of Arc	minarc	0.00029088821 rad
Radian	rad	1 rad
Revolution (cycle)	rev	6.2831853 rad
Second of Arc	secarc	4.8481368E-06 rad
Angular Frequency		
Revolutions per minute	pm	6°/s
Area		
Acre	ac	4046.856422 m2
Acre	acre	4046.856422 m2
Hectare	ha	10000 m2
Capacitance		
Farad	Fa	1 s4-amp2/kg-m2
Charge		
Coulomb of Charge	Co	1 s-amp
GigaCoulomb of Charge	GCo	1000000000 s-amp
KiloCoulomb of charge	kCo	1000 s-amp
MillaCoulomb of charge	mCo	0.001 s-amp
MegaCoulomb of charge	MCo	1000000 s-amp
NanoCoulomb of charge	nCo	1.00E-09 s-amp
PicoCoulomb of charge	pCo	1.00E-12 s-amp
TeraCoulomb of charge	TCo	1E+12 s-amp

Unit	Abbreviation	Definition
MicroCoulomb of charge	uCo	1.00E-06 s-amp
Currency		
US Dollar	$	(user defined)
Euro	EUR	(user defined)
British Pound	GBP	(user defined)
Japanese Yen	YEN	(user defined)
Australian Dollar	AUD	(user defined)
Brazilian Real	BRL	(user defined)
Canadian Dollar	CAD	(user defined)
Chinese Yuan	CNY	(user defined)
Czech Koruna	CZK	(user defined)
Danish Krona	DKK	(user defined)
Hong Kong Dollar	HKD	(user defined)
Hungarian Forint	HUF	(user defined)
Mexican Peso	MXN	(user defined)
New Zealand Dollar	NZD	(user defined)
Norwegian Krone	NOK	(user defined)
Russian Rouble	RUB	(user defined)
Singapore Dollar	SGD	(user defined)
Swedish Krona	SEK	(user defined)
Swiss Franc	CHF	(user defined)
South African Rand	ZAR	(user defined)
Thousand US Dollar	k$	1000 $
Thousand Euro	kEUR	1000 EUR
Thousand British Pound	kGBP	1000 GBP
Thousand Japanese Yen	kYEN	1000 YEN
Thousand Australian Dollar	kAUD	1000 AUD
Thousand Brazilian Real	kBRL	1000 BRL
Thousand Canadian Dollar	kCAD	1000 CAD
Thousand Chinese Yuan	kCNY	1000 CNY
Thousand Czech Koruna	kCZK	1000 CZK
Thousand Danish Krone	kDKK	1000 DKK
Thousand Hong Kong Dollar	kHKD	1000 HKD
Thousand Hungarian Forint	kHUF	1000 HUF
Thousand Mexican Peso	kMXN	1000 MZN
Thousand New Zealand Dollar	kNZD	1000 NZD
Thousand Norwegian Krone	kNOK	1000 NOK
Thousand Russian Rouble	kRUB	1000 RUB
Thousand Singapore Dollar	kSGD	1000 SGD
Thousand Swedish Krona	kSEK	1000 SEK
Thousand Swiss Franc	kCHF	1000 CHF

Unit	Abbreviation	Definition
Thousand South African Rand	kZAR	1000 ZAR
Million US Dollar	M$	1000000 $
Million Euro	MEUR	1000000 EUR
Million British Pound	MGBP	1000000 GBP
Million Japanese Yen	MYEN	1000000 YEN
Million Australian Dollar	MAUD	1000000 AUD
Million Brazilian Real	MBRL	1000000 BRL
Million Canadian Dollar	MCAD	1000000 CAD
Million Chinese Yuan	MCNY	1000000 CNY
Million Czech Koruna	MCZK	1000000 CZK
Million Danish Krone	MDKK	1000000 DKK
Million Hong Kong Dollar	MHKD	1000000 HKD
Million Hungarian Forint	MHUF	1000000 HUF
Million Mexican Peso	MMXN	1000000 MZN
Million New Zealand Dollar	MNZD	1000000 NZD
Million Norwegian Krone	MNOK	1000000 NOK
Million Russian Rouble	MRUB	1000000 RUB
Million Singapore Dollar	MSGD	1000000 SGD
Million Swedish Krona	MSEK	1000000 SEK
Million Swiss Franc	MCHF	1000000 CHF
Million South African Rand	MZAR	1000000 ZAR
Current		
Ampere	amp	1 amp
GigaAmpere	Gamp	1000000000 amp
KiloAmpere	kamp	1000 amp
MilliAmpere	mamp	0.001 amp
MegaAmpere	Mamp	1000000 amp
NanoAmpere	namp	1.00E-09 amp
PicoAmpere	pamp	1.00E-12 amp
TeraAmpere	Tamp	1E+12 amp
MicroAmpere	uamp	1.00E-06 amp
Dose		
GigaGray (dose absorbed)	GGy	1000000000 m2/s2
GigaSievert (dose equivalent)	GSv	1000000000 m2/s2
Gray (dose absorbed)	Gy	1 m2/s2
KiloGray (dose absorbed)	kGy	1000 m2/s2
KiloSievert (dose equivalent)	kSv	1000 m2/s2
MilliGray (dose absorbed)	mGy	0.001 m2/s2
MegaGray (dose absorbed)	MGy	1000000 m2/s2
MilliSievert (dose equivalent)	mSv	0.001 m2/s2
MegaSievert (dose equivalent)	MSv	1000000 m2/s2

Unit	Abbreviation	Definition
NanoGray (dose absorbed)	nGy	1.00E-09 m2/s2
NanoSievert (dose equivalent)	nSv	1.00E-09 m2/s2
PicoGray (dose absorbed)	pGy	1.00E-12 m2/s2
PicoSievert (dose equivalent)	pSv	1.00E-12 m2/s2
RAD dose	RADD	0.01 m2/s2
REM dose	REM	0.01 m2/s2
MilliREM dose	mREM	1.00E-05 m2/s2
Sievert (dose equivalent)	Sv	1 m2/s2
TeraGray (dose absorbed)	TGy	1E+12 m2/s2
TeraSievert (dose equivalent)	TSv	1E+12 m2/s2
MicroGray (dose absorbed)	uGy	1.00E-06 m2/s2
MicroSievert (dose equivalent)	uSv	1.00E-06 m2/s2
Electrical Resistance		
GigaOhm	Gohm	1000000000 kg-m2/s3-amp2
KiloOhm	kohm	1000 kg-m2/s3-amp2
MilliOhm	mohm	0.001 kg-m2/s3-amp2
MegaOhm	Mohm	1000000 kg-m2/s3-amp2
PicoOhm	pohm	1.00E-12 kg-m2/s3-amp2
NanoOhm	nohm	1.00E-09 kg-m2/s3-amp2
Ohm	ohm	1 kg-m2/s3-amp2
TeraOhm	Tohm	1E+12 kg-m2/s3-amp2
MicroOhm	uohm	1.00E-06 kg-m2/s3-amp2
Energy		
British Thermal Unit (Int'l)	BTU	1055.056 kg-m2/s2
Calorie	cal	4.1868 kg-m2/s2
Electron Volt	eV	1.60E-19 kg-m2/s2
GigaCalorie	Gcal	4186800000 kg-m2/s2
GigaElectron volt	GeV	1.60E-10 kg-m2/s2
GigaJoule	GJ	1000000000 kg-m2/s2
Joule	J	1 kg-m2/s2
KiloCalorie	kcal	4186.8 kg-m2/s2
KiloElectron volt	keV	1.60E-16 kg-m2/s2
KiloJoule	kJ	1000 kg-m2/s2
Kilowatt-hour	kwh	3600000 kg-m2/s2
MilliCalorie	mcal	0.0041868 kg-m2/s2
MegaCalorie	Mcal	4186800 kg-m2/s2
MilliElectron volt	meV	1.60E-22 kg-m2/s2
MegaElectron volt	MeV	1.60E-13 kg-m2/s2
MilliJoule	mJ	0.001 kg-m2/s2
MegaJoule	MJ	1000000 kg-m2/s2

Unit	Abbreviation	Definition
NanoCalorie	ncal	4.19E-09 kg-m2/s2
NanoElectron volt	neV	1.60E-28 kg-m2/s2
NanoJoule	nJ	1.00E-09 kg-m2/s2
PicoCalorie	pcal	4.19E-12 kg-m2/s2
PicoElectron volt	peV	1.60E-31 kg-m2/s2
PicoJoule	pJ	1.00E-12 kg-m2/s2
TeraCalorie	Tcal	4.1868E+12 kg-m2/s2
TeraElectron volt	TeV	1.60E-07 kg-m2/s2
TeraJoule	TJ	1E+12 kg-m2/s2
MicroCalorie	ucal	4.19E-06 kg-m2/s2
MicroElectron volt	ueV	1.60E-25 kg-m2/s2
MicroJoule	uJ	1.00E-06 kg-m2/s2
Flux (Volume)		
Acre-feet/day	afd	0.01427641 m3/s
US Barrels/day	bpd	1.84E-06 m3/s
Cubic feet per second	cfs	0.028316847 m3/s
US Gallons per minute	gpm	6.31E-05 m3/s
Million gallons per day	MGD	0.043812639 m3/s
Force		
Dyne	dyne	1.00E-05 kg-m/s2
GramForce	gf	0.00980665 kg-m/s2
GigaNewton	GN	1000000000 kg-m/s2
Kilogram Force	kgf	9.80665 kg-m/s2
1,000 Pound force	kip	4448.221909 kg-m/s2
KiloNewton	kN	1000 kg-m/s2
Pound force	lbf	4.448221909 kg-m/s2
Milligram force	mgf	9.81E-06 kg-m/s2
MilliNewton	mN	0.001 kg-m/s2
MegaNewton	MN	1000000 kg-m/s2
Newton	N	1 kg-m/s2
NanoNewton	nN	1.00E-09 kg-m/s2
Ounce force	ozf	0.278013869 kg-m/s2
PicoNewton	pN	1.00E-12 kg-m/s2
TeraNewton	TN	1E+12 kg-m/s2
Ton force	tonf	8896.443819 kg-m/s2
MicroNewton	uN	1.00E-06 kg-m/s2
Frequency (non-angular, Rate)		
PicoHertz (frequency)	pHz	1.00E-12 1/s
Becquerel	Bq	1 1/s
Curie	Ci	37000000000 1/s
GigaBecquerel	GBq	1000000000 1/s

Unit	Abbreviation	Definition
GigaHertz (frequency)	GHz	1000000000 1/s
Hertz (frequency)	Hz	1 1/s
KiloBecquerel	kBq	1000 1/s
KiloHertz (frequency)	kHz	1000 1/s
MilliBecquerel	mBq	0.0011/s
MegaBecquerel	MBq	1000000 1/s
MilliHertz (frequency)	mHz	0.001 1/s
MegaHertz (frequency)	MHz	1000000 1/s
NanoBacquerel	nBq	1.00E-09 1/s
NanoHertz (frequency)	nHz	1.00E-09 1/s
PicoBecquerel	pBq	1.00E-12 1/s
Picocurie	pCi	0.037 1/s
TeraBacquerel	TBq	1E+12 1/s
TeraHertz (frequency)	THz	1E+12 1/s
MicroBecquerel	uBq	1.00E-06 1/s
MicroCurie	uCi	37000 1/s
MicroHertz (frequency)	uHz	1.00E-06 1/s
Illuminance		
Lambert	lamb	10000 cd/m2
Lux (1 lm/m^2)	lx	1 cd/m2
Inverse Area		
Miles per gallon	mpg	425143.68321/m2
Items		
Item	item	(dimensionless)
Persons	pers	1 item
Thousand Persons	kpers	1000 item
Million Persons	Mpers	1000000 item
Length		
Angstrom	Ang	1.00E-10 m
Centimeter	cm	0.01 m
Fathom	fath	1.8288 m
Furlong	flng	201.168 m
Foot (US)	ft, '	0.3048 m
GigaMeter	Gm	1000000000 m
Inch	in, "	0.0254 m
KiloMeter	km	1000 m
Light Year	ly	9.46E+15 m
Meter	m	1 m
Mile	mi	1609.344 m
Mil=0.001 inch	mil	2.54E-05 m
MilliMeter	mm	0.001 m

Unit	Abbreviation	Definition
MegaMeter	Mm	1000000 m
Nautical Mile	naut	1852 m
NanoMeter	nm	1.00E-09 m
PicoMeter	pm	1.00E-12 m
Rod	rd	5.0292 m
TeraMeter	Tm	1E+12 m
MicroMeter	um	1.00E-06 m
Yard	yard	0.9144 m
Luminous Intensity		
Candela	cd	1 cd
GigaCandela	Gcd	1000000000 cd
KiloCandela	kcd	1000 cd
Lumen (cd/Sterradian)	lm	0.079577472 cd
MilliCandela	mcd	0.001 cd
NanoCandela	ncd	1.00E-09 cd
PicoCandela	pcd	1.00E-12 cd
TeraCandela	Tcd	1E+12 cd
MicroCandela	ucd	1.00E-06 cd
MegaCandela	Mcd	1000000 cd
Mass		
Gram	g	0.001 kg
GigaGram	Gg	1000000 kg
KiloGram	kg	1 kg
Pound (mass)	lbm	0.4535924 kg
MilliGram	mg	1.00E-06 kg
MegaGram	Mg	1000 kg
NanoGram	ng	1.00E-12 kg
Ounce (mass)	ozm	0.028349525 kg
PicoGram	pg	1.00E-15 kg
Slug Mass	slug	14.5939039 kg
TeraGram	Tg	1000000000 kg
Ton (mass)	tonm	907.1848 kg
Tonne	tonne	1000 kg
MicroGram	ug	1.00E-09 kg
Math Constants		
Parts per billion	ppb	1.00E-09
Parts per million	ppm	1.00E-06
Percentage	%	0.01
Permeability (seepage)		
Darcy	Darcy	9.87E-13 m2
Millidarcy	md	9.87E-16 m2

Unit	Abbreviation	Definition
Power		
GigaWatt	GW	1000000000 kg-m2/s3
Horsepower (550 ft-lb/sec)	hp	745.6999209 kg-m2/s3
KiloWatt	kW	1000 kg-m2/s3
MilliWatt	mW	0.001 kg-m2/s3
MegaWatt	MW	1000000 kg-m2/s3
NanoWatt	nW	1.00E-09 kg-m2/s3
PicoWatt	pW	1.00E-12 kg-m2/s3
TeraWatt	TW	1E+12 kg-m2/s3
MicroWatt	uW	1.00E-06 kg-m2/s3
Watt	W	1 kg-m2/s3
Pressure, Stress		
Atmosphere	atm	101325 kg/m-s2
Bar	bar	100000 kg/m-s2
GigaBar	Gbar	1E+14 kg/m-s2
GigaPascal	GPa	1000000000 kg/m-s2
KiloBar	kbar	100000000 kg/m-s2
KiloPond	kp	98066.5 kg-m/s2
KiloPascal	kPa	1000 kg/m-s2
MilliBar	mbar	100 kg/m-s2
MegaBar	Mbar	1E+11 kg/m-s2
MilliPascal	mPa	0.001 kg/m-s2
MegaPascal	MPa	1000000 kg/m-s2
NanoBar	nbar	0.0001 kg/m-s2
NanoPascal	nPa	1.00E-09 kg/m-s2
Pascal	Pa	1 kg/m-s2
PicoBar	pbar	1.00E-07 kg/m-s2
PicoPascal	pPa	1.00E-12 kg/m-s2
Pound per square foot	psf	47.88026215 kg/m-s2
Pound per square inch	psi	6894.757749 kg/m-s2
TeraBar	Tbar	1.00E+17 kg/m-s2
Torr (mm Hg)	torr	133.3221913 kg/m-s2
TeraPascal	TPa	1E+12 kg/m-s2
MicroBar	ubar	0.1 kg/m-s2
MicroPascal	uPa	1.00E-06 kg/m-s2
Quantity of Matter		
GigaMol	Gmol	1000000000 mol
KiloMole	kmol	1000 mol
MilliMole	mmol	0.001 mol
MegaMole	Mmol	1000000 mol
Mole	mol	1 mol

Unit	Abbreviation	Definition
NanoMole	nmol	1.00E-09 mol
PicoMole	pmol	1.00E-12 mol
TeraMole	Tmol	1E+12 mol
MicroMole	umol	1.00E-06 mol
Temperature		
Celsius temperature	C	1 K
Celsius degree	Cdeg	1 K
Fahrenheit temperature	F	0.555555556 K
Fahrenheit Degree	Fdeg	0.555555556 K
GigaKelvin temperature	GK	1000000000 K
Kelvin temperature	K	1 K
KiloKelvin temperature	kK	1000 K
MilliKelvin temperature	mK	0.001 K
MegaKelvin temperature	MK	1000000 K
NanoKalvin temperature	nK	1.00E-09 K
PicoKelvin temperature	pK	1.00E-12 K
Rankine temperature	R	0.555555556 K
TeraKelvin temperature	TK	1E+12 K
MicroKelvin temperature	uK	1.00E-06 K
Time		
Year	a, yr	31557600 s
Day	d, day	86400 s
GigaSeconds of time	Gs	1000000000 s
Hour	hr	3600 s
Kilosecond of time	ks	1000 s
Minute of time	min	60 s
Month	mon	2629800 s
MilliSecond of time	ms	0.001 s
MegaSecond of time	Ms	1000000 s
NanoSecond of time	ns	1.00E-09 s
PicoSecond of time	ps	1.00E-12 s
Second of time	s, sec	1 s
TerraSecond of time	Ts	1E+12 s
MicroSecond of time	us	1.00E-06 s
Week	week	604800 s
Date	date	86400 s
Date and time	datetime	86400 s
Velocity		
Feet per minute	fpm	0.00508 m/s
Feet per second	fps	0.3048 m/s
Kilometer per hour	kph	0.277777778 m/s

Unit	Abbreviation	Definition
Knots	kt	0.514444444 m/s
Miles per hour	mph	0.44704 m/s
Viscosity (Absolute)		
Centipose	cp	0.001 kg/m/s
Poise	poise	0.1 kg/m/s
Viscosity (Kinematic)		
Stoke	stoke	0.0001 m2/s
Voltage		
GigaVolt	GV	1000000000 kg-m2/s3-amp
KiloVolt	kV	1000 kg-m2/s3-amp
MilliVolt	mV	0.001 kg-m2/s3-amp
MegaVolt	MV	1000000 kg-m2/s3-amp
NanoVolt	nV	1.00E-09 kg-m2/s3-amp
PicoVolt	pV	1.00E-12 kg-m2/s3-amp
TeraVolt	TV	1E+12 kg-m2/s3-amp
MicroVolt	uV	1.00E-06 kg-m2/s3-amp
Volt	V	1 kg-m2/s3-amp
Volume		
Acre-feet	af	1233.48183754752 m3
Thousand Acre-feet	kaf	1233481.83754752 m3
Million Acre-feet	Maf	1233481837.54752 m3
Barrel (US, oil)	bbl	0.1589873 m3
Barrel (US, dry)	bbldry	0.11563 m3
Barrel (US, liquid)	bblliq	0.11924 m3
Bushel	bushel	0.03523907 m3
Cubic Centimeter	cc	1.00E-06 m3
Cup, US	cup	0.000236588 m3
Fluid ounce	floz	2.96E-05 m3
Gallon (US)	gal	0.003785412 m3
Gallon (Imperial)	gali	0.00454609 m3
Gallon (US)	galus	0.003785412 m3
GigaLitre	Gl, GL	1000000 m3
KiloLitre	kl, kL	1 m3
Litre	l, L	0.001 m3
MilliLitre	ml, mL	1.00E-06 m3
MegaLitre	Ml , ML	1000 m3
NanoLitre	nl	1.00E-12 m3
Pint, US liquid	pint	0.000473177 m3
PicoLitre	pl, pL	1.00E-15 m3
Quart (US)	qt	0.000946353 m3

Unit	Abbreviation	Definition
Standard cubic foot	stcf	0.028316847 m3
Tablespoon	tbsp	1.48E-05 m3
TeraLitre	Tl, TL	1000000000 m3
Teaspoon	tsp	4.93E-06 m3
MicroLitre	ul, uL	1.00E-09 m3

Appendix E: Database Input File Formats

> Art and science cannot exist but in minutely organized particulars.
>
> William Blake, *To the Public*

Appendix Overview

In simulations which require a great deal of input, it may be desirable that the simulation model can access the various data sources directly to ensure the quality of the data transfer.

To facilitate this, GoldSim data entry elements can be linked directly to an ODBC-compliant database.

Read more: Linking Elements to a Database (page 1107).

After defining the linkage, you can then instruct GoldSim to download the data at any time. When it does this, *GoldSim internally records the time and date at which the download occurred*, along with other reference information retrieved from the database (e.g., document references), and this is stored with the model in the Run Log. This allows you to confirm that the correct data were loaded into your model, and provides very strong and defensible quality control over your model input data.

GoldSim can import from three different types of databases: a Generic Database, a Simple GoldSim Database, and an Extended GoldSim Database. This appendix describes the details of the structure and format for each of these three database types.

In this Appendix

This appendix discusses the following:

- Creating a Generic Database
- Creating a Simple GoldSim Database
- Creating an Extended GoldSim Database

Creating a Generic Database

The generic database format requirements are very general:

- The database must be ODBC compliant;
- The selected table must have a field (column) which contains unique IDs which will be used to map data to specific GoldSim elements. These IDs would typically be the GoldSim element names (but they do not have to be).
- The table must have one or more columns containing the data items to be downloaded.

Note that by assigning multiple records and using multiple fields for each ID, you can download vector and matrix data from the generic database.

Read more: Downloading from a Generic Database (page 1111).

The file GenericDatabase.gsm in the General Examples/Database folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) provides an example of how to use a Generic database. This folder also includes the sample database referenced by this file (GenericDatabase.accdb), created using Microsoft Access. In order to use the GoldSim file, you will need to add the database as data sources to your computer.

Read more: Adding Data Sources to Your Computer (page 1109).

Creating a Simple GoldSim Database

A Simple GoldSim database contains the following three tables:

- tbl_Parameter
- tbl_Parameter_Reference
- tbl_Probability_Value_Pairs

Each of these tables is discussed in detail below.

Parameter Table

The Parameter Table (tbl_Parameter) must contain the following fields (which must be named as shown below):

Field Name	Type	Description
UID	AutoNumber	Unique integer number assigned to each element.
Parameter_Name	Text	The ID of the GoldSim element. Note that the length of an element ID in GoldSim is limited to 30 characters.
Parameter_Path	Memo	The full path to the element in GoldSim. This attribute is optional. GoldSim tries to find a record set in the database using the name and path information. If this query is not successful it will try again just querying the name. If a path is specified it must end with '\'.
Type_Code	Text	Code to describe the parameter type (see below).

Field Name	Type	Description
ModDate	Date/Time	Last Date that the parameter properties were changed. Note that this field is for information purposes only and is not used by GoldSim.
Current	Yes/No	This version of the parameter (this record) is considered active in GoldSim if this flag is set to Yes. Note that only one parameter with the same name (and path) should have the current flag set to true.
Description	Text	Description of the parameter, inserted into the Description field for the element.
Unit	Text	Unit abbreviation for the parameter. See Appendix D for unit abbreviations. The unit should be specified without parentheses or brackets.
Arg_1	Number (double)	Value for the first argument for the parameter. All parameters have at least one argument.
Arg_2	Number (double)	Value for the second argument for the parameter
Arg_3	Number (double)	Value for the third argument for the parameter
Arg_4	Number (double)	Value for the fourth argument for the parameter

Note: Particular care must be taken when importing Stochastics from a database, as different Stochastics could have different dimensions (e.g., a Binomial is always dimensionless; a Boolean is always a condition). If a Stochastic is defined in your model as a paticular type of distribution whose output is inconsistent with that of the distribution that you are trying to import from the database, GoldSim will display an error.

Note: Care must also be taken when importing Stochastics that represent temperatures. This is because temperatures have an absolute reference (i.e., absolute zero). *Differences* between temperatures are expressed in 'deg' units (Cdeg, Fdeg). This can lead to errors when importing Stochastics, since GoldSim assumes a single unit for the distribution parameters, while some types of distributions would require two different types of units. For example, a Normal distribution representing a temperature would require the Mean to be specifed in absolute units (e.g., C) and the Standard Deviation to be specified in difference units (e.g., Cdeg). If faced with this problem, there are several approaches for addressing this: 1) Use a distribution type where all parameters have the same units (e.g., triangular, uniform, cumulative); or 2) Specify and import the distributions as dimensionless and then apply a unit to the sampled value using an Expression element.

Read more: Dealing with Temperature Units (page 92).

Warning: The special GoldSim units "date" and "datetime" cannot be used when importing from a database.

Note that the Parameter_Path does not need to be defined (it can be blank). In this case, it does not matter where the element exists in the model. If you specify a path, it must start and end with a backslash (e.g., \container1\container2\ ). If you want to specify the top-level Container (the model root), you should use a single backslash.

If you specify a path, GoldSim first tries to find a record with the specified element name and path. If it does not find it, it tries again, ignoring the path.

If GoldSim finds multiple records with the same name and path, and both have the Current field marked "Yes", it will issue an error message (i.e., if multiple records in the database have the same name and path, only one record can have the Current flag set to Yes).

Parameter Type Codes and Arguments

The codes for the various parameter types, and their required arguments are shown below:

Distribution	Type_Code	Arg_1	Arg_2	Arg_3	Arg_4
constant (Data element)	100	Value			
constant (vector Data element)	101	Number of rows	1 (Number of columns)		
constant (matrix Data element)	102	Number of rows	Number of columns		
uniform	2100	Minimum	Maximum		
log-uniform	2101	Minimum	Maximum		
normal	2200	Mean	Std. Deviation		

Distribution	Type_Code	Arg_1	Arg_2	Arg_3	Arg_4
truncated normal	2202	Mean	Std. Deviation	Minimum	Maximum
log-normal (geometic input)	2300	Geometric Mean	Geometric Std. Deviation		
truncated log-normal (geometric input)	2302	Geometric Mean	Geometric Std. Deviation	Minimum	Maximum
log-normal (true mean input)	2330	True Mean	True Std. Deviation		
truncated log-normal (true mean input)	2332	True Mean	True Std. Deviation	Minimum	Maximum
triangular	2400	Minimum	Most Likely	Maximum	
log triangular	2401	Minimum	Most Likely	Maximum	
triangular (10/90)	2402	10^{th} percentile	Most Likely	90^{th} percentile	
log triangular (10/90)	2403	10^{th} percentile	Most Likely	90^{th} percentile	
cumulative	2500	references Probability_Value_Pairs table (see below)			
Log-cumulative	2501	references Probability_Value_Pairs table (see below)			
discrete	2600	references Probability_Value_Pairs table (see below)			
poisson	2700	Expected Value			
beta (generalized)	2800	Mean	Std. Deviation	Minimum	Maximum
beta (success, failure)	2804	Sucesses	Failures		
BetaPERT	4200	Minimum	Most Likely	Maximum	
BetarPERT 10/90	4201	10^{th} percentile	Most Likely	90^{th} percentile	
gamma	2900	Mean	Std. Deviation		
truncated gamma	2902	Mean	Std. Deviation	Minimum	Maximum

Distribution	Type_Code	Arg_1	Arg_2	Arg_3	Arg_4
weibull	3000	Minimum	Weibull Slope	Mean-Minimum	
truncated weibull	3002	Minimum	Weibull Slope	Mean-Minimum	Maximum
binomial	3100	# of Picks (Batch size)	Probability of Success		
boolean	3200	Probability of True			
Student's t	3300	Degrees of freedom			
exponential	3400	Mean			
pareto	3500	a	b		
truncated Pareto	3502	a	b	Maximum	
negative binomial	3600	Successes	Probability of Success		
extreme value (minimum)	3800	Location	Scale		
extreme value (maximum)	3803	Location	Scale		
extreme probability (minimum)	3900	Number of Samples			
extreme probability (maximum)	3903	Number of Samples			
Pearson type III	4000	Location	Scale	Shape	
sampled results (no extrapolation)	4100	references Probability_Value_Pairs table (see below)			
sampled results (extrapolation)	4103	references Probability_Value_Pairs table (see below)			

Note that for the Discrete, Cumulative and Sampled Results distributions, the first argument references the *val_pair_UID* field in the Probability Value Pairs table (described below).

Parameter Reference Table

The Parameter Reference Table (tbl_Parameter_Reference) allows you to specify reference information for the element.

The table has the following fields:

Field Name	Type	Description
Parameter_UID	Text	Primary Key – link from UID in Parameter Table
GS_Parameter_Note	Text	The text in this field overwrites the Note associated with the element in GoldSim. If left blank here, the Note in GoldSim is not overwritten.

When GoldSim imports text from a database into a GoldSim Note, it automatically converts text to hyperlinks in the Note under the following circumstances:

- Any text beginning the prefixes listed below is converted to a hyperlink. The hyperlink terminates when a space in encountered. As a result, hyperlinks with spaces will not be recognized by GoldSim.
  - http://
  - www.
  - ftp://
  - ftp.
  - file://
- If the character @ is encountered, and text before and after the @ not delimited by a space or a line break will be considered part of the hyperlink.

Array Values Table

The Array Values Table (tbl_Array_Values) is used to store an arbitrary number of array values for a vector or matrix Data element.

The table has the following fields:

Field Name	Type	Description
ID	Number	Unique integer number assigned to each row in the table.
Array_UID	Number	The parameter ID from the Parameter Table (tbl_Parameter) identifying the Data element.
Value	Number	The value for the specified row and column of the array.
Row	Number	The row of the array. This index is 1-based.
Column	Number	The column of the array. This index is 1-based. It must be set to 1 for vectors.

Probability Value Pairs Table

The Probability Value Pair Table (tbl_Probability_Value_Pairs) is used to store an arbitrary number of value pairs used in defining discrete, cumulative and sampled results distributions. No other type of element uses this table.

The table has the following fields:

Field Name	Type	Description
Val_pair_UID	Number	Identifies a set of value-probability-pairs that are used by discrete, cumulative and sampled results distributions. This distribution must specify this ID in arg_1 in tbl_Parameter.
Probability	Number	The probability (for discrete distributions) or cumulative probability (for Cumulative distributions) of the data pair (dimensionless). Ignored for sampled results distributions.
Value	Number	The value corresponding with the defined probability level for Discrete, Cumulative and Sampled Results distributions. Uses the unit defined in the parameter table.

Example File and Database Template

The file SimpleDatabase.gsm in the General Examples/Database folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) provides an example of how to use a Simple GoldSim database. This folder also includes the sample database referenced by this file (SimpleDatabase.accdb), created using Microsoft Access. In order to use the GoldSim file, you will need to add the database as data sources to your computer.

Read more: Adding Data Sources to Your Computer (page 1109).

The Database subfolder also includes a template for creating Simple GoldSim databases (SimpleDatabaseTemplate.accdb). This template file includes two additional tables (providing parameter type codes and unit abbreviations) which can be used to support the implementation of custom forms which allow the user to pick a parameter type code and unit from a list.

Creating an Extended GoldSim Database

An Extended GoldSim database must contain the following three tables:

- GS_Parameter
- GS_Parameter_Value
- GS_Value_Component

Each table is described in detail below.

Note: The tables described below can contain additional fields not used by GoldSim. When importing information, GoldSim will ignore any extra fields.

Parameter Table

The Parameter Table (GS_Parameter) has one record for each linked Element. It contains basic descriptive information about the Element, and an index (Parameter_ID) which links it into the GS_Parameter_Value table. It must

contain the following fields:

No.	Field	Notes
1	Parameter_ID	Unique integer number assigned to each element
2	Parameter_Name	Key field which must match the GoldSim element ID
3	Description	Text description of the element
4	Units	String with GoldSim abbreviations for units of the data (see Appendix D for correct unit abbreviations)
5	Parameter_Code	100 Data element 1nn Array Data element, where nn is the # of columns (01 for vectors) 2100 Stochastic: uniform 2101 Stochastic: log-uniform 2200 Stochastic: normal 2202 Stochastic: truncated normal 2300 Stochastic: lognormal (geometric mean) 2302 Stochastic: truncated lognormal (geometric mean) 2330 Stochastic: lognormal (true mean) 2332 Stochastic: truncated lognormal (true mean) 2400 Stochastic: triangular 2401 Stochastic: log-triangular 2402 Stochastic: triangular (10/90) 2403 Stochastic: log-triangular (10/90) 2500 Stochastic: cumulative 2501 Stochastic: Log-cumulative 2600 Stochastic: discrete: 2700 Stochastic: Poisson 2800 Stochastic: Generalized Beta 2804 Stochastic: Beta (Success, Failure) 2900 Stochastic: Gamma 2902 Stochastic: Truncated Gamma 3000 Stochastic: Weibull 3002 Stochastic: Truncated Weibull 3100 Stochastic: Binomial 3200 Stochastic: Boolean 3300 Stochastic: Student's t 3400 Stochastic: Exponential 3500 Stochastic: Pareto 3502 Stochastic: Truncated Pareto 3600 Stochastic: Negative Binomial 3800 Stochastic: extreme value (minimum) 3803 Stochastic: extreme value (maximum)

No.	Field	Notes
		3900 Stochastic: extreme probability (minimum) 3903 Stochastic: extreme probability (maximum) 4000 Stochastic: Pearson type III 4100 Stochastic: sampled results 4103 Stochastic: sampled results (extrapolation) 4200 Stochastic: BetaPERT 4201 Stochastic: BetaPERT (10/90) 5100 1-D Table 52nn 2-D Table, where nn is the no. of columns File element (no code required)
6	indep_row_units	String with GoldSim abbreviations for units of a table element's Row independent variable (only required for tables)
7	indep_col_units	String with GoldSim abbreviations for units of the 2-D table element's Column independent variable (only required for 2-D tables)
8	bc_date	The default effective date for this item, in format YYYY-MM-DD HH:MM:SS. If no effective date is specified when downloading data, this date is used for this particular element.

Note: Particular care must be taken when importing Stochastics from a database, as different Stochastics could have different dimensions (e.g., a Binomial is always dimensionless; a Boolean is always a condition). If a Stochastic is defined in your model as a paticular type of distribution whose output is inconsistent with that of the distribution that you are trying to import from the database, GoldSim will display an error.

Note: Care must also be taken when importing Stochastics that represent temperatures. This is because temperatures have an absolute reference (i.e., absolute zero). *Differences* between temperatures are expressed in 'deg' units (Cdeg, Fdeg). This can lead to errors when importing Stochastics, since GoldSim assumes a single unit for the distribution parameters, while some types of distributions would require two different types of units. For example, a Normal distribution representing a temperature would require the Mean to be specifed in absolute units (e.g., C) and the Standard Deviation to be specified in difference units (e.g., Cdeg). If faced with this problem, there are several approaches for addressing this: 1) Use a distribution type where all parameters have the same units (e.g., triangular, uniform, cumulative); or 2) Specify and import the distributions as dimensionless and then apply a unit to the sampled value using an Expression element.

Read more: Dealing with Temperature Units (page 92).

Warning: The special GoldSim units "date" and "datetime" cannot be used when importing from a database.

Parameter Value Table

The Parameter Value Table (GS_Parameter_Value) has one record for each Element and each effective date. Each record must have a unique Effective_Date and Value_ID. The Value_ID is an index which is used to link into the actual data values, which are stored in table GS_Value_Component. The GS_Parameter_Value table must contain the following fields:

No.	Field	Notes
1	Parameter_ID	Key to link from items in table GS_Parameter
2	Value_ID	Unique integer key for value record(s) in table GS_Value_Component
3	Effective_Date	The effective date for this item, in format YYYY-MM-DD HH:MM:SS
4	Reference_Document	Written by GoldSim to the Run Log (an optional string)
5	Document_ID	Written by GoldSim to the Run Log (an optional string)
6	DTN	Written by GoldSim to the Run Log (an optional string)
7	MOL	Written by GoldSim to the Run Log (an optional string)
8	DOC_Path	Network path for the source document (required only for File elements, as discussed below)
9	DOC_SIG	CRC signature for File source document (a string required only for File elements)
10	Parameter_Note	Text that is imported into the element's Note. This must be a "Memo" field, and does not support rich text or HTML. Only plain text can be imported.

The CRC signature is an alphanumeric code that can be used to uniquely identify whether the file contents have changed. When you download a file, GoldSim compares the CRC signature of the downloaded file with the original signature that was stored in the database. If these are not identical (indicating that the file has been changed), the download will fail.

You can generate a CRC signature for a file using the EFIViewer, a small utility program that is installed with GoldSim.

Value Component Table

The Value Component Table (GS_Value_Component) stores the actual data values. There are one or more records for each data value. Each record must contain the following fields:

No.	Field	Notes
1	Value_ID	The index used to link from the GS_Parameter_Value table
2	Component_ID	Unique index

No.	Field	Notes
3	Type_Code	Row number for sorting rows in vectors and matrices (used only arrays).
4 - 63	Value_Column_1, …, Value_Column_60	Data values, to support tables and matrices with up to 60 columns.

For a Data element, the data value is stored in Value_Column_1.

For vector Data elements, the data for each item is stored in Value_Column_1, and there should be one record for each row (item) in the vector. For matrix Data elements, the data for each row of the matrix is stored in Value_Column_1 through Value_Column_nn (where nn is as specified in the Parameter_Code field of the Parameter Table), and there should be one record for each row of the matrix.

For a 1-D Table element, the independent variable values are stored in Value_Column_1, and the dependent variable values are stored in Value_Column_2. There is one record for each row in the table.

For a 2-D Table element, the row independent variable values are stored in Value_Column_1, and the dependent variable values are stored in Value_Column_2 through Value_Column_n, where n is one greater than the number of columns in the table. The first record for a 2-D Table element contains values for the column independent variable in Value_Column_2 through Value_Column_n, and the successive records contain values for the Row independent variable followed by values for the dependent variable.

Note: Matrices and 2-D tables can have no more than 60 columns.

For Stochastic elements other than discrete, cumulative and sampled results, the arguments are stored, in sequence, in the Value_Column_1 … Value_Column_n entries. The order of the arguments for each type of Stochastic is listed below:

Stochastic	Order of Arguments
Uniform	minimum, maximum
Log-uniform	minimum, maximum
Normal	mean, standard deviation
Truncated Normal	mean, standard deviation, minimum, maximum
Log-normal (geometric)	geometric mean, geometric standard deviation
Truncated Log-normal (geometric)	geometric mean, geometric standard deviation, minimum, maximum
Log-normal (true mean)	true mean, true standard deviation
Truncated Log-normal (true mean)	true mean, true standard deviation, minimum, maximum
Triangular	Minimum (or 10%), most likely, maximum (or 90%)
Log-triangular	Minimum (or 10%), most likely, maximum (or 90%)
Poisson	expected value
Beta	Successes, Failures

Stochastic	Order of Arguments
Generalized Beta	Mean, standard deviation, minimum, maximum
BetaPERT	Minimum (or 10%), most likely, maximum (or 90%)
Gamma	mean, standard deviation
Truncated Gamma	mean, standard deviation, minimum, maximum
Weibull	minimum, slope, mean-mimimum
Truncated Weibull	minimum, slope, mean-minimum, maximum
Binomial	# picks, probability of success
Boolean	probability of true
Student's t	degrees of freedom
Exponential	mean
Pareto	a, b
Truncated Pareto	a, b, maximum
Negative Binomial	successes, probability of success
Extreme Value (minimum)	location, scale
Extreme Value (maximum)	location, scale
Extreme Probability (mimimum)	number of samples
Extreme Probability (maximum)	number of samples
Pearson type III	location, scale, shape

For a discrete, cumulative or sampled results Stochastic element type, there are multiple rows in the table, with one row for each value. Value_Column_1 contains the probability values, and Value_Column_2 contains the result values. For a sampled results distribution, there is only one value (the result) and this is placed in Value_Column_2 (Value_Column_1 is ignored).

For a Sampled Results distribution, there are multiple rows in the table, with one row for each value. Value_Column_2 contains the result values. Any probabilities entered in Value_Column_1 are ignored (all results have equal weights).

Example File

The file ExtendedDatabase.gsm in the General Examples/Database folder of your GoldSim directory (accessed by selecting **File | Open Example...** from the main menu) provides an example of how to use an Extended GoldSim database. This folder also includes the sample database referenced by this file (ExtendedDatabase.accdb), created using Microsoft Access. In order to use the GoldSim file, you will need to add the database as data sources to your computer.

Read more: Adding Data Sources to Your Computer (page 1109).

Appendix F: Integration Methods and Timestepping Algorithm

> On two occasions I have been asked [by members of Parliament], 'Pray, Mr. Babbage, if you put into the machine wrong figures, will the right answers come out?' I am not able rightly to apprehend the kind of confusion of ideas that could provoke such a question.
>
> Charles Babbage

Appendix Overview

The elements and links in a GoldSim model represent a system of equations. Except in the simplest cases, these are systems of differential equations, and they are often nonlinear and discontinuous. In general, the systems of equations that GoldSim must solve will not have an analytical solution (i.e., they cannot be solved exactly), and must be solved *numerically* (i.e., using an algorithm that provides a numerical approximation to the actual solution).

In order to effectively use GoldSim, particularly for complex problems, it is important to have a basic understanding of the factors affecting the accuracy of your model, and the nature of the numerical approximations used by GoldSim.

This appendix provides a brief discussion of these numerical algorithms.

In this Appendix

This appendix discusses the following:

- Factors Affecting the Accuracy of Simulation Models
- Primary Numerical Approximations in GoldSim
- Summary of GoldSim's Dynamic Timestepping Algorithm

Factors Affecting the Accuracy of Simulation Models

A simulation model is an abstract representation of an actual (or hypothetical) system. By definition, it is a simplification of reality, with the goals being to include those aspects that are assumed to be important and omit those which are considered to be nonessential, so as to derive useful predictions of system performance in an efficient manner.

In addition, for most real world systems, there will be significant uncertainty regarding the processes that are controlling the system and the parameter values describing those processes. As a result, the most important factor impacting the accuracy of your model is the degree to which your conceptual and mathematical model have captured reality and the degree to which you have quantitatively represented your uncertainty in the system. In most real world systems that you would simulate in GoldSim, *the uncertainty in the simulated result due to your uncertainty in the processes and parameters controlling the system will be far greater than any inaccuracies introduced by the numerical solution method.* As a result, it will generally be more worthwhile for you to spend your time ensuring that your model captures the key aspects of the system realistically rather that worrying about the numerical accuracy of the solution.

Having said that, it is still important to understand the nature of the inaccuracies that can arise from GoldSim's numerical approximations in order to ensure that these do indeed remain small. The primary numerical factors affecting the accuracy of a GoldSim model are as follows:

- **Integrating Differential Equations:** GoldSim solves differential equations by numerically integrating them (via Stocks and Delays). This numerical integration is the largest potential source of numerical inaccuracies in a GoldSim model.
- **Solving Coupled Equations:** In some cases, the system you wish to model may include coupled equations or coupled differential equations. Solutions of these types of equations can be computationally-intensive (e.g., nonlinear coupled differential equations). For some specific types of coupled systems, GoldSim provides fast and accurate solution techniques. In other cases, these equations must be solved approximately using Previous Value elements. The use of Previous Value elements in this case can introduce numerical approximations that are of the same order as those introduced via numerical integration of ordinary differential equations.

  Read more: Using Advanced Algorithms to Solve Coupled Equations (page 1218).

- **Representing Discrete Events:** In many real world systems, discrete events occur which impose discontinuous changes onto the system. Superimposing such discontinuities onto a continuously-varying system discretized in time can introduce inaccuracies. GoldSim provides a powerful timestepping algorithm for accurately representing such systems.

These items are discussed in the topics below.

Note: Round-off error is sometimes noted as an important source of error in simulation models. Although this can indeed be important for some specialized engineering and science simulation tools, given the nature of GoldSim applications, and the fact that GoldSim uses double-precision to carry out its calculations, it is highly unlikely that round-off error could ever have a noticeable impact on a GoldSim model.

Primary Numerical Approximations in GoldSim

GoldSim Numerical Integration Algorithm

Stocks (Integrators, Reservoirs and Pools) represent integrals of the form:

$$\text{Value} = \text{Initial Value} + \int (\text{Rate of Change})dt$$

The Rate of Change, of course, can be a function of time.

In this case, we are solving the following differential equation:

$$\frac{d\text{Value}}{dt} = \text{Rate of Change}; \text{Value}_{t=0} = \text{Initial Value}$$

Numerically, GoldSim approximates the integral shown above as a sum:

$$\text{Value}(t_n) = \text{Initial Value} + \sum_{i=1}^{n} \text{Rate of Change}(t_i - \Delta t_i)\,\Delta t_i$$

where:

Δt_i is the timestep length just prior to time t_i (typically this will be constant in the simulation);

Rate of Change($t_i - \Delta t_i$) is the Rate of Change at time=$t_i - \Delta t_i$; and

Value(t_i) is the value at end of timestep i.

Note that the Value at a given time is a function of the Rate of Change at previous timesteps (but is not a function of the Rate of Change at the current time).

This particular integration method is referred to as ***Euler integration***. It is the simplest and most common method for numerically solving such integrals. The key assumption in the method is that the rate remains constant over a timestep. The validity of this assumption is a function of the length of the timestep and the timescale over which the rate is changing. The assumption is reasonable if the timestep is sufficiently small.

To get a feeling for the errors that can be produced by Euler integration, consider the following very simple integral:

$$\text{Value} = \text{Initial Value} + \int -k * (\text{Value})dt$$

where k is a constant. This is the equation for simple (exponential) first-order decay, and the analytical solution is:

$$\text{Value} = \text{Initial Value} * e^{-kt}$$

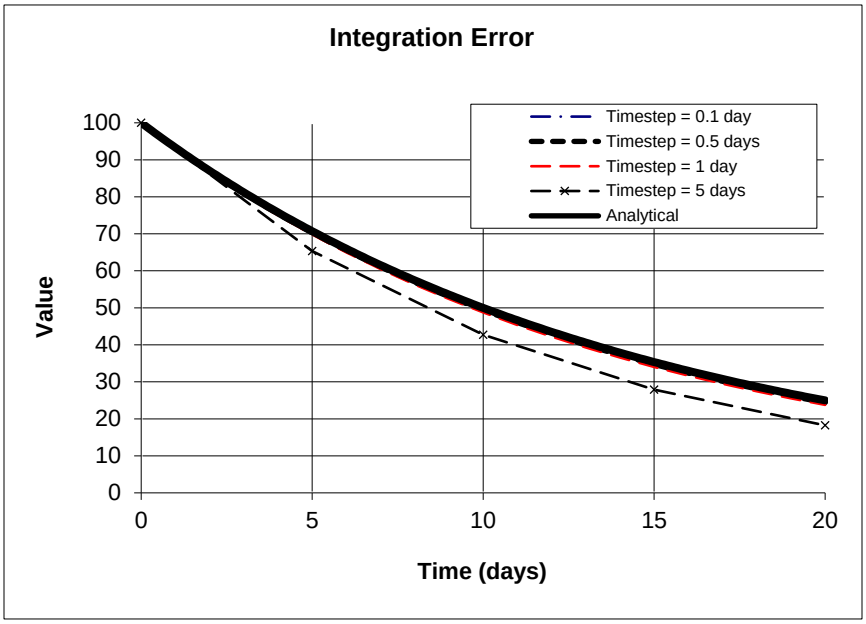
The timescale of the dynamic process can be quantified in terms of a *half-life* (the time it takes the current value to decay to half of its initial value). The half life is equal to 0.693/k. The table below compares the results of computing the

Value analytically and numerically (by comparing the results at 20 days assuming an initial value of 100 and a half-life of 10 days):

Solution	Value at 20 days	% Error*
Analytical Solution	25.00	-
Timestep = 5 days	18.24	9.0%
Timestep = 1 days	23.78	1.6%
Timestep = 0.5 days	24.40	0.8%
Timestep = 0.1 days	24.89	0.1%

*Error computed as $\frac{\text{Simulated - Analytical}}{\text{Analytical- Initial Value}}$

A plot of these results is shown below:



As can be seen, with the exception of the 5 day timestep, the Euler integration method is relatively accurate. In fact, for most systems that you will be simulating using GoldSim, a numerical error of several percent is likely to be acceptable (and much smaller than the error caused by the uncertainty in the initial conditions, the parameters, and the conceptual model). As a general rule, your timestep should be 1/3 to 1/10 of the timescale of the fastest process being simulated in your model.

Read more: Selecting the Proper Timestep (page 1216).

Warning: The magnitude of the integration error depends on the nature of the model. In stable models that are dominated by negative feedback loops (and hence tend toward equilibrium), the errors tend to diminish with time. Systems that are unstable and grow exponentially or oscillate with no damping tend to accumulate errors over time. For these types of systems (e.g., a swinging pendulum), a very small timestep may be required to accurately simulate the system using Euler integration.

Note: In cases where a small timestep is required to maintain accuracy, this can be done in a very computational efficient way by using Containers with Internal Clocks, which allow you to locally use a much smaller timestep.

Read more: Specifying Containers with Internal Clocks (page 493).

Other Integration Methods

Although the Euler method is simple and commonly used, other integration methods exist which can achieve higher accuracy with a larger timestep (e.g., Runga-Kutta, variable timestep methods). Because these methods can use a much larger timestep without losing accuracy, they are more computationally efficient.

These methods, while being important for some types of systems (e.g., sustained oscillators like a pendulum), are not incorporated into GoldSim for the following reasons:

- Higher order methods are most useful when simulating physical systems in which the mathematical model, initial conditions and input parameters are known very precisely, and small integration errors can be significant. For the most part, the kinds of systems that you will be simulating using GoldSim can be handled effectively using Euler integration.
- Higher-order methods work best when simulating continuously-varying systems. They do not deal well with systems that behave discontinuously and/or are impacted by discrete changes. Most real world systems do not vary continuously, and GoldSim therefore provides powerful algorithms for accurately superimposing discrete changes (discontinuities) onto a continuously-varying system. These algorithms are incompatible with higher-order integration methods.

  Read more: Accurately Simulating Discrete Events that Occur Between Timesteps (page 1217).

- For some kinds of systems (e.g., mass or heat transport using the Contaminant Transport Module), GoldSim uses powerful algorithms to accurately solve nonlinear coupled differential equations. These algorithms are incompatible with higher-order integration methods.

  Read more: Using Advanced Algorithms to Solve Coupled Equations (page 1218).

As mentioned above, in cases where a small timestep is required to maintain accuracy using Euler integration, this can be done in a very computational efficient way by using Containers with Internal Clocks, which allow you to locally use a much smaller timestep.

Read more: Specifying Containers with Internal Clocks (page 493).

Approximate Solutions to Coupled Equations

In some situations, you may wish to simulate a static or dynamic processes in which the variables in the system are coupled such that they respond instantaneously to each other, with no time lags. In GoldSim, these are referred to as *recursive loops*, and they are treated differently from feedback loops.

If you encounter a system such as this in one of your models, you can handle it in one of two ways. First, you could solve the system of equations directly either prior to running the model (e.g., using substitution), or dynamically while running the model (e.g., using an External element or GoldSim's matrix

functions to solve the appropriate equations). Note, however, that for many complex models (e.g., non-linear coupled equations), the solution could be very computationally intensive.

GoldSim offers an alternative: solve the equations approximately and iteratively using ***Previous Value elements***. A Previous Value element allows you to reference the previous value (i.e., the previous timestep) of an output.

Read more: Creating Recursive Loops Using Previous Value Elements (page 1033).

Selecting the Proper Timestep

As a general rule, your timestep should be 3 to 10 times shorter than the timescale of the fastest process being simulated in your model. In simple systems, you should be able to determine the timescales of the processes involved. In more complex models, however, it may be difficult to determine the timescales of all the processes involved.

In addition, for some kinds of models (e.g., some oscillating systems), this general rule may not be sufficient and you may need a smaller timestep).

Therefore, after building your model, you should carry out the following experiment:

1. Carry out an expected value or median value simulation.
2. Reduce the timestep length by half (increase the number of timesteps by a factor of 2), rerun the model, and compare results.
3. Continue to half the timestep length until the differences between successive simulations are acceptable.

Summary of GoldSim's Dynamic Timestepping Algorithm

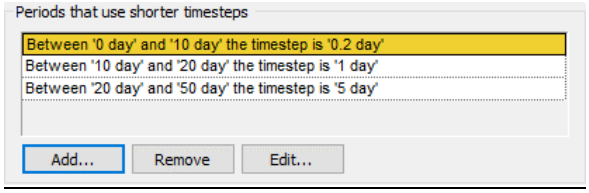
GoldSim provides a powerful timestepping algorithm that can dynamically adjust to more accurately represent discrete events, respond to rapidly changing variables in your model, represent specified SubSystems in your model using different timesteps, and accurately represent some special kinds of systems (e.g., mass and heat transport within the Contaminant Transport Module).

These features are discussed in detail elsewhere in this document. To complement the rest of the information provided in this appendix, however, these features are summarized here.

Defining Specific Periods with Shorter Timesteps

GoldSim allows you to increase or decrease the timestep length according to a specified schedule during a simulation (e.g., start with a small timestep, and then telescope out to a larger timestep). This can be useful, for example, if you know that early in a simulation, parameters are changing rapidly, and hence you need a smaller timestep.

You do this by defining Periods Steps, which have different durations and timestep lengths. An example of pre-specified time periods is shown below:



In this example, the model uses a 0.2day timestep for the first 10 days, a 1 day timestep between 10 days and 20 days, and a 5 day timestep between 20 days and 50 days

(Although not indicated here, it then reverts to the default timestep of 10 days for the remainder of the simulation).

Read more: Adding Shorter Timesteps Over Defined Periods (page 485).

Dynamically Adjusting the Timestep

Although defining shorter timesteps over defined periods can be very useful, you must fully specify them prior to running the simulation. That is, you must know how you would like to alter your timestep prior to running the model. In some cases, however, it may not be possible to do this. That is, in complex systems (particularly ones with uncertain parameters), variables may change at different rates in different realizations, in ways that you cannot predict prior to running the model.

To better simulate these kinds of systems, GoldSim provides an advanced feature that allows you to dynamically adjust the timestep during a simulation (i.e., insert "internal" timesteps) based on the values of specified parameters in your model. For example, you could instruct GoldSim to use a timestep of 1 day if X was greater than Y, and 10 days if X was less than or equal to Y. Similarly, you could instruct GoldSim to use a short timestep for a period of 10 days after a particular event occurs, and then return to the default timestep.

Read more: Dynamically Controlling the Timestep (page 490).

Assigning Different Timesteps to SubSystems

In addition to providing a dynamic timestepping algorithm on a global scale (i.e., for the entire model), GoldSim also enables you to apply dynamic timestepping to specific Containers. This allows you to specify different timesteps for different parts (i.e., Containers) in your model. For example, if one part of your model represented dynamics that changed very rapidly (requiring a 1 day timestep), while the rest of the model represented dynamics that changed much more slowly (requiring a 10 day timestep), you could assign a 10 day timestep to the model globally, and a 1 day timestep to the container representing the SubSystem that changed rapidly.

Read more: Specifying Containers with Internal Clocks (page 493).

Accurately Simulating Discrete Events that Occur Between Timesteps

In some cases, events or other changes in the model may not fall exactly on a scheduled update. That is, some events or changes may actually occur between scheduled updates of the model. These trigger an "unscheduled update" of the model. Unscheduled updates are timesteps that are dynamically inserted by GoldSim during the simulation in order to more accurately simulate the system. That is, they are not specified directly prior to running the model. GoldSim inserts them automatically (and, generally, without you needing to be aware of it).

"Unscheduled updates" can be generated in the following ways:

- When events are ouput by a Timed Event, Event Delay, Discrete Change Delay or Time Series element;
- By manually specifying a dynamic timestep (i.e., dynamically controlling the time between updates);
- When a Reservoir element reaches an upper or lower bound;
- When a Resource becomes exhausted;
- When any element is triggered by an *At Stock Test*, *At Date* or *At Etime* triggering event; and
- By some specialized elements in GoldSim extension modules (Action and Function elements in the Reliability Module, Fund elements in the

Financial Module, and Cell elements in the Flow Module and Contaminant Transport Module).

When any of these events occur, GoldSim automatically inserts an unscheduled update at the exact time that the event or change occurs. For example, if you had specified a one day timestep, and aTimed Event occurs at 33.65 days (i.e., between the scheduled one-day updates), GoldSim would insert an unscheduled update at 33.65 days.

Read more: Understanding Timestepping in GoldSim (page 473).

By default, scheduled updates are always dynamically inserted by GoldSim. However, in some (rare) cases, you may want to prevent unscheduled updates from being inserted. For example, if your model included a specialized algorithm that was designed based on the assumption that the timestep was constant, inserting unscheduled updates could invalidate the algorithm. To support such situations, GoldSim allows you to disable unscheduled updates.

Warning: Because unscheduled updates are intended to more accurately represent a complex dynamic system, disabling this feature should be done with caution, and is generally not recommended.

Read more: Controlling Unscheduled Updates (page 489).

Using Advanced Algorithms to Solve Coupled Equations

For some special types of systems, GoldSim provides additional dynamic timestepping algorithms (different from the timestep algorithms described above) to more accurately solve these equations. For example, the Contaminant Transport Module utilizes dynamic timestep adjustment to solve the coupled differential equations associated with mass and heat transport.

This algorithm allows GoldSim to handle "stiff" systems (systems with widely varying time constants) as well as nonlinear aspects of the system in a very accurate and computationally efficient manner. This algorithm is discussed in the **GoldSim Contaminant Transport Module User's Guide**.

Glossary of Terms

Activation ID

A 32-digit code (8 groups of 4 digits each, separated by hyphens) that is used to activate your license.

Active Scenario

When scenarios have been defined, the scenario that is being viewed when you are browsing a model.

Affects View

A special browser view in GoldSim that allows you to see all the elements the selected element affects.

Alias

The name by which an exposed output of a localized Container is referenced.

Allocator

An element that allocates an incoming signal to a number of outputs according to a specified set of demands and priorities. Typically, the signal will be a flow of material (e.g., water), but it could also be a resource, or a discrete transaction.

Array

A collection of variables that share common output attributes and can be manipulated in GoldSim elements or input expressions.

Array Labels

A collection of labels identifying the items of an array.

Autocorrelate

To correlate a Stochastic element to a previous value of itself.

Browser

An alternative view of a GoldSim model, in which elements are displayed in a tree, and organized either hierarchically, or by type.

Built-in Constants

Constants (such as pi) that are built-in to GoldSim and can be used when creating expressions in input fields.

Built-in Functions

Mathematical functions (such as sine, maximum, round) that are built-in to GoldSim and can be used when creating expressions in input fields.

Capture Times

User-defined points in time during a simulation at which "Final Value" results are captured for result display. The final time point in the simulation is always included as a Capture Time, but additional times can be added.

Causality Sequence

The specific order in which GoldSim updates (computes) elements every timestep.

Change Note

A note added to an element when using versioning that is subsequently displayed when showing changes.

Chart Style

A collection of settings for a particular type of result display chart.

Clones

Sets of elements whose properties change simultaneously when any one member of the set is edited.

Complementary Cumulative Distribution Function

The complement of the cumulative distribution function.

Conceptual Model

A representation of the significant features, events and processes controlling the behavior of a system.

Condition

An output Type. A Condition is a Boolean switch (e.g., Yes/No, True/False, On/Off).

Conditional Expression

An expression which evaluates to (produces) a Condition (rather than a Value).

Conditional Tail Expectation

The expected value of the output given that it lies above a specified quantile. That is, it represents the mean of the worst $100(1 - \alpha)\%$ of outcomes, where α is the specified quantile.

Container

An element that acts like a "box" or a "folder" into which other elements can be placed. It can be used to create hierarchical models.

Convolution Element

An element that solves a convolution integral.

Coupled Link

A link between two elements which causes the elements to be solved in a coupled (rather than a sequential) manner. Coupled links can only be created when using an extension module.

Cumulative Distribution Function

The integral of a probability density function.

Data Source

A source of data external to your GoldSim model that can be automatically imported into GoldSim elements. External data sources are either spreadsheets, text files, databases or DLLs.

Date-time Simulation

A simulation that tracks time using the simulated Date/time.

Delay Elements

A class of elements that simulate processes that delay continuous or discrete signals and flows. The output of a delay element lags its inputs.

Deterministic Simulation

A simulation in which the input parameters are represented using single values (i.e., they are "determined" or assumed to be known with certainty).

Dimensions

An output attribute for an element that defines the dimensionality (in terms of Length, Time and other fundamental dimensions) of the output.

Discrete Change

An element that generates discrete change signals that can subsequently modify stock elements.

Discrete Change Signal

A discrete signal that contains information regarding the response to an event.

Discrete Event Signal

A discrete signal indicating that something (e.g., an accident, an earthquake, a bank deposit) has occurred.

Discrete Signal

A special category of output that emits information discretely, rather than continuously.

Display Units

The units (e.g., m, g, $/day) in which an output is displayed within GoldSim.

Drawing Tools Toolbar

A toolbar at the top of the GoldSim interface that provides buttons for adding graphical components to your model.

Edit Mode

The state of a model when it is being edited and does not contain simulation results.

Elapsed Time Simulation

A simulation that tracks time using the elapsed time.

Euler Integration

A simple and commonly used numerical integration method.

Exposed

Description of an output within a localized Container that can be referenced outside of the Container.

Expression Element

A function element that produces a single output by calculating user-specified mathematical expressions.

External Functions

User-defined modules that can be linked to GoldSim at runtime as Dynamic Link Libraries (DLLs).

Feedback Loop

A looping system in which the variables in the loop represent a closed chain of cause and effect. Note that the terms "feedback" and "cause and effect" intentionally imply that the relationship between the variables is dynamic and the system changes over time (although systems with feedback loops can also reach a dynamic equilibrium). Feedback loops contain at least one state variable.

Function Elements

Elements that instantaneously compute outputs based on one or more defined inputs.

Function Of View

A special browser view in GoldSim that allows you to see all the elements that affect the selected element.

Graphical Objects

Objects in GoldSim that are used to embellish or document the model.

Graphics Pane

The primary portion of the GoldSim interface, where the graphical depiction of the model is shown.

History Generator

An element that generates stochastic time histories of variables. A stochastic time history is a random time history that is generated according to a specified set of statistics.

Importance Sampling

An algorithm that biases sampling of probability distributions in order to better resolve the tails of the distributions.

Information Delay

A delay element that delays information signals, and does not enforce conservation of the signal.

Input Elements

Elements that are used to define basic inputs for a model.

Interactive Result

A result display that is shown in a modal window (i.e., windows that always retain the focus). Interactive results can be converted to modeless Result elements.

Keywords

Text delimited by the % symbol (e.g., %x_unit%) that can be used when creating chart styles to insert context sensitive text (e.g., for axis labels).

Kurtosis

A measure of how "fat" a distribution is relative to a normal distribution with the same standard deviation. A normal distribution has a kurtosis of 0. The kurtosis is a function of the fourth moment of the distribution.

Latin Hypercube Sampling

A stratified sampling method that has the effect of better ensuring that the space of the parameter is uniformly spanned.

Link Cursor

A special cursor for creating links invoked by double-clicking on an input or output object in a browser.

Live Model

When using GoldSim's scenario features, a "scratch" model, or a temporary placeholder model where you can experiment before saving something as a scenario.

Localize

An action that you can apply to a Container that creates a separate scope for the elements in that Container.

Lookup Table Element

A function element that allows you to create a 1, 2, or 3-dimensional lookup table (response surface).

Material

Tangible things (water, dirt, cash, widgets) that are tracked in a simulation.

Material Delay

A delay element that delays flows of materials (e.g., masses, volumes, items).

Mathematical Model

A set of input assumptions, equations and algorithms describing the behavior of a system.

Matrix

A two-dimensional array.

Mean

The expected value (average) of a distribution. It is the first moment of the distribution.

Median

The 50th percentile of a distribution.

Menu Bar

A bar at the top of the GoldSim interface that provides access to menus from which nearly any GoldSim operation can be carried out.

Model Objects

Objects in GoldSim that are used to quantitatively represent the variables and relationships in a model. The primary model object is the element.

Model Root

The top-level Container in a GoldSim model.

Modes

The states that a GoldSim model can be in at a given time. There are three modes: Edit Mode, Run Mode, and Result Mode.

Monte Carlo Simulation

A method for propagating (translating) uncertainties in model inputs into uncertainties in model results.

Network License

A GoldSim license that resides on a License Server and is intended to be shared between multiple users. In order to use the license, your computer must be persistently connected to the License Server (although Network licenses can be "borrowed" from the License Server so that they temporarily reside on your computer and a connection to the License Server is no longer necessary).

Normal Link

A standard link between two elements.

Note Pane

A dockable window in GoldSim that displays a Note associated with the selected element.

Numerical Integration

An approximate solution to an integral equation, carried out by discretizing a variable (e.g., time) into discrete intervals.

Output Attributes

Three properties of an element's output that determine the kinds of inputs to which it can be linked: type, order and dimensions.

Performance Measure

A specific model output by which you judge the performance of a system.

Plot Points

Points in time at which the value of outputs are saved for plotting time history data.

Pool

A stock element that integrates and conserves flows of materials. A Pool is a more powerful version of a Reservoir (it has additional features to more easily accommodate multiple inflows and outflows).

Ports

Small boxes on the side of the element in the graphics pane. You can left-click on a port to access the element's inputs and outputs.

Precedence

The order in which mathematical operators are evaluated in an expression.

Previous Value Element

An element that outputs the value of its input from the previous model update.

Primary Output

For an element with multiple outputs, the output that has the same name as the element.

Probabilistic Simulation

A simulation in which the uncertainty in input parameters is explicitly represented by defining them as probability distributions.

Probability Density Function

A plot of the relative likelihood of the values of an uncertain variable.

Probability Distribution

A mathematical representation of the relative likelihood of a variable having certain specific values.

Probability Histories

A probabilistic representation of the time history of an output in which the percentiles for multiple realizations are plotted.

Probability Mass Function

A plot of the relative likelihood of the values of a discrete uncertain variable.

Realization

A single model run within a Monte Carlo simulation. It represents one possible path the system could follow through time.

Recursive Loop

A system with circular logic that does not contain any state variables.

Reference Version

The version to which your current model is compared when tracking changes.

Reporting Periods

Regular time points during a simulation (e.g., every month, every year) at which you can compute and view results associated with that period (e.g., monthly averages, annual cumulative values).

Reservoir

A stock element that integrates and conserves flows of materials.

Resource

Something that has a limited supply (e.g., spare parts, fuel, skilled personnel, money) and is required in order for elements of the modeled system to carry out certain actions.

Result Element

An element that can be used to organize, analyze and display results.

Result Mode

The state of a model when it has been run and contains simulation results for a single set of input parameters.

Run Control Toolbar

A toolbar at the top of the GoldSim interface that provides buttons for running a model.

Run Log

Text that is stored with a GoldSim model once it has been run. It contains basic information regarding the simulation, and any warning or error messages that were generated.

Run Mode

The state of a model when it is running.

Run Properties

A set of fundamental properties that track the progress of the simulation (e.g., Time, Realization) and can be referenced like outputs in expressions.

Scalar

An output consisting of a single value or condition.

Scenario

A specific set of input data (and corresponding outputs) for a model. Multiple scenarios can be defined for a model. Different scenarios within a model are specifically differentiated by having different values for one or more Data elements.

Scenario Data

Data elements that differentiate the various scenarios in a model.

Scenario Manager

A dialog that allows you to create, define and run scenarios.

Scenario Mode

The state of a model when it contains scenario results, allowing multiple scenarios to be compared.

Scheduled Timesteps

Timesteps that are directly specified by the user prior to running the model.

Scope

The portion of a model from which an element's output can be referenced. You cannot reference an element in a different scope unless that output is specifically exposed.

Script Element

An element that can be used to create a list of executable statements (e.g., variable definitions, variable assignments and statements controlling the

sequence of execution such as loops and if statements) in order to implement complex logic and operations.

Secondary Output

For an element with multiple outputs, an output that has a different name than the element.

Simulation Model

The implementation of a mathematical model of a system within a specific computational tool (or set of tools).

Skewness

A measure of the symmetry of a distribution. A symmetric distribution has a skewness of 0. The skewness is a function of the third moment of the distribution.

Splitter

An element that splits an incoming signal between a number of outputs based on specified fractions or amounts. Typically, the signal will be a flow of material (e.g., water), but it could also be a resource, or a discrete transaction.

Spreadsheet Element

An element that can dynamically link to an Excel spreadsheet.

Standard Deviation

The square root of the variance of a distribution. The variance is the second moment of the distribution and reflects the amount of spread or dispersion in the distribution.

Standalone License

A GoldSim license that resides on an individual computer and is licensed for use just on that computer. As such, it can be used by only one person at a time. The license can be transferred between computers (quickly and easily). There are two types of Standalone licenses: Desktop Standalone licenses, and Enterprise Standalone licenses. The licenses are identical in all respects with one exception: Desktop Standalone licenses limit the number of license transfers (to 6 per year). Enterprise Standalone licenses allow an unlimited number of transfers.

Standard Toolbar

A toolbar at the top of the GoldSim interface that provides buttons for common GoldSim actions.

State Variable

The output of an element in GoldSim whose value is computed based on the historical value of the element's inputs (as opposed to only being a function of the current value of the element's inputs). State variables have well-defined initial conditions. Feedback loops can only be created if they contain at least one state variable.

Status Bar

A bar at the bottom of the GoldSim interface that provides information regarding the status of the model.

Stochastic

An element that can be used to quantitatively represent the uncertainty in a model input.

Stock Elements

A class of elements that numerically integrate inputs, and hence are responsible for internally generating the dynamic behavior of many systems.

Store

Stockpiles or places where a Resource (e.g., parts, personnel) is stored or located when not being used. Resource Stores can be thought of as having physical locations in the system you are modeling. The can be global or local (associated with a Container).

Style File

An external file which stores chart style that you can import.

SubModel

A specialized element that allows you embed one complete GoldSim model within another GoldSim model. This facilitates, among other things, probabilistic optimization, explicit separation of uncertainty from variability, and manipulation of Monte Carlo statistics.

SubSystem

A specialized Container that is completely "self-contained". SubSystems can take on some useful features and properties (e.g., conditionality, having an internal clock, and being able to loop), but also have some limitations (with regard to how they can be incorporated into feedback loops).

System Units File

A file on your hard drive (named units.dat) that stores all of your unit settings.

Table Function

A special function for referencing user-defined lookup tables that can be referenced in input fields. It is automatically created whenever you create a Lookup Table element.

Timed Event

An element that generates discrete event signals based on a specified rate of occurrence.

Timestep

A discrete interval of time used in dynamic simulations.

Total System Model

A simulation model that focuses on creating a consistent framework in which all aspects of the system, as well as the complex interactions and interdependencies between subsystems, can be represented.

Unit Categories

A category of units defined by a name (e.g., Area) and a specific set of dimensions (Length^2).

Unit Strings

Strings containing only unit abbreviations used to define compound units (e.g., m/sec, lbf/m2).

Unscheduled Updates

Timesteps that are inserted automatically by GoldSim during a simulation and are not directly specified by the user prior to running the model.

Vector

A one-dimensional array.

Version

A "snapshot" of your model at a particular point in time.

Versioning

The process of tracking changes that you make to your model file.

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