Addis Ababa University
Addis Ababa Institute of Technology
School of Graduate Studies

Tandem Reservoir Operation of Cascade Hydropower Plants
Case of Genale - Dawa River Basin

A thesis submitted and presented to the school of graduate studies of Addis Ababa University in partial fulfillment of the degree of Masters of Science in Civil Engineering (Major Hydropower Engineering)

By

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Advisor

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Addis Ababa University
Ethiopia
September, 2014

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CERTIFICATION

I, the undersigned, certify that I have read and here by recommended for acceptance by the Addis Ababa University a dissertation entitled: **Tandem Reservoir Operation of Cascade Hydropower Plants Case of Genale - Dawa River Basin** and here by recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements of the degree of Masters of Science in Hydropower Engineering.

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Date

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I, Tsegazeab Dejene Mekonnen, declare that this is my own original work and that it has not been presented and will not be presented to any other University for similar or any degree award.

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Date

Dedicated to

My father, Dejene Mekonnen

ACKNOWELEDGEMENT

First and above all, I praise God the almighty, his mother saint Virgin Mary and his saints for providing me this opportunity and granting me the capability to proceed successfully.

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Abstract

Genale – Dawa river basin is one of the twelve river basins in Ethiopia with catchment area of 74,010 Km^2 and has the third largest surface area (about 170,000km^2) after Wabishebele and Abay River basins. Genale-Dawa river basin has an estimated hydropower potential of 9,300 GWh/year and is expected to contribute about 5.8% of the total estimated potential of the country.

Out of the nine large scale hydropower potential projects in the basin, this study deals with the optimal operation of the cascade hydropower plants namely, GD-3, GD-5 and GD-6 that are located on the main river channel of Genale River. The upper most hydropower plant, GD-3, is already under construction and the other two are under study.

The latest version of HEC-ResSim (Version 3.1) introduced by U.S. Army Corps of Engineers in 2013 is used to simulate the multi-reservoir system network. The physical and operational data are obtained from previous studies of these projects and used as input in reservoir network module of ResSim Model. Implicit (default) and Explicit (user defined) system storage balance has been used to get the maximum power and energy and plot the optimal guide curve so as to be used by the operator to attain the optimal overall energy generated from the system. The explicit system storage balance has generated a better power and energy for the reservoir system.

The study showed that, when the individual hydropower reservoirs deliver energy and capacity into a common power system, operating the projects as system has produce more average energy or firm energy than the sum of individual projects operating independently. The maximum overall average energy of the system found in this study is 4417.7GWh/yr. Comparing with the feasibility study, the proposed model is capable to produce an extra amount of 487.7 GWh average electrical energy (a 12.4% increment) annually.

The optimal guide curve denotes that there is a tendency, in the optimal explicit system storage, to leave more water from GD-3 reservoir and prepare the storage to hold more water during high flood seasons. The water released from this reservoir can generate additional power at the downstream power plants. The reverse is true for the operation of the downstream power plants. The pool level of GD-5 is almost in the flood zone except for the first three months, January to March, where the pool level is in the active live storage zone. In GD-6 the reservoir pool level is in the flood zone throughout the year.

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Abbreviations

DEM	Digital elevation Model
EEPCO	Ethiopian Electric Power Corporation
ET_O	Potential Evapotranspiration
FSL	Full supply level
GIS	Geographic Information System
HEC	Hydrologic Engineering Center
HEC-ResSim	Hydrologic Engineering Center Reservoir Simulation
HEC-DSS	Hydrologic Engineering Center Data Storage Service
MoWIE	Ministry of water, irrigation and energy
Max	Maximum
Min	Minimum
MOL	Minimum operating Level
masl	meter above sea level
NMA	National meteorological Agency
GD	Genale - Dawa
ICS	Interconnected system

Units

ha	Hectare
km	Kilometer
Km^2	kilometer square
l/s	Liter per second
mm	millimeter
Mm_3	million cubic meters
MW	Mega watt
MWh	Mega watt hour
GWh	Giga Water hour

1. INTRODUCTION

1.1 Background

Power is a very important part of the infrastructure development of a nation and it is also too important for the economic growth of the country. In a country like Ethiopia for improvement of standard of living, the development of power is of vital importance. Ethiopia is blessed with abundant water resources distributed in many parts of the country. However, it has not made significant progress in the field of water resources development during the past four decades (Solomon, 2009). In particular, the exploitation of hydropower potential was not noticeably successful in spite of being given priority as major field of national development. Ethiopia has possible source for energy requirement in the country with plenty amount of water and suitable topographical feature for head development of a plant in hydropower.

Considering the substantial hydropower resources, Ethiopia has one of the lowest levels of per capita electrical consumption in the world. Out of hydropower potential of about 45,000 MW, only about 1939.6MW (i.e. about 4.3%) has been exploited up to 2013(EEPCo, 2013)

The existing power generation in Ethiopia and the projected energy requirements from the year 1990 through 2040 indicate and prove that the power generation needs to be increased by 4 times by the year 2000, more than 14 times by 2020 and about 25 times by 2040 (Solomon, 2009).

Genale –Dawa river basin being one of the largest basins, with catchment area of 74,010 Km^2 has an estimated potential of 9,300 GWh/year and is expected to contribute 5.8% of the total estimated potential of river basin in the country. Moreover early studies show that Genale- Dawa river basin has a potential site of 18 small scaled (40MW), 4 medium scaled (40-60MW) and 9 large scale (>60MW) with a total of 31(Solomon, 2009). According to the natural feature of the river basin the river can be exploited by cascading so as to make best use of the river fall. Out of the above mentioned large scale hydropower plants this research deals on the optimal operation of the three cascade hydropower plants, namely GD-3, GD-5 and GD-6.

The presence of plenty of water resource and construction of large to low scale hydropower plants, water supplies, irrigation etc. cannot be guarantee for the proper use and sustainability of the resource. To ensure this sustainability, and use the resource to the best, resource management is mandatory.

Reservoirs are one of the major storages of surface water and optimally operating single or multi-reservoir network forms an integral part in water resources management. By altering the spatial and temporal distribution of runoff, reservoirs serve many purposes, such as flood control, hydropower generation, navigation, recreation, etc. (Chen et al., 2011). Reservoir operation is a complex problem that involves many decision variables, multiple objectives as well as considerable risk and uncertainty (Oliveira and Loucks, 1997). In addition, the conflicting objectives lead to significant challenges for operators when making operational decisions. Traditionally, reservoir operation is based on heuristic procedures, embracing rule curves and subjective judgments by the operator. This provides general operation strategies for reservoir releases according to the current reservoir level, hydrological conditions, water demands and the time of the year (Long le Ngo et al., 2006). Established rule curves, however, do not allow a fine-tuning (and hence optimization) of the operations in response to changes in the prevailing conditions. Therefore, it would be valuable to establish an analytic and more systematic approach to reservoir operation, based not only on traditional probabilistic/stochastic analysis, but also on the information and prediction of extreme hydrologic events and advanced computational technology in order to increase the reservoir's efficiency for balancing the demands from the different users.

During the past few decades, various optimization and simulation models have been developed in order to support the decision-making process of the reservoir operation and reviewed by many authors. These techniques include Linear Programming (LP); Nonlinear Programming (NLP); Dynamic Programming (DP); Stochastic Dynamic Programming (SDP); and Heuristic Programming such as Genetic algorithms, Shuffled Complex Evolution, Fuzzy logic, and Neural Networks etc.

Most of the hydropower plants are still managed on fixed predefined operating rules. This is mainly due to institutional, rather than technological and mathematical limitations(Chen et al., 2011). These predefined operating rules are usually presented in the form of graphs and tables and called reservoir operation charts. It represents all the regular functions of operating rules and provides guidance to system operators. Although various operation models based on optimization and simulation models are available, conventional simulation model is still widely used for deriving operation rules due to its concise and direct viewing.

However it is used in single reservoir operations, and cannot be used in combined operation of cascade reservoirs. Therefore poor storage distribution can be seen among cascade reservoirs. Hence, much of flood water resources are wasted during flooding seasons. Several attempts have been made to solve this problem in the recent past.

Due to the lack of such advanced reservoir operation system in the country the fluctuation and shortage of power production and improper operation of any one of the reservoir technically inefficient operation that failed to meet the desired objective has been noticed. Therefore, this study will attempt to develop advanced reservoir operation for the combined operation of cascade reservoirs using the HEC-ResSim model.

1.2 Problem Statement

Ethiopia is endowed with abundant water resources distributed in many parts of the country, which can be appropriately utilized to enhance socio-economic development of its people. Due to underdevelopment of this resource among others, the people of Ethiopia have been exposed to major problems such as impacts of drought and flood, shortage of clean water supply and inadequate energy supply.

Like many river basins in Ethiopia, water resources in the Genale Dawa river basin are not fully developed and optimally allocated yet. And also no great research effort has been put into evaluation of the developed master plan under updated models for water allocation or other purpose.

Hydropower projects on tributaries and the main stream could rapidly modify seasonal flows by means of their storages. Improper operation of any one reservoir especially in the case of series reservoir systems, will lead to technically and economically inefficient operation that fail to meet the desired objective (Genet, 2008).

Most of the reservoirs in our country have a lack of predetermined, up-to-date and real time reservoir operation policy that will benefit all users in the basin. It is not unusual to observe that most of the reservoirs are unable to meet the desired purpose due to lack of optimum operation policies (Daniel, 2011).

Power interruption is common in years of severe drought over the country and shortages in water disrupt power plant operation. For example, the 2008–9 droughts caused a power interruption that was lasted for about four months with a one-day-per-week complete interruption throughout the country; hampering all business and economic activities. The crisis has also reached a critical point that blackouts occurred every other day with the water level in the currently operating hydropower generation dams going down by an average of one to two centimeters every day (Daniel, 2011).

Therefore, proper reservoir operation is mandatory both at the planning and real time operation in order to attain the objective of the power plants.

Furthermore, joint operation of reservoirs in series may generate more power than the sum of the power generated operating each reservoir individually.

According to the natural feature of the river basin, Genale river can be exploited by cascading so as to make best use of the river fall. Feasibility study of the three cascaded hydropower plants has been studied and one of them, GD-3 that is located up stream of the two plants, final design has been completed and it is already under construction. Reservoir operation of the three reservoirs in series at Genale river shall then be studied with up to date technology at the planning stage in order to use the potential resource of the river.

Thus, identifying the total inflow to and outflow volume from the selected reservoirs, developing operation rule and assessing optimal hydropower production capabilities of the Cascade reservoirs in the main stream of Genale river by operating the reservoirs jointly shall be studied for the proper use of the potential water resource in the river.

1.3 Objective of the Study

1.3.1 General Objective

The general objective of this study is to develop the Tandem cascade multi-reservoir system operation of the three planned hydropower plants at the main stream of Genale river using HEC-ResSim (Hydrologic Engineering Center –Reservoir System Simulation) model.

1.3.2 Specific Objective

- To construct and set up a river/reservoir simulation model for the three cascaded reservoirs (GD-3, GD-5 and GD-6) in Genale River using the HEC-ResSim model.
- To undertake reservoir joint operation simulation, that helps in evaluating the best way to utilize the reservoir storage for power generation
- To develop reservoir water release rule for the each hydropower schemes.

1.4 Structure of the Thesis

The thesis has been organized to have seven chapters including the introductory section. General overviews of each chapter are discussed as follows

Chapter 1 comprises the introduction part, problem statement and objectives of the study.

Chapter 2 is the literature review and discusses about methods how to manage water resources at a river basin scale and general river/reservoir simulation and operation techniques. The chapter reviews the available simulation models and describes the HEC-ResSim model, it characteristics and applications. Besides, the general condition and previous studies conducted in the basin are broadly discussed in the chapter.

Chapter 3 gives a description of the study area, including the main characteristics of the Genale-Dawa river basin including the location, rainfall characteristics, land use and topography. The chapter also discusses about the location, physical and operational characteristics of the existing hydropower plants and reservoirs

Chapter 4 describes methodology used to achieve the objectives of the thesis. The chapter focuses on hydrological, meteorology, operational and physical data collection and analysis.

Chapter 5 deals with how HEC-ResSim model was developed for Genale-Dawa river basin and the number of alternatives used for the analysis to get the optimal power and/or energy from the system.

The results are discussed in Chapter 6 and conclusion and recommendation are given on Chapter 7. Finally References and Appendices are attached.

2. LITERATURE REVIEW

2.1 Decision Making Technologies in Water Management

The competition for available water resources in much of the developing world is growing rapidly due to ever-increasing and conflicting demands from agriculture, industry, urban water supply and energy production. The demand is fueled by factors such as population growth, urbanization, dietary changes and increasing consumption accompanying economic growth and industrialization. Climatic changes are expected to further increase the stress on water resources in many regions.

The traditional fragmented approach is no longer viable and a more holistic and coordinated approach to water management is essential. River basin management engages the development, conservation, control, regulation, protection, allocation and beneficial use of water in streams, rivers, lakes, and reservoirs. Public recreation, water quality, erosion and sedimentation, protection and enhancement of fish, wildlife, and other environmental resources are important considerations in managing reservoir/river systems.

Nevertheless, the multi-interdepent objective and constraints of river basin systems has made it difficult to satisfy large number of possible design and operating policies. Very often there is no assurance that the best combination of policies and structural measures can be found, especially when the river basin is large with a large number of reservoirs (or reservoir systems) and a large variety of short- and long-term interests that have to be satisfied. Thus the need to manage these complex integrated interests in a river basin or Reservoir system has lead to a need for computer based Decision Support Systems (DDS) that can provide balanced use of water as well as allow the decision maker to easily modify operating policy and physical and economic characteristics of a particular river basin.

Computer based Decision Support Systems (DSS) are being used worldwide in order to manage more wisely our water resources. Simonovic (1996) presents the role of DSS in achieving a sustainable use of water resources:“A Decision Support System allows decision-makers to combine personal judgment with computer output, in a user machine interface, to produce meaningful information for support in a decision-making process. Such systems are capable of assisting in solution of all problems (structured, semi structured, and unstructured) using all information available on request. They use quantitative models and database elements for problem solving. They are an integral part of the decision-makers approach to problem identification and solution". According to him a DSS must help decision makers at the upper levels, must be flexible and respond to questions quickly, must provide a solution for "what if" scenarios and must consider the specific requirements of the decision makers. Particularly water allocation models are being widely used in order to assess the impacts of future development trends, water management strategies, climate change, etc on the availability of water resources (Simonovic, 1996).

2.2. Reservoir operation

Reservoir operation is the method used to allocate water stored in the reservoir among different upstream and downstream users. It is an important element in water resources planning and management. Reservoir operation consists of several control variables that defines the operation strategies for guiding a sequence of releases to meet a large number of demands from stakeholders with different objectives, such as flood control, hydropower generation and allocation of water to different users. A major difficulty in the operation of reservoirs is the often conflicting and unequal objectives that require optimal operation rule and strong decision support system.

2.2.1. Reservoir System Operation Policy

The coordinated operation of multiple-reservoir systems is typically a complex decision-making process involving many variables, many objectives, and considerable risk and uncertainty. System operators are challenged to meet often conflicting objectives while complying with all legal contracts, agreements, and traditions affecting water allocations and use.

An operating plan or release policy is a set of guidelines for determining the quantities of water to be stored and to release or withdraw from a reservoir or system of several reservoirs under various conditions. Operating decisions involve allocation of storage capacity and water releases between multiple reservoirs, between project purposes, between water uses, and between time periods. Typically, a release plan includes a set of quantitative criteria within which significant flexibility exists for qualitative judgment. Operating plans provide guidance to reservoir management personnel. In modeling and analysis of a reservoir system, some mechanism for representing operating rules and/or decision criteria must be incorporated in the model. Reservoir system analysis models contain various mechanisms for making period-by-period release decisions within the framework of user-specified operating rules and/or criteria functions.

2.2.2. Reservoir Rule Curves

The terms rule curve or guide curve are typically used to denote operating rules which define ideal or target storage levels and provide a mechanism for release rules to be specified as a function of storage content. Rule curves are usually expressed in as water surface elevation or storage volume versus time of the year. Although the term rule curve denotes various other types of storage volume designations as well, the top of conservation pool is a common form of rule curve designation.

The top of conservation pool may be varied seasonally, particularly in regions with distinct flood seasons. The seasonal rule curve illustrated by Figure 2-1 reflects a location where summer months are characterized by high water demands, low stream flows, and a low probability of floods. The top of conservation pool could also be varied as a function of watershed moisture conditions, forecasted inflows, floodplain activities, storage in other system reservoirs, or other parameters as well as season of the year. A seasonally or otherwise varying top of conservation pool elevation defines a joint use pool which is treated as part of the flood control pool at certain times and part of the conservation pool at other times. Figure 2-2 illustrates such an operating plan where upper and lower zones are used exclusively for flood control and conservation purposes, respectively, and the storage capacity in between is used for either purpose depending on season or other factors. Also, either the flood control or conservation pool can be subdivided into any number of vertical zones to facilitate specifying reservoir releases as a function of amount of water in storage.

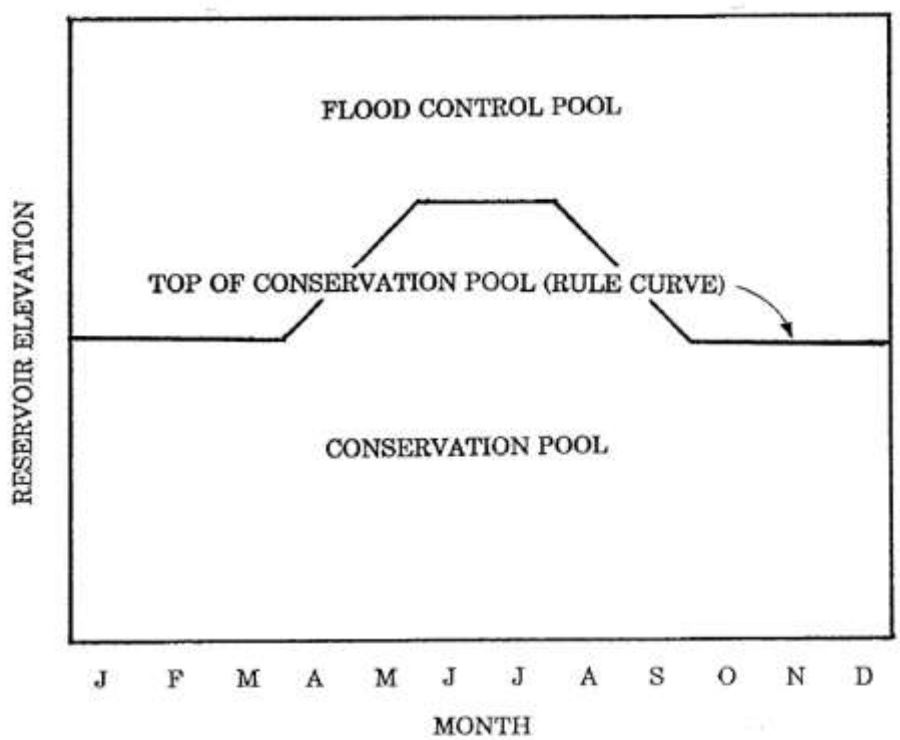


Figure 2-1 Seasonal Top of Conservation pool (Mulu Sewinet, 2009)

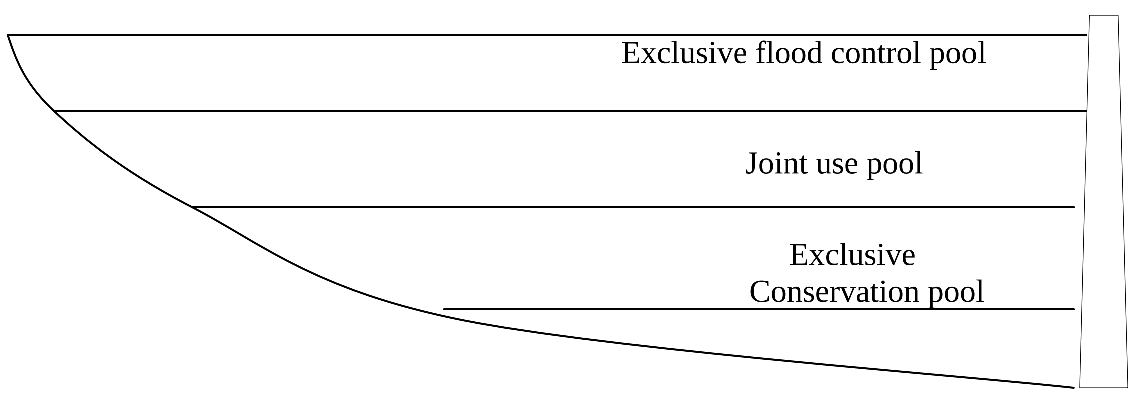


Figure 2-2 Operating zones of a pool

Operating plans may be expressed in various formats. A water control diagram represents a compilation of regulating criteria, guidelines, rule curves, and specifications that govern the storage and release functions of a reservoir. A water control diagram or set of rule curves specify release rules as a function of storage levels, season of the year, and related factors. The format and type of rules reflected in water control diagrams vary greatly for different reservoir projects.

2.2.3. Multiple-Reservoir System Operations

Multiple-reservoir release decisions occur in situations in which water needs can be met by releases from two or more reservoirs. In Figure 2-3, diversions 1 and 3 are from specific reservoirs, but diversion 4 can be met by releases from any of the three reservoirs. In stream flow, as well as diversion, requirements at diversion location 4 can be met by release from the reservoirs.

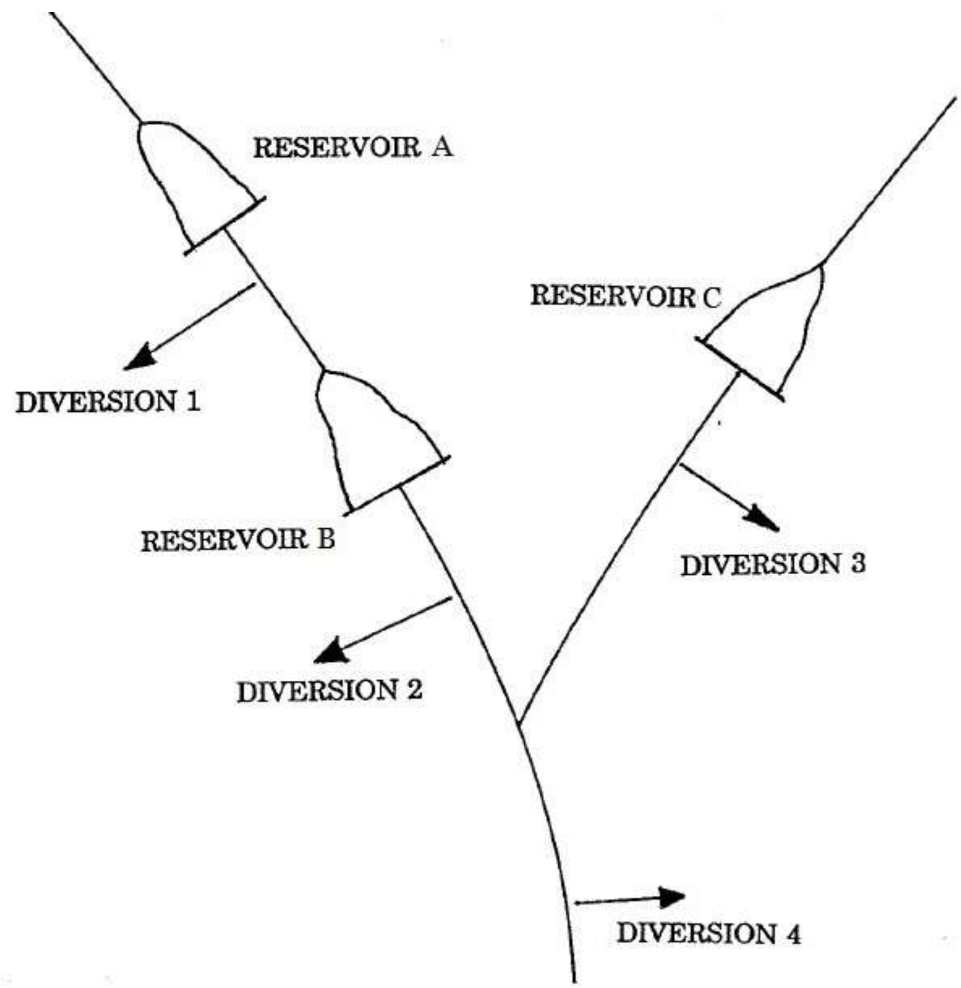


Figure 2-3 Multiple – Reservoir System

One criterion for deciding from which reservoir to release is to minimize spill, since, it represents water loss from the system. Spill from an upstream reservoir (such as reservoir A in Figure 2-3) may still be stored in a downstream reservoir (reservoir B) and thus are not loss to the system. The term spill refers to discharges through an uncontrolled spillway or controlled releases made simply to prevent the reservoir surface from rising above the designated top of conservation pool. For reservoirs in series, such as Reservoirs A and B in Figure 2-3, the downstream reservoir would be depleted before using upstream reservoir water to meet downstream demands. In addition to minimizing spills from the downstream reservoir, this procedure maximizes the amount of water in storage above and thus accessible by gravity flow to each diversion location. For reservoirs in parallel, such as Reservoirs B and C in Figure 2-3, minimizing spills involves balancing storage depletions in the different reservoirs. The simplest approach might be to release from the reservoir with the largest ratio of conservation pool storage content to storage capacity. Thus, release decisions would be based on balancing the percent depletion of the conservation pools. Other more precise and more complex approaches can be adopted to select the reservoir with the highest likelihood of incurring future spills (Mulu Sewinet, 2009).

Numerous other considerations may be reflected in multiple-reservoir release decisions. If the reservoirs have significantly different evaporation potential, minimization of evaporation may be an objective. The criteria of minimizing spills or evaporation are pertinent to either single-purpose systems. Multiple-purpose, multiple-reservoir release decisions can involve a wide variety of interactions and trade-offs.

As illustrated in Figure 2-4, conservation pools can be subdivided into any number of zones to facilitate formulation of multiple-reservoir release rules. The multiple-zones mechanism can be reflected in the operating rules actually followed by reservoir operators. Also, even in cases where operating rules are not actually precisely defined by designation of multiple zones, the multiple-zone mechanism can be used in computer models to approximate the somewhat judgmental decision process of actual operators. The zones provide a general mechanism or format for expressing operating rules. Multiple-reservoir release rules are defined based on balancing the storage content such that the reservoirs are each in the same zone at a given time to the extent possible. In meeting the downstream diversion (or in stream flow) requirement of Figure 2-4, water is not released from zone 2 of one reservoir until zone 3 has been depleted in all the reservoirs. With the storage content falling in the same zone of each reservoir, the release is made from the reservoir which is most full in terms of percentage of the storage capacity of the zone (Mulu Sewinet, 2009).

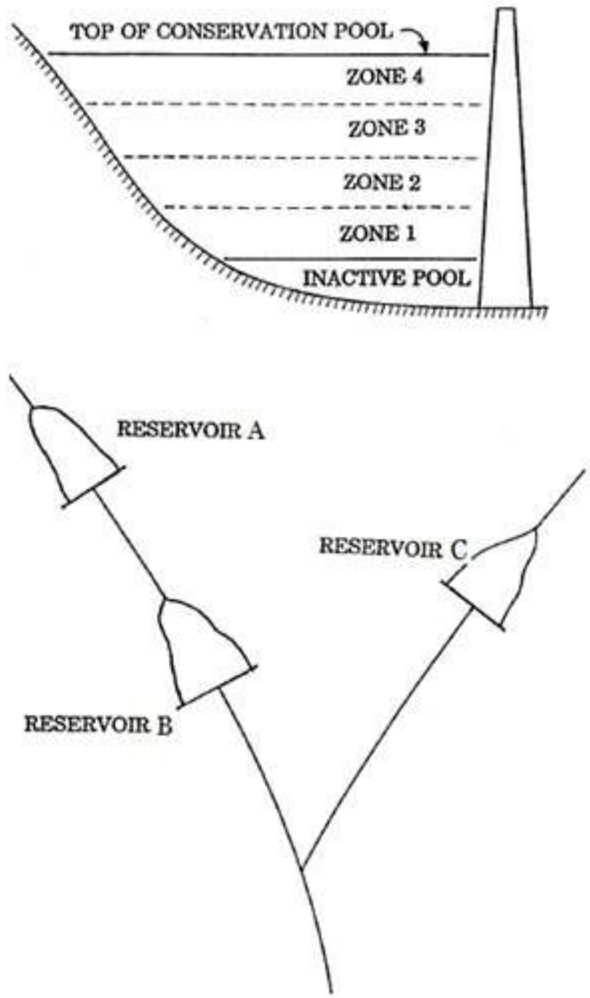


Figure 2-4 Storage for Defining Release Rules

2.3 Water accounting in reservoir system models

Computations accounting for the regulation of flow and storage of water are the central core of a reservoir/river system model. Stream flows provide the inflows to the system. Reservoirs regulate the stream flows through storage and releases. Water flows through river reaches, is diverted for beneficial use, and is lost through evaporation. (Mulu Sewinet, 2009).

Basic Volume Balance

Water accounting procedures are based upon conservation of mass. Since, for most reservoir/river system analysis applications, water is a constant density fluid, conservation of mass implies conservation of volume as well. For any control point or node in the reservoir/river system

$S_{t+\Delta t} - S_t = \sum I_{vol} - \sum O_{vol}$ ………………………………………………………………. 2.1

Where S_t and $S_{t+\Delta t}$ denote the storage volume at the beginning and end, respectively, of an interval of time Δt, and $\sum I_{vol}$ and $\sum O_{vol}$ denote the total inflow and outflow volumes during the time period. With no reservoir storage at the river location

$\sum I_{vol} = \sum O_{vol}$ ……………………………………………………………………………… 2.2

Inflows could include regulated flows from upstream, unregulated flows from the incremental local watershed, or return flows from diversions at another location. Outflows include downstream regulated flows, diversions, and net reservoir evaporation.

In modeling of reservoir operations for conservation purposes, Equation 2.1 is expressed as

$S_{t+\Delta t} = S_t$ + all inflows – all outflows ………………………………………………………2.3

Or $S_{t+\Delta t} = S_t$ + stream inflows– releases – spills – net evaporation……………………….… 2.4

Net evaporation is evaporation from the reservoir water surface less precipitation.

2.4 Reservoir System Analysis Models

Uncertainty in availability of water in space and time poses challenges for efficient planning and design of water resources systems. System analysis models are commonly categorized as being descriptive or prescriptive. Descriptive models demonstrate what will happen if specified decisions are made. Prescriptive models determine what decision should be made to achieve a specific objective. Simulation models are descriptive and Optimization models are prescriptive. Optimization techniques are meant to give global optimum solutions and simulation is a trial and error approach leading to the identification of the best possible solution. The academic research community in particular and many practitioners as well, have been extremely enthusiastic about optimization, in the sense of mathematical programming techniques, applied to reservoir operation problems. The characteristics of certain reservoir operation problems are ideally suited for applying linear and dynamic programming and various other nonlinear programming algorithms. Research results, case studies, and limited experience in application of optimization models in actual planning and real-time operation decision appear to indicate a high potential for improving reservoir operation through their use. However, optimization techniques have played a relatively minor role compared to simulation models concerning to influence decisions made in the planning and operation of actual project (Ralph A, 2005). Moreover a descriptive reservoir system simulation model may incorporate an optimization algorithm.

2.4.1 Simulation

Simulation models still remain the primary tool for reservoir operation studies. It is an abstraction of reality and replicates the physical behavior of the system under a given set of conditions. Simulation models are used to evaluate the consequences of a set of decisions (what-if analysis) over a hydrologic period of interest. Simulation is the process of experimenting with a simulation model to analyze the performance of the system under varying conditions. The operation rule in a complex system involving many projects and purposes of development in a river basin system may be tested with the aid of simulation models. Hence, the simulation model enables the analysis to test the alternatives scenarios (e.g. different operation rules) and examines the consequence before actually implementing them. In a pure simulation model, reservoir releases are determined by a set of predetermined operating rules. Through a series of simulations, these rules can be modified and improved until model results are judged acceptable. A reservoir system simulation model is based on a mass-balance accounting procedure for tracking the movement of water through a reservoir-stream system, and performed by repeatedly solving the storage equation for a reservoir (inflow minus outflow equals change in storage) over a certain period. In a general form, the mass balance or quantity equation for reservoirs can be formulated as:

$$S_t = S_{t-1} + I_t - R_t - L \qquad \text{.........2.5}$$

Where:

S_t is the reservoir storage at the end of time step t

S_{t-1} is the reservoir storage at the beginning of time step t

I_t is the inflow into the reservoir at time step t

R_t is the release for demands at time step t

L_t is the loss or water wasted from the reservoir at time step t.

2.4.2 Optimization

Optimization refers to a mathematical formulation in which an algorithm is used to compute a set of decision variable values that minimize or maximize an objective function subject to constraints. Optimization models automatically search for an optimum set of decision variable values. Typical reservoir objective functions to be maximized or minimized could be a quantitative measure of an objective such as economic benefits and cost, water availability and reliability and hydroelectric power generation. Decision variables might be targets and release rates. Constraints typically include physical characteristics of the reservoir system, such as maximum and minimum storage, maximum and minimum releases, and regulatory or policy requirements (minimum in stream flows, restrictions on allocations and transfers etc.), and mass balances.

Optimization models are more efficient to find an optimum decision for system operation meeting all system constraints while maximizing or minimizing some objective. However, simulation models are effective tools for evaluating water resource systems and provide the response of the system for certain inputs.

2.5 Review of river basin simulation models

Notwithstanding the development and growing use of optimization techniques, simulation models remain the primary tool for river basin planning and management studies in practice. Simulation models have been routinely applied for operation of reservoir projects. Most of the models were customized for particular system. However, recently, general simulation models has been developed that can be applied to any river basin or reservoir system (McCartney, 2007). Some of the most common applicable reservoir application models are briefly described hereunder.

WEAP: Water Evaluation and Planning Model is developed and distributed by Stockholm Environmental Institute Boston Center at the Tellus Institute located in Boston, Massachusetts. It is a simulation model developed to evaluate planning and management issues associated with water resource development. WEAP can be applied to both municipal and agricultural systems and can address a wide range of issues including: sectoral demand analysis water conservation, water right, and allocation priorities, stream flow simulation reservoir operation and project cost benefit analysis (http://weap21.org/index.asp).

ARSP: The Acres Reservoir Simulation Program (ARSP) was developed by Acres International Corporation. The original model was developed to assess alternative operation policies for a 48-reservoir multiple-purpose water supply, hydropower, and flood control system in the Trent River Basin in Ontario, Canada. The ARSP network flow programming based model simulates multi-purpose, multi-reservoir systems. Operating policies are defined by prioritizing water demands. Monthly, weekly, daily, or hourly time steps may be used. The software assigns upper and lower bounds and cost functions to the network flow paths for the network flow programming formulation based on the input provided by the user.

MIKE BASIN: runs within and is an extension to ArcView which is a geographical information system (GIS) software product available from ESRI (Environmental System Research Institute). MIKE BASIN integrates GIS capabilities with reservoir/river system modeling. Features also facilitate interconnected use of Microsoft Excel with MIKE BASIN. The model simulates multipurpose, multi-reservoir systems based on a network formulation of nodes and branches. Although the time step is user-selected, solutions are stationary for each time station without flow routing dynamics. Thus, a monthly time step is common. Time series of inflows from catchments to each branch of the stream system are normally provided as input. However, the model can also be connected to watershed precipitation-runoff capabilities provided by the MIKE11.

HEC-5: Simulation of flood control and conservation systems software developed by the hydrologic Engineering center of US army corps of Engineering. It is designed to perform a sequential reservoir operation based on a specified project demand and constraints. The simulation is performed with the specified flow data in the time interval for simulation. The simulation software determines the reservoir release at each time steps and the resulting downstream flows. It can be applied for both single and a system of reservoirs operating to reuse the downstream flooding for the system of reservoirs on parallel streams operated for the common downstream points and tandem operation. The model effectively applied to control the release according to the constraint made

HEC-ResSim: The Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers has developed a new reservoir simulation model, HEC-ResSim, as the successor to the well-known HEC-5. HEC-ResSim is a generalized reservoir simulation program that has been developed to provide watershed managers an effective tool for real-time decision support and use in planning studies. HEC-ResSim uses an original rule-based approach to mimic the actual decision-making process that reservoir operators must use to meet operating requirements for flood control, power generation, water supply, and environmental quality. Parameters that may influence flow requirements at a reservoir include time of year, hydrologic conditions, water temperature, and simultaneous operations by other reservoirs in a system. Basic reservoir operating goals are defined by flexible at-site and downstream control functions and multi-reservoir system constraints. The generalized nature of HEC-ResSim, its flexible scheme for describing reservoir operations, and its powerful new features, such as outlet prioritization, scripted state variables, and conditional logic, make it applicable for modeling almost any single- or multi-purpose reservoir system. Thus, as a result of unique features mentioned it is primarily selected for this study (Hydrologic Engineering Center, 2013).

2.6 The Reservoir operation simulation model (HEC-ResSim)

2.6.1 General

HEC-ResSim, successor to the well-known HEC-5 is widely used public domain simulation software developed by the hydrologic engineering center of the U.S. Army of corps of Engineers. HEC-ResSim represents a significant advancement in the decision support tools available to water managers. It is designed to simulate reservoir operations for flood management as well as flow augmentation.

HEC-ResSim uses an original rule-based approach to mimic the actual decision-making process that reservoir operators must use to meet operating requirements for flood control, power generation, water supply, and environmental quality. Parameters that may influence flow requirements at a reservoir include time of year, hydrologic conditions, water temperature, and simultaneous operations by other reservoirs in a system. The reservoirs designated to meet the flow requirements may have multiple and/or conflicted constraints on their operation. HEC-ResSim describes these flow requirements and constraints for the operating zones of a reservoir using a separate set of prioritized rules for each zone. Basic reservoir operating goals are defined by flexible at-site and downstream control functions and multi-reservoir system constraints. As HEC-ResSim has evolved, advanced features such as outlet prioritization, scripted state variables, and conditional logic have made it possible to model more complex systems and operational requirements. The graphical user interface makes HEC-ResSim easy to use and the customizable plotting and reporting tools facilitate output analysis(Hydrologic Engineering Center, 2013).

HEC-ResSim is unique among reservoir simulation models because it attempts to reproduce the decision making process that human reservoir operators must use to set releases. The program represents the physical behavior of reservoir systems with a combination of hydraulic computations for flows through control structures, and hydrologic routing to represent the lag and attenuation of flows through segments of streams. It represents operating goals and constraints with an original system of rule-based logic that has been specifically developed to represent the decision-making process of reservoir operation(Hydrologic Engineering Center, 2013).

HEC-ResSim has a graphical user interface (GUI) and utilizes the HEC data storage system (HEC-DSS) for storage and retrieval of input and output time series data. HEC-DSS is designed as the data base system, which effectively store and retrieve data, such as time series data, curve data and spatially oriented girded data and more(Hydrologic Engineering Center, 2013).

2.6.2 Hec-ResSim Modules

HEC-ResSim offers three separate sets of functions called Modules that provide access to specific types of data within a watershed. These modules are Watershed Setup, Reservoir Network, and Simulation. Each module has a unique purpose and an associated set of functions accessible through means, toolbars, and schematic elements. The Figure 2.5 illustrates the basic modeling features available in each module.

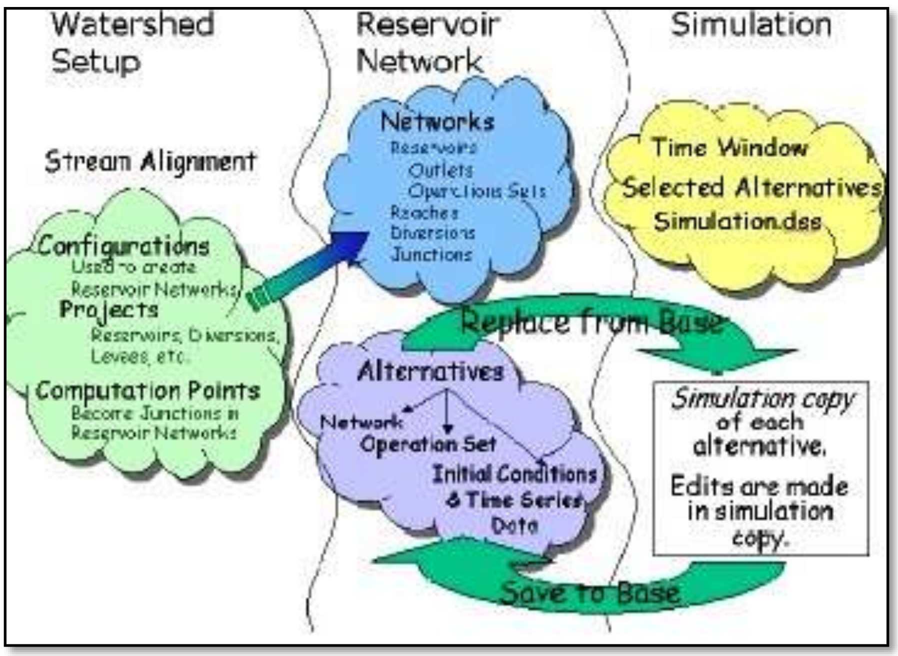


Figure 2-5 HEC-ResSim module concepts (HEC-ResSim user Manual)

Watershed Setup

The purpose of this module is to provide a common framework for watershed creation and definition. A watershed is associated with a geographic region for which multiple models and area coverage can be configured. A watershed may include all of the streams, projects, e.g., reservoirs, levees, gage locations, impact areas, time series locations, and hydrologic and hydraulic data for a specific area. All of these details together, once configured, form a watershed framework.

Reservoir Network

The purpose of the Reservoir Network module is to isolate the development of the reservoir model from the output analysis. In the Reservoir Network module, the river schematic is built, the physical and operational elements of the reservoir model is described, and the alternatives that would be analyzed are developed. Using configurations that are created in the Watershed Setup module as a template, the basis of a reservoir network is created. Routing reaches and possibly other network elements to complete the connectivity of the network schematic may be added. Once the schematic is complete, physical and operational data for each network element are defined. Also, alternatives are created that specify the reservoir network, operation set(s), initial conditions, and assignment of DSS pathnames (time-series mapping).

Simulation Module

The purpose of the Simulation module is to isolate the output analysis from the model development process. Once the reservoir model is complete and the alternatives have been defined, the Simulation module is used to configure the simulation. The computations are performed and results are viewed within the Simulation module(Hydrologic Engineering Center, 2013).

2.6.3 System of Storage reservoirs in HEC-ResSim

Reservoirs are usually considered to be in a system when they are located on the system stream that the upstream reservoir is operating for the downstream reservoir or where they are located on different (parallel) stream but operating for the common downstream control points.

HEC-ResSim provides for tandem operation to manage the storage distribution for reservoirs on the same stream, and a parallel operation for two or more reservoirs located on different streams but a common downstream controlling point. (Mulu Sewinet, 2009)

2.6.4 Reservoir Operation rule in HEC-ResSim

A reservoir in HEC-ResSim must have a target elevation. A reservoir's target elevation, represented as a function of time, is called its Guide Curve. It is the dividing line between the upper zones of the reservoir (typically called the flood-control pool) and the lower zones (typically called the conservation pool).

The release decision logic in HEC-ResSim starts and ends with the guide curve. When the reservoir's pool elevation is above the guide curve ("in flood control"), the reservoir wants to release more water than is entering the pool; when below guide curve ("in conservation"), and the reservoir wants to release less water than is entering the pool. All operating rules and physical limitations act as constraints upon the reservoir's ability to meet the goal of returning the pool to its guide curve elevation. Without rules, the reservoir will be constrained only by physical capacity of the outlets to get to and stay at the guide curve elevation. (HEC, 2013)

2.6.5 Tandem operation rule in HEC-ResSim

Tandem operation is the method in HEC-ResSim reservoir simulation model that used to analyses the reservoir operation in the system and the storage distribution among the reservoirs on the same stream. When a tandem reservoir system is defined, the model determines amount of release from the upper reservoir in order that the downstream reservoir is operating towards a storage balance.

For every decision interval an end-of-data, storage is first estimated for each reservoir based on the sum of the beginning of date storage and daily average inflow value, minus all potential outflow volumes. The estimated end of date storage for each reservoir is computed to a desired storage that is determined by using a system storage balance scheme. The priority for release is then given to the reservoir that is furthest above the desired storage. When a final release decision is made, the end of period storage is recomputed. Depending on other constraints or higher priority rules, system operation strives for a storage balance such that the reservoirs have either reached their guide curve or they are operating at the desired storage (HEC, 2013).

2.6.6 Implicit and Explicit system storage balance

The implicit and explicit system storage balances are the default and the user defined desired storage balances in system reservoirs, respectively. The methods are applied to both tandem and parallel system operations. The implicit method is automatically created by the model when a reservoir system is established by either of the system operation methods.

Thus, the desired storage for each reservoir is determined through an implicit balance line, which is simply a linear relationship between the storage at each reservoir and the system storage. For each reservoir, the balance line hinges on the intersection of the reservoir empty storage and system empty storage, reservoir-guide curve storage and the system-guide curve storage, and reservoir full storage and system full storage.

The explicit method is optional and allows the user to define a desired storage balance in the reservoir system. The user can further modify the implicit balance lines explicitly to characterize the desired storage distribution using one or more system zones (i.e., adding one or more special division of the conservation pool in both of the reservoirs) and placing inflection points along the balance line. The inflection points effectively transfer the implicit balance line into explicit curves, (HEC, 2013).

The process of determining desired storages is repeated every decision interval in order to assign the priority for release to the reservoir that is furthest above the desired storage. A release decision made for a particular time period may not necessarily achieve the desired balance. The reservoirs are considered in balance when both reservoirs have reached their Guide Curves or are operating at the desired storage levels along their balance line curves as prescribed in the explicit storage balance scheme.

2.6.7 Studies using Hec-ResSim Models

Due to its feature of flexibility and ability to simulate complex one or more projects having multipurpose function, Hec-ResSim has been widely used since the release of the program. Reservoir operation simulation studies done on different basin of Ethiopia and other countries using ResSim model has been referred for the preparation of this study. These papers include, Reservoirs Water Balance Analysis, Joint Operation and Optimal Operation Rules Curve for

System Performance (A Case Study Of Proposed Reservoirs on the Main Blue Nile River, Ethiopia), (Genet, 2008), Water Use and Operation Analysis of Water Resource Systems in Omo Gibe River Basin (Daniel, 2011), Application of Reservoir Simulation and Flow Routing Models to the Operation of Multi-Reservoir System In terms of Flood Controlling and Hydropower's Regulation (Madani, 2013)

2.7 Previous Study in the Basin

2.7.1 Potential Sites and Studies

1986 CESEN

In the principal findings of this comprehensive energy study for the country (CESEN, 1986) it was estimated that a sizeable hydro energy potential is available in the Genale-Weyb basin, when expressed as "areal energy density". The calculated energy density of the Genale-Weyb head basins taken together amounted to 1.45 GWh/km^2-year, which is slightly higher than the Blue Nile basin but lower than the Baro basin. Furthermore, gross hydro energy potential available from the small slope (low head) plants without flow regulation was also estimated to be substantial, on average 168 MWh/km^2-year.

This interesting analysis is summarized for the Genale river reaches in Table 2-1.

The study did not, however, address the potential location of power plants or their technical characteristics.

Table 2-1: Energy Potential (Lineal) of the Genale River according to CESEN

River section	**Length (km)**	**Mean flow (m^3/s)**	**Gross energy (GWh/year)**	**Energy Density (GWh/km^2-year)**
Bore to Chenemasa	207	52	2,550	12.3
Chenemasa to Welmel	113	190	5,730	50.7
Welmel confluence to Bogol	216	271	2,520	11.7
Bogol Manyo to Dolo Olo	164	217	560	3.4
Total	700		11,360	16.2

1990 WAPCOS

Hydropower investigations were carried out within the National Water Resources Master plan (EVDSA/WAPCOS, 1990). The major findings generally superseded previous studies and, to a large extent, created the basis for potential hydropower development on the Genale-Dawa basin – which is still the most valid and up to-date source when looking at the basin as a whole.

Resulting from these study 31 sites were identified and preliminarily evaluated. The evaluation consisted simply of estimating mean flow and, together with site topography (river-reservoir levels and available head), calculation of continuous power and total energy. The technical potential (GWh/year) was estimated as 0.7x total energy.

Preliminary cost estimation, based apparently on topography: dam crest length and head, was also made. This enabled economic comparison of the various schemes in terms of specific capacity and energy costs.

A replication of the WAPCOS evaluation is given in appendix A, In regard to actual site selection, the main criteria applied by WAPCOS, which are considered to be very sound and reasonable, are replicated in the Table A-3.

Selection of hydropower sites in the river basins is based on the study of topographic sheets on 1:250,000 scale and 1:50,000 scale maps wherever available. Besides the topographic sheets, other reports were referred wherever relevant. A two-week aerial reconnaissance of portions of Abbay, Baro-Akobo, Gilgel-Ghibe, Awash, Rift Valley, Wabi Shebelle and Genale Dawa was also helpful.

In viewing the table, it is interesting to observe the range of potential capacity (MW) and generating heads available in the respective sub-basins. Lower capacities, implying relatively small-scale plants, are predominant in the Weyb sub-basin.

The total potential of Genale and Dawa sub-basins is very similar in which both contain medium to large developable capacities, some exceeding 100 MW. The highest head available at a single site, amounting to 400m, is located on the Mormora tributary of the Dawa river.

In regard to actual site selection, the main criteria applied by WAPCOS, which are considered to be very sound and reasonable, are replicated in the Table A-3.

Selection of hydropower sites in the river basins is based on the study of topographic sheets on 1:250,000 scale and 1:50,000 scale maps wherever available. Besides the topographic sheets, other reports were referred wherever relevant. A two-week aerial reconnaissance of portions of Abbay, Baro-Akobo, Gilgel-Ghibe, Awash, Rift Valley, Wabi Shebelle and Genale Dawa was also helpful.

The general criteria adopted for the selection of a hydropower site was guided on the following broad principles:

- The length of dam/diversion weir is restricted to about 500 to 750m and height limited to 120m.
- The sites were selected after screening of the entire river from source to confluence. In Abbay & Baro basins both main rivers & tributaries were screened. In other basins, only the main rivers were examined.
- River reaches with goose-neck formation (a boulder reach) with valley spreading upstream & downstream are preferable.
- Wherever a series of projects on the same river or tributary are planned, it is preferable to have the upstream most projects with largest storage. The regulated release from this project will feed the lower projects in the cascade. This will result in reduction of cost of the lower dams.
- Sites where scope for grid tie or delayed grid tie is present were preferred.
- Easy access and availability of construction material for the dam or diversion structure in the vicinity were considered.
- Demand for power in the nearby area was assessed.
- The need of electric power in the nearby Awraja was estimated. At least one plant to meet the requirement of energy in any Awraja, however remote, was taken into account.
- In case of major powerplants, particularly on River Abbay, the export potential was kept in mind.

1997 MoWR: Genale sites GD-2 / GD-3 / GD-4

A follow-up reconnaissance study (to the previous) was carried out by MoWR under the Medium Scale Hydropower Plants Study Programme (MoWR, 1997). This study concentrated on the immediately most promising sites on the Genale river: denoted as GD-2, GD-3 and GD-4.

These sites are located in the upper-central region of the Genale main river. Both GD-2 and GD-3 involve the construction of a large dam to provide sufficient storage and regulation in which a shaft/tunnel conduit connects with the powerhouse located a short distance downstream. Given design net heads of 103m and 93m, installed capacities resulted in 138 MW and 180 MW respectively. A somewhat different configuration of was defined for GD-4 consisting of a lower dam and smaller storage reservoir with a 25km long power canal in order to gain a net head of 150m. Installed capacity amounted to 300 MW.

Through application of a costing and economic evaluation procedure commensurate with the study level, each scheme was found to be similarly favourable. The specific generation cost and benefit cost ratio of GD-4 resulted to be slightly inferior to that of GD-2 and GD-3.

As a conclusion a stage development, possibly involving all 3 projects, was considered feasible in which the construction of GD-2 or GD-3 alone would alleviate the need to construct a dam exclusively for exploitation of irrigation potential downstream.

1999 Norplan: Genale sites GD-2 / GD-3

In this pre-feasibility study the Genale hydropower concept was taken one step further in which more detailed work concentrated on the development of GD-2 and GD-3 sites (Norplan, 1999).

In the case of GD-3, several alternatives were evaluated from which the alternative denoted “middle-long” was chosen. Compared to the previous study the layout of this scheme was completely re-configured, whereby a 1,460m long headrace tunnel leads the water to a powerhouse cavern, from where a 6,500m long tailrace links up with the Genale River. The net head amounts to 180m. The optimised installed capacity resulted in 164 MW at a plant factor of 80%.

It should be mentioned that GD-2, with modified cost parameters, has been included as a project to be implemented in the “all-hydro scenario” system expansion plan (ACRES, 2003).

A brief appraisal of the Genale hydropower projects, and possible favourable implications for future implementation under the ICS, is given in the Sectoral Study Report Section J: Energy.

MoWR 1998

In the reconnaissance studies carried out by the MoWR a total of 29 potential dam sites were identified, serving individual or combined development purposes under: irrigation, hydropower and multi-purpose.

An inventory of these sites, indicating purpose and MoWR (GDH-) identification code is given in Table A-1 of the Appendix A.

As indicated further in the table, a number of these sites appear to coincide with those identified by WAPCOS for hydropower development.

GDMP by Layhmeyer, 2003

A study has been carried between 2004 to 2007 by a joint venture of Layhmeyer international consulting Engineers of Germany and Yeshi-Ber consult of Ethiopia. The overall goals of the master plan are defined in the Ethiopia Water Resource Management Policy (WRMP), which sets out guidelines for water resource planning, development and management. This policy aims at enhancing and promoting all national efforts towards the efficient, equitable and optimum utilization of the available water resources of the country for significant socio-economic development on sustainable development on sustainable basis.

The target of the Hydropower Sector Study was to screen hydropower options in the Genale-Dawa River Basin to identify projects which can generate power at a cost below that of thermal plant. GIS codes for the hydropower projects used in this study are cross-referenced to the codes used by the Ministry of Water Resources in the fold-out on the last page of the report.

These projects are candidate projects for the ICS power system expansion and possibly also for export to earn foreign exchange, in line with the national policies for the sector.

Over 40 hydropower options, identified in previous studies, were first pre-screened, eliminating all projects which not likely to be economic, e.g. projects with insufficient head, and projects with intermittent flow and without storage. The 22 remaining projects were then optimized by varying dam heights and powerhouse locations.

Finally, 9 projects were found to have generation costs below that of equivalent thermal power plants, as shown in Table A-4 of Appendix A. The economic hydropower potential is about 1,200 MW capacity with a corresponding energy generation of 5,500 GWh (not accounting for the Weyb-Wabi project).

Furthermore, the Feasibility study of the Multipurpose Hydropower Project of GD-3 by Lahmeyer International and Yeshi-Ber Consult, 2007 and Feasibility Study Genale GD-6 Hydropower Project undertaken by Norplan and Norconsult in association with Shebelle Consult, 2009 are also primarily used for this study.

3. DESCRIPTION OF THE STUDY AREA

3.1 Location of Genale-Dawa Basin

Genale Dawa River basin is the southernmost basin in Ethiopia and lies between latitude $3^0$30' and $7^0$20' N and longitude $37^0$05' and $43^0$20' E. The river basin is located in the regional state of Somalia and Oromia regional state. The elevation of the study basin varies between 200m to 3333m a.s.l average elevation. In an aerial ranking it has the third largest surface area (about 170,000km^2) after Wabishebele and Abay River basins. Neighbouring river basins are Wabishebelle to the north and east, and Riftvalley Basin to the west. The main Drainage system is defined by three principal rivers: Genale, Dawa and Weyib, and their respective sub-catchments.

Due to its hydropower potential, Genale – Dawa River basin has drawn the attention of the Ethiopian Ministry of Water and Energy to undertake number of studies, as mentioned in sec 2.5.1 above. After subsequent studies an Integrated Development Master plan has been studied for Genale – Dawa River Basin by Lahmeyer International and Yeshi-Ber Consult, 2007. The study reveals that the dam for GD-3 project, found up stream of the cascade system, has a multipurpose i.e., for hydropower, irrigation and flood control. When the GD-3 project is built, it provides almost full regulation of the river flows. The downstream projects GD-5 and GD-6 will benefit from the almost constant inflows to produce very reliable power and energy outputs. Moreover this project combined with GD-5 and GD-6, is a good candidate for power export to Kenya. The project seems very attractive as it may have the opportunity to boost export earnings by supplying neighboring Kenya with electricity. This GD-3 Project has a mean flow of 92m3/s and rated head of 260m. The project would have a capacity of 254MW and generate on average 1640GWh of energy per year, 73% of it as firm (Lahmeyer International and Yeshi-Ber Consult, 2007,).

The proposed GD-3 Schemes are located in the Genale-Dawe River basin, in the middle reach of the Genale River around 655Km by road south-east of Addis Ababa. The Scheme, from the reservoir to its tailrace outfall, will extend over a corridor some 55Km long. The approximate centroid of the project area lies at latitude $5^0$38'N and longitude $39^0$43'E . Administratively the project area falls under the jurisdiction of the Liben and Mede Welabu woredas in the Guji and Bale zones of the Oromia National Regional Administration.

The GD-5 Scheme which is located in between the two proposed hydropower Scheme with a watershed area of about 12,906km^2 of the upper and mid-sections of The Genale basin.

The GD-6 sub-basin encompasses a relatively small area of some 13,350 km^2 of the upper and mid-sections of the Genale basin. The basin has an elongated shape. Its straight line length down to GD-6 site is around 250 km. The width of the basin varies from some 100km in the upper part to less than 20 km in the vicinity of GD-6 project. Elevation of the project basin decreases from some 3700 m a.s.l. in the summits of headwater area to 520 m at the GD-6 dam site.

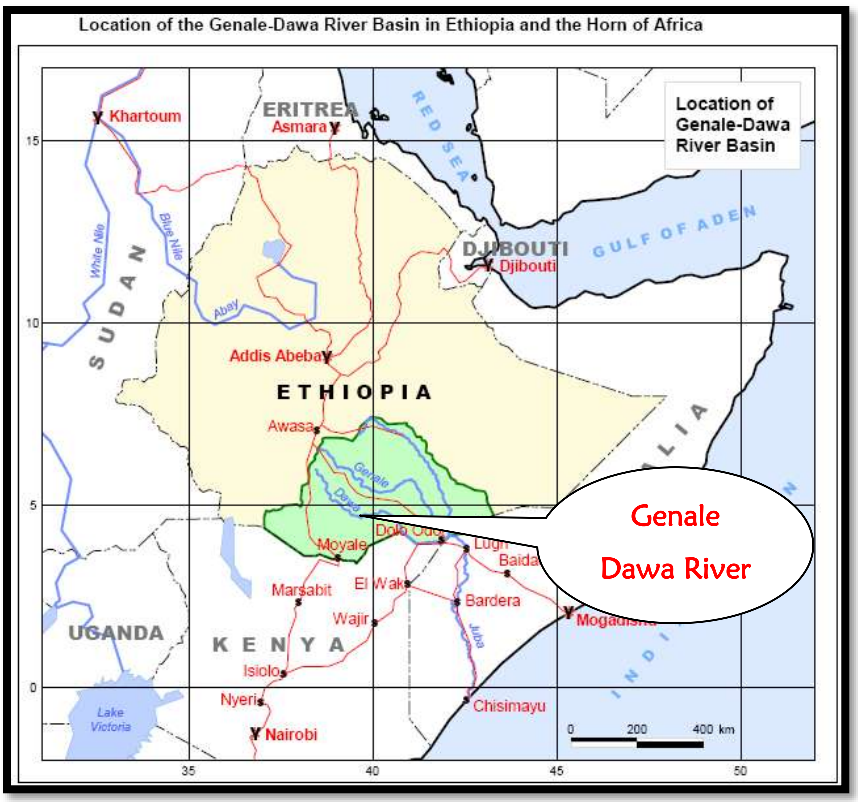


Figure 3-1 Location of the Genale Dawa River Basin

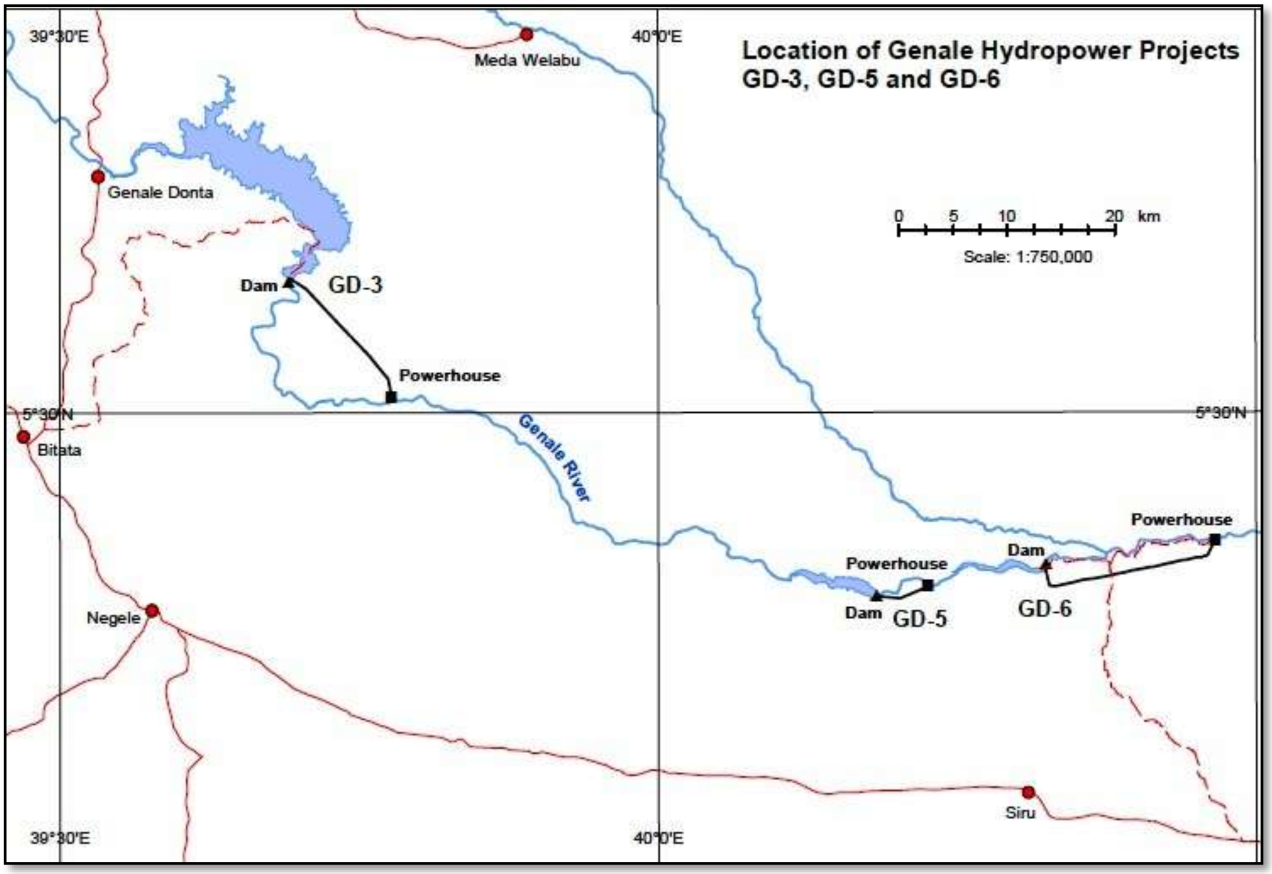


Figure 3-2 Genale Hydropower Cascade

3.2 Topography

The Project catchment area encompasses the upper and mid sections of Genale main river sub basin up to the proposed hydroelectric project sites. The longest river course which defines the Genale River originates at the Logita tributary, upper Genale River, with head water in the Koro forest. The Logita River flows to south-west and meets the major Genale tributary at around 1900m, after it first flows to the westwards.

Table 3-1 Principal Physical Parameter of Genale Project area
(Source; Master plan study, 2007)

Parameter	Unit	Sub-basins		
		Upper Genale	Geberticha	Lya
Area	Km^2	4582	2335	1507
	%	43.6	22.3	14.4
Maximum Elevation	m a.s.l	3686	3746	3745
Minimum Elevation	m a.s.l	1252	1266	1221
Mean Elevation	m a.s.l	2249	2206	2058
Area>2500m	%	40.6	27.5	13.4
2500>Area>1500m	%	50.5	67.9	79.7
1500>Area>1000m	%	8.9	4.6	6.9
Area<1000m	%	0	0	0
Longest flow path	km	191	146	128
Average Slope	%	16.9	22.6	20.7

3.3 Climate

The weather system of the Genale Basin is mainly governed by position of the Inter-Tropical Convergence Zone (ITCZ). Displacement of ITCZ results in bimodal annual distribution of rainfall with a higher peak in April and a lower one in October. Distributions both of basin precipitation and basin temperature are strongly related to the altitude with precipitation increasing and temperature decreasing with altitude. The moisture regime of the Genale basin varies from humid in the high-elevated headwaters part of the basin to semi-arid in the vicinity of the GD-6 dam site.

Traditional Ethiopian climate classifications based on altitude and temperature shows the presence of four principal climate zones in the Genale River basin.

- Dega - temperate highland climate above 2500 m altitude with mean temperature in the range 6-16 ºC – headwater area.
- Weina Dega - sub-tropical warm, between 1500 - 2500 m altitude with mean temperature in the range 16-20 ºC – mountainous upper basin
- Kola - tropical hot and arid type, between 1500-500m altitude with mean temperature in the range 20-28 ºC.
- Bereha – tropical hot and arid type, below 500m altitude with mean temperature above 28^{o}C.

3.3.1 Rainfall

The entire Genale river basin falls under the “bi-modal” rainfall regime with two wet seasons. There are two sub- divisions of the “bi-modal” regime. Type I in which the rainfall continues for a period of some 7 months from April to October with less pronounced peaks at the beginning and end, and Type II in which pronounced rainfall peaks occur in April and October with little rainfall between these peaks. Some 80% of the Genale catchment area draining to the GD-3 project site is within the “bi-modal” Type I rainfall regime with prolonged wet season. Only some 20% of the catchment is within the “bi-modal” Type II rainfall regime as shown in Figure 3-3. This Type II regime begins upstream of the project components (dam and powerhouse) of GD-3, in the region just north of Kibremengist and extends downstream to the middle and lower reaches of the Genale River (Lahmeyer International and Yeshi-Ber Consult, 2007)

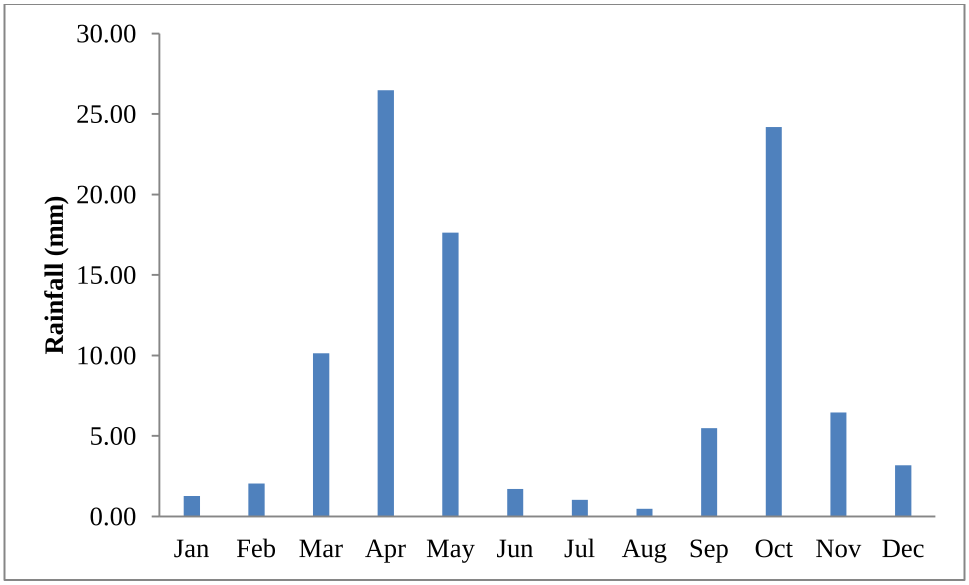


Figure 3-3 Monthly Mean Areal Rainfall at Project Area

3.3.2 Temperature

It is widely agreed that in the region distribution of temperature is strongly reliant on elevation. Previous studies on Genale Dawa River Basin show that the predicted drop of temperature with a decreasing elevation was some 0.64ºC per 100 m elevation. Latitude is a secondary factor influencing mean monthly temperature. With decreasing latitude in the southerly direction both the temperature and the aridity increase. The mean annual temperature at the mountainous Robe station is only 14.9^{0}C. With elevation drop of more than 1000 m and some 1.50 degree to the south the mean annual temperature at Filtu is around 22^{0}C. It may be expected that mean annual temperature over the Genale basin will vary from less than 15^{0}C in the river headwater area to more than 25^{0}C, at the elevation of some 500 m, in the vicinity of the GD-6 project site.

3.4 Water Resource

The main source of stream flow for the study area is found at Chenemesa gauging station which has relatively longest and continuous flow record. The annual series of average stream flow of this station with mean annual river flow of 96.2m3/s is as shown in the figure 3-6.

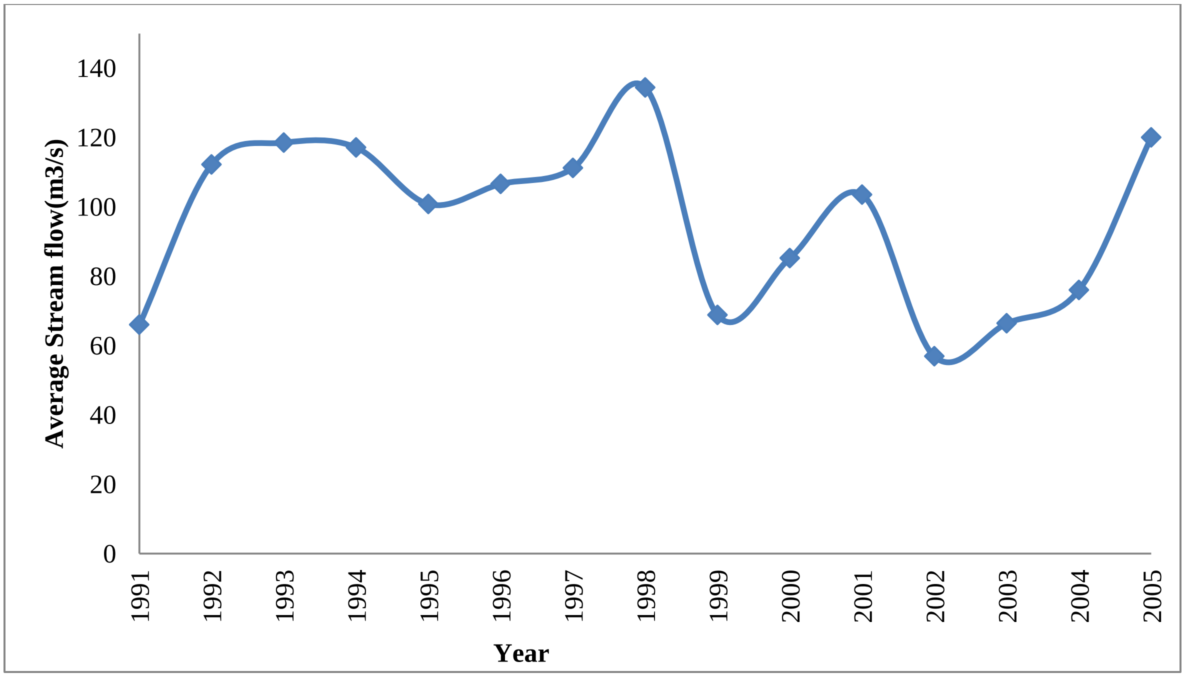


Figure 3-4 Average annual stream flow of Genale River at Chenemassa station

3.5 Land Use and Land Cover

From the total area covered by the reservoir within the Liben wereda, cultivated land shares 22.2%, grassland (with bush/shrub grassland) 71.6%, natural vegetation 1.2%, dispersed settlement area 0.2% and water body (River) 4.8%, while in the Medawelabu Wereda the reservoir area is characterized by 50.4% of Cultivated Land, 43.4% of grassland (with bush/shrub grassland), 1.9% of natural vegetation, 0.5% of dispersed settlement area and water body (Rivers and ponds) within the reservoir is 3.7% . In both Weredas where the reservoir flooded, annual and perennial crops like Sugarcane, Banana, Mango, Maize, Sorghum, Teff and Vegetables were cultivated at a various degree. Whereas, both dense and open wooded and shrub grassland are also the features of the project area (Lahmeyer International and Yeshi-Ber Consult, 2007).

3.6 Features of the Proposed Hydropower schemes

Hydropower has been recognized for decades as a single most valuable resource in Ethiopia. The hydropower potential of the country has been estimated at some 45,000MW(EEPCo, 2013).

The existence of rivers flowing in deep valleys provides very attractive condition for medium to large scale hydropower schemes. The Genale Dawa River basin was identified as one of the most promising hydro-energy generation.

Extensive hydropower development studies were undertaken by the Ministry of Water Resource on Genale Dawa River basin. About 40 schemes were identified as potential sites for hydropower development. Nine of the projects proved to be economically attractive compared to equivalent thermal generation. The total economic hydropower potential in the basin was estimated to have annual generation of energy 9,300GWh(Solomon, 2009). Among these three of the cascaded hydropower schemes that lie on the main stream of Genale River were found interesting with the GD-3 project being the best hydropower project by far.

When the GD-3 project is built, it provides almost full regulation of the river flows. The downstream projects GD-5 and GD-6 will benefit from the almost constant inflows to produce very reliable power and energy outputs. Moreover this project combined with GD-5 and GD-6, is a good candidate for power export to Kenya (Lahmeyer International and Yeshi-Ber Consult, 2007,).

3.6.1 GD-3 Hydropower Scheme

3.6.1.1 Location

The project area is located some 400km (air distance) south-south-east of Addis Ababa and some 200km (air distance) north of the border with Kenya. The scheme, including the reservoir and power waterways, extends over a river corridor some 55km long. The approximate centroid of the project area lies at latitude 5º 38’ North and longitude 39º 43’ East.

3.6.1.2 Purpose

The GD-3 hydropower scheme is a comprehensive multipurpose water resource development project planned to utilize potential benefits for hydropower, flood control and irrigation with other downstream planned projects and hydropower generation as its main purpose.

3.6.1.3 Reservoir

The GD-3 reservoir created by a dam at the GD-3 will have a total storage capacity of 2,570 Mm^3 at full supply level (1120 m asl) and will cover an area of 98 km^2. The minimum operating level will be 1080masl and storage at MOL will be 260 Mm^3 and this will cover 23 km^2. The active storage is some 2310 Mm^3.

The elevation-surface area-capacity relations of the valley upstream of the GD-3 dam site have been compiled from the SRTM (Space Shuttle Radar Topography Mission) data downloaded from the Internet in the form of a DEM (Digital Elevation Model) with elevations averaged over 90m square cells. The resulting relationships are plotted in Figure 3-5 and tabulated on Table 3-2

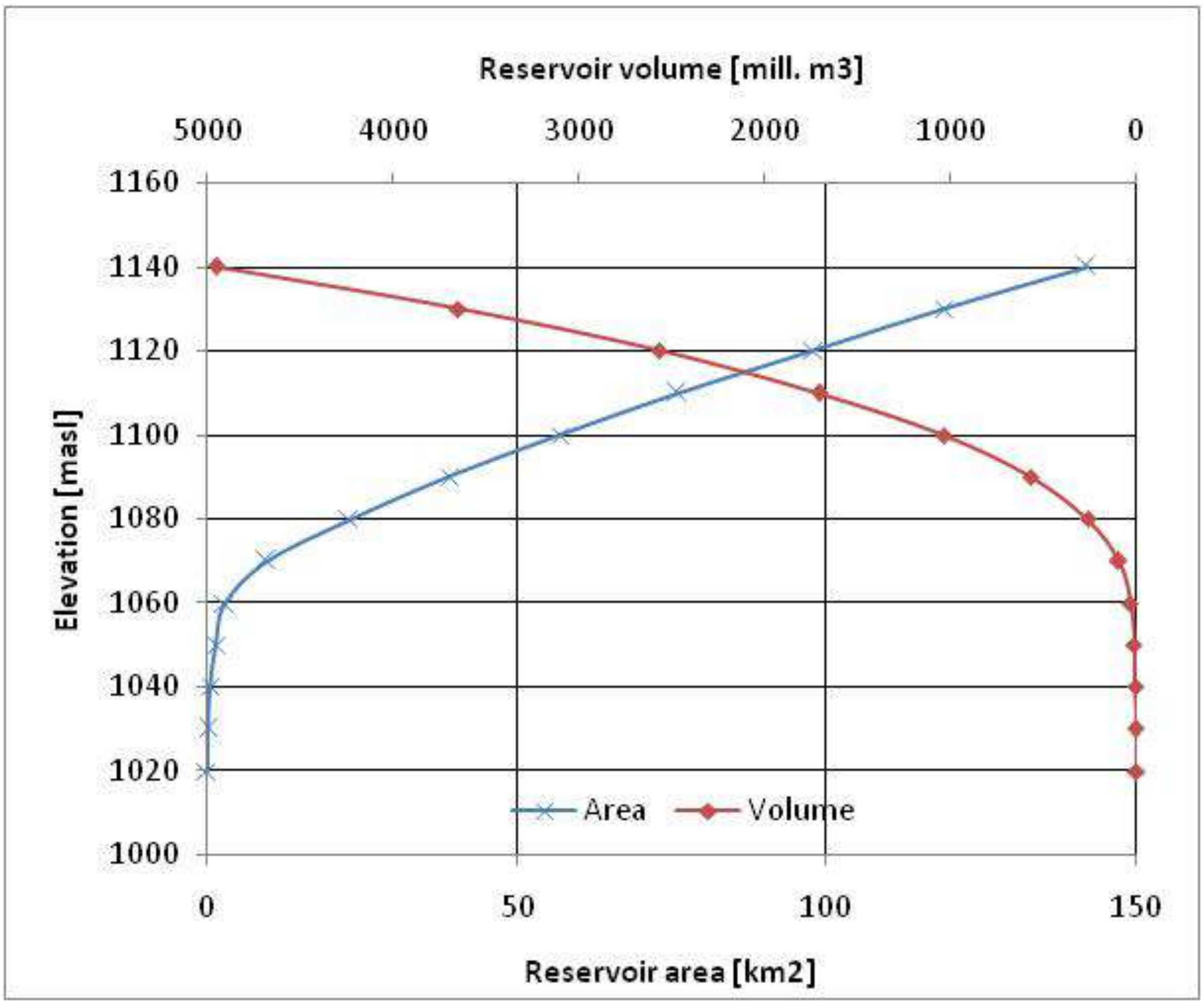


Figure 3-5 Elevation-Storage-Area Curve for GD-3 Reservoir

Table 3-2 Elevation-Storage-Area for GD-3 Reservoir

Elevation (m asl)	Storage (Mm^3)	Area (ha)
1020	0.0	0
1030	1.0	150
1040	4.0	470
1050	13.0	1400
1060	34.0	2800
1070	95.0	9500
1080	260.0	23000
1090	570.0	39000
1100	1040.0	57000
1110	1710.0	76000
1120	2570.0	98000
1130	3650.0	119000
1140	4950.0	142000

3.6.1.4 Hydrological Site Conditions

The long term mean flow at the GD-3 site is estimated to be 92.5m^3/s. The driest year on record (2002) had a mean flow of only 59.2m^3/s, while the wettest year on record (1998) had a mean flow of 139.5m3/s. The catchment area amounts to 10,445 km^2.

The flow regime shows a distinctive wet season from April to November, which makes up nearly 90% of the annual flow, and a dry season from December to March. The highest discharges normally occur in October, the lowest at the end of the dry season in March.

3.6.1.5 Expected Energy Production

Considering a total installed capacity of 254 MW, a plant discharge of about 116 m^3/s (equal to 1.25 times the mean flow) and a rated head of 254.5 m, the GD-3 scheme would show the following energy production features:

- Average energy production: 1640 GWh/year

- Firm energy generated: 1600 GWh/year
- mean power production: 254 MW
- plant factor: 72 %

Around 96 % of the river flow would be used for energy generation; the rest is diverted by the spillway during floods or lost by evaporation.

The above figures do not take into account possible effects of additional schemes further upstream (e.g. the implementation of GD-02) as the feasibility study on GD-02 was not available or not done yet.

3.6.1.6 GD-3 and Regulation of the Downstream River

GD-3 will provide almost total regulation of the flows in the downstream river. The present low flows will be augmented, and there will also be a significant reduction of flood peaks and frequency, consequently the average regulated flow over the year will change insignificantly, i.e. only resulting from the net evaporation losses from the reservoir. With the GD-03 regulation at the top of the cascade, power generation of the GD-5 and GD-6 hydropower plant will become much more steady and reliable (Lahmeyer International and Yeshi-Ber Consult, 2007).

3.6.2 GD-5 Hydropower Scheme

3.6.2.1 Location

This Hydropower plant is found partly in Oromia region, bale zone of Medewlabu Woreda and Filtu woreda,Liben Zone of somalia region.The nearest access facility to GD-5 proposed hydropower scheme is a 24 km long dry weather track that branches off from the National Road 44 some 500 m east of Haya Suftu and ends at the river at a location some 15 km upstream of GD-5. The Dam site is located around $5^0$20’N and $40^0$10’E.

3.6.2.2 Purpose

The GD-5 hydropower scheme will benefit the almost constant inflow to produce very reliable power output. This project combined with hydropower projects GD-3 and GD-6, is a good candidate for power export to Kenya.

3.6.2.3 Reservoir

The reservoir created by a dam at the GD-5 will have a total storage capacity of 132Mm^3 at full supply level (690m asl) and will cover an area of 6.5 km^2. The minimum operating level will be 672masl and storage at MOL will be 75Mm^3 and this will cover 3.5km^2. The active storage is some 57Mm^3.

As the existing topography does not allow the provision of a large-scale reservoir, only limited additional flow regulation (with daily/weekly pondage) will be possible. GD-5 is one out of the sites with particularly narrow valley profiles that had been identified along the reach of Genale River downstream of GD-3.

The elevation-surface area-capacity relations of the valley upstream of the GD-5 dam site have been compiled from the SRTM (Space Shuttle Radar Topography Mission) data downloaded from the Internet in the form of a DEM (Digital Elevation Model) with elevations averaged over 90m square cells. The resulting relationships are tabulated in Table 3-3 and plotted in figure 3-6.

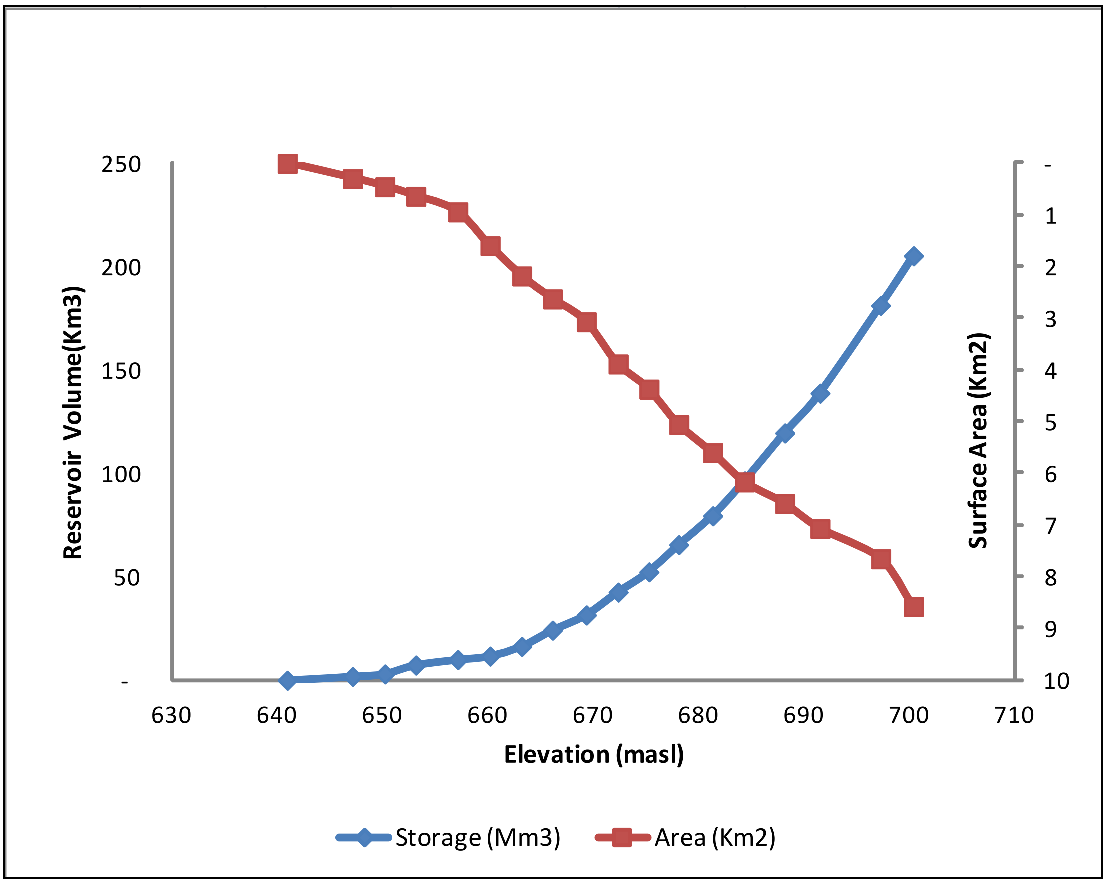


Figure 3-6 Elevation-Storage-Area Curves for GD-5 Reservoir

Table 3-3 Elevation-Storage-Area for GD-5 Reservoir

Elevation (m asl)	Storage (Mm^3)	Area (ha)
640.92	-	-
647.12	1.86	29.46
650.18	3.05	45.24
653.12	7.36	63.63
657.11	10.02	93.74
660.17	11.68	159.15
663.18	16.35	217.86
666.10	24.24	262.13
669.31	31.59	306.39
672.33	42.64	388.09
675.25	52.44	436.81
678.08	65.56	505.23
681.30	79.54	559.55
684.33	96.40	616.34
688.14	119.61	658.02
691.49	138.86	706.52
697.25	181.34	765.00
700.37	205.28	857.21

3.6.2.4 Hydrological Site Conditions

As per the master plan study of the mean flow of Genale River at the GD-5 site has been estimated to be $97m^3/s$. The catchment area amounts to 12,906 km^2.

The flow regime is very unbalanced and shows a distinctive wet season from April to November, which makes up nearly 90% of the annual flow, and a dry season from December to March. The highest discharges normally occur in October, the lowest at the end of the dry season in March.

3.6.2.5 Expected Energy Production

Considering a total installed capacity of 106 MW, a plant discharge of about 120m³/s and a rated head of 83 m, the GD-3 scheme would show the following energy production features:

- Average energy production: 712 GWh/year
- mean power production: 106 MW
- plant factor: 56 %
- percentage of firm energy 71%

Around 96 % of the river flow would be used for energy generation; the rest is diverted by the spillway during floods or lost by evaporation.

3.6.3 GD-6 Hydropower Scheme

3.6.3.1 Location

The project area straddles the Somali and Oromia Regions with the Oromia Zone of Bale (Meda Welabu Wereda) on the left bank and the Somali Zone of Liben on the right bank. Road access to site will start at Siru, which is located on the main road between Negele and Filtu.

The Genale GD-6 Hydropower project is located on the Genale River of the Genale Dawa River basin, approximately 80 km east of Negele, in Liben Zone of the Somali National Regional State. The project area is approximately 700 km by road south and east of Addis Ababa. The project forms the downstream power plant in a series of three utilizing the large reservoir of the planned hydropower project GD-3 located some 82 km further upstream along the Genale River. Just upstream of the reservoir of GD-6 is a potential Hydropower Project GD-5, which is discussed in section 3.6.2, which forms the middle hydropower project in the series.

The project GD-6 exploits the head over an approximately 31 km stretch of the river with a maximum gross head of 234 m between the elevations 585 masl and 351 masl.

3.6.2.2 Purpose

The GD-6 hydropower scheme will benefit the almost constant inflow to produce very reliable power output. This project combined with hydropower projects GD-3 and GD-5, is a good candidate for power export to Kenya.

3.6.2.3 Reservoir

The reservoir created by a dam at the GD-6 will have a total storage capacity of 183.6Mm^3 at full supply level (585masl) and will cover an area of 8.15km^2. The minimum operating level will be 580masl and storage at MOL will be 143.6Mm^3 and this will cover 7.2km^2. The active storage is some 40Mm^3.

At full supply level 585 masl the headwater of the reservoir extends more than 12 km upstream with a width of the reservoir of some 600 m near the dam site. 650 m will be the average width of the reservoir.

The objective of a dam at GD-6 is therefore in the first place to create the required gross head for energy generation. As the existing topography does not allow the provision of a large-scale reservoir, only limited additional flow regulation (with daily/weekly pondage) will be possible. GD-6 is one out of the sites with particularly narrow valley profiles that had been identified along the reach of Genale River downstream of GD-3.

The reservoir elevation-area-capacity relationships have been established from the digital maps, measuring digitally the areas delineated in the reservoir by the 5 m contour lines. The reservoir capacity was then determined by integrating the elevation-area curve. The resulting relationships are plotted in Figure 3-7 and tabulated as Table 3-4.

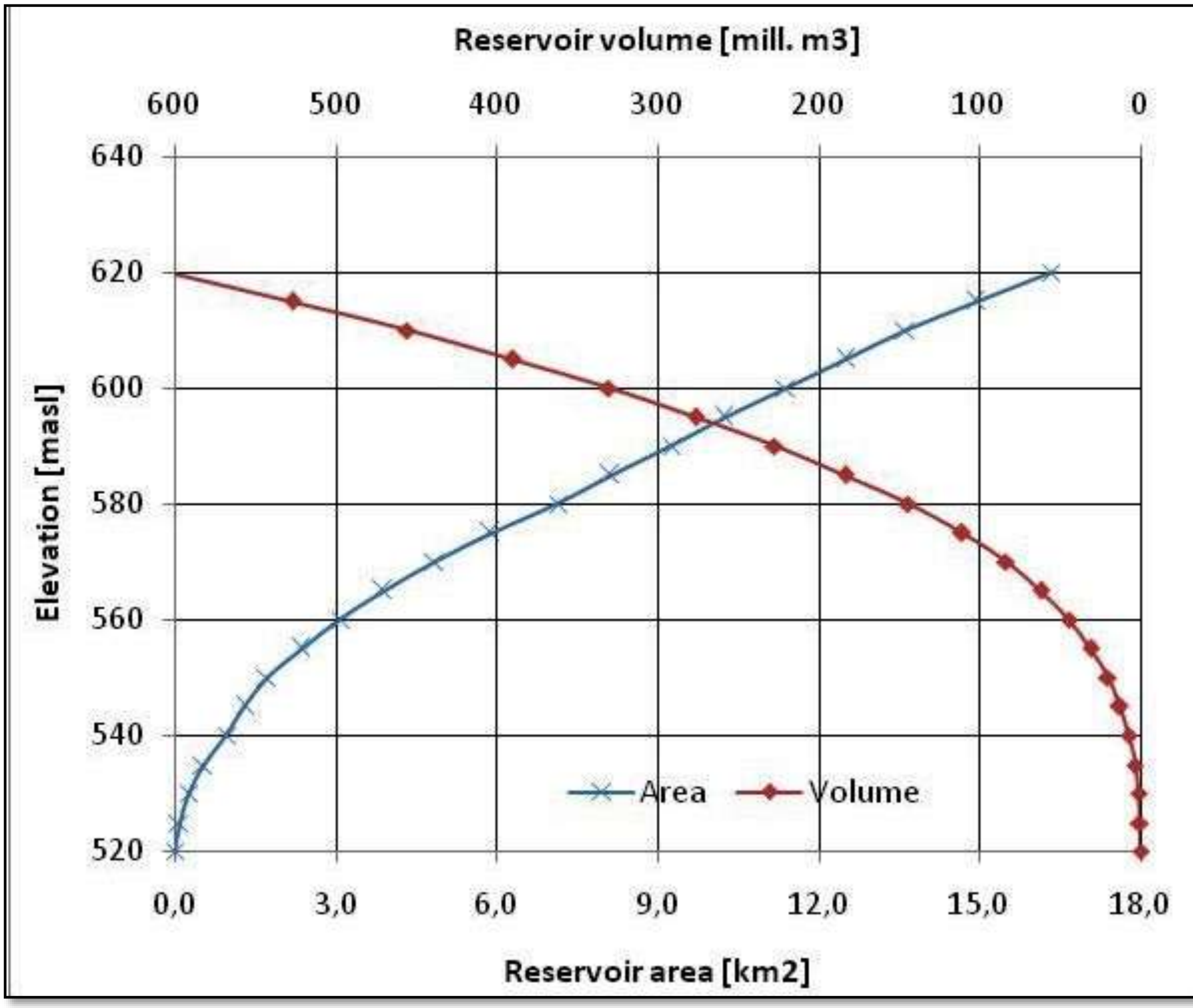


Figure 3-7 Elevation- area-storage curve for GD-6 Reservoir

3.6.2.4 Hydrological Site Conditions

The river basin, the mean flow of Genale River at the GD-5 site has been estimated to be 102.3m³/s. The catchment area amounts to 13,356 km².

The flow regime is very unbalanced and shows a distinctive wet season from April to November, which makes up nearly 90% of the annual flow, and a dry season from December to March. The highest discharges normally occur in October, the lowest at the end of the dry season in March.

Table 3-4 Elevation-Storage-Area for GD-6 Reservoir

Elevation (m)	Storage (m^3)	Area (ha)
522	0	0
525	0.3	10
530	1.2	30
535	3.3	50
540	7.1	100
545	12.8	130
550	20.4	170
555	30.7	240
560	44.3	310
565	61.7	390
570	83.6	490
575	110.5	590
580	143.6	720
585	183.6	810
590	227.1	930
595	275.9	1020
600	330	1140

3.6.2.5 Expected Energy Production

Considering a total installed capacity of 246 MW, a plant discharge of about 120m^3/s and a rated head of 182 m, the GD-3 scheme would show the following energy production features:

- Average energy production: 1575 GWh/year
- Firm energy production: 1540 GWh/year
- mean power production: 246 MW
- plant factor: 73 %

4. METHODOLOGY

4.1 General

Prior to any river basin simulation, it is mandatory to search and collect basic inputs about the principal simulation components to be used for the proper simulation of the basin. Hence the following were collected for the simulation of Genale – Dawa River basin to achieve the main objective of the study:

1. Spatial configuration of the river basin system
2. River basin hydrology
3. Physical characteristics of reservoirs, spillways and outlet works, hydroelectric power plants, and other water control facilities

HEC-ResSim model computes reservoir storage contents, evaporation, water supply withdrawals, hydroelectric energy generation, and river flows for specified system operating rules and input sequences of stream inflows and evaporation rates. Hence, different data were collected from review of previous studies as well as data from institutions such as Ministry of Water, Irrigation and Energy (MoWIE), National Meteorological Agency (NMA), Ethiopian Electric Power Corporation (EEPCO) and information from the internet.

After collecting the necessary data and checking data quality for this research, filling of missed data, flow transferring and evaporation loss analysis have been made. Finally the inputs are incorporated in to the HEC-ResSim model, where these data are configured and analyzed, to get the required output. The general frame work of the methodology is shown in figure 4-1

Material Used

The materials used for this research are Arc view GIS tool to obtain hydrological and physical parameters and spatial information, ArcMap10 software to delineate the basin of the study area, Global Mapper to manipulate the DEM data in line with the shape files of the river basin, HEC-ResSim model for basin simulation and Microsoft EXCEL to analyze HEC-ResSim outputs.

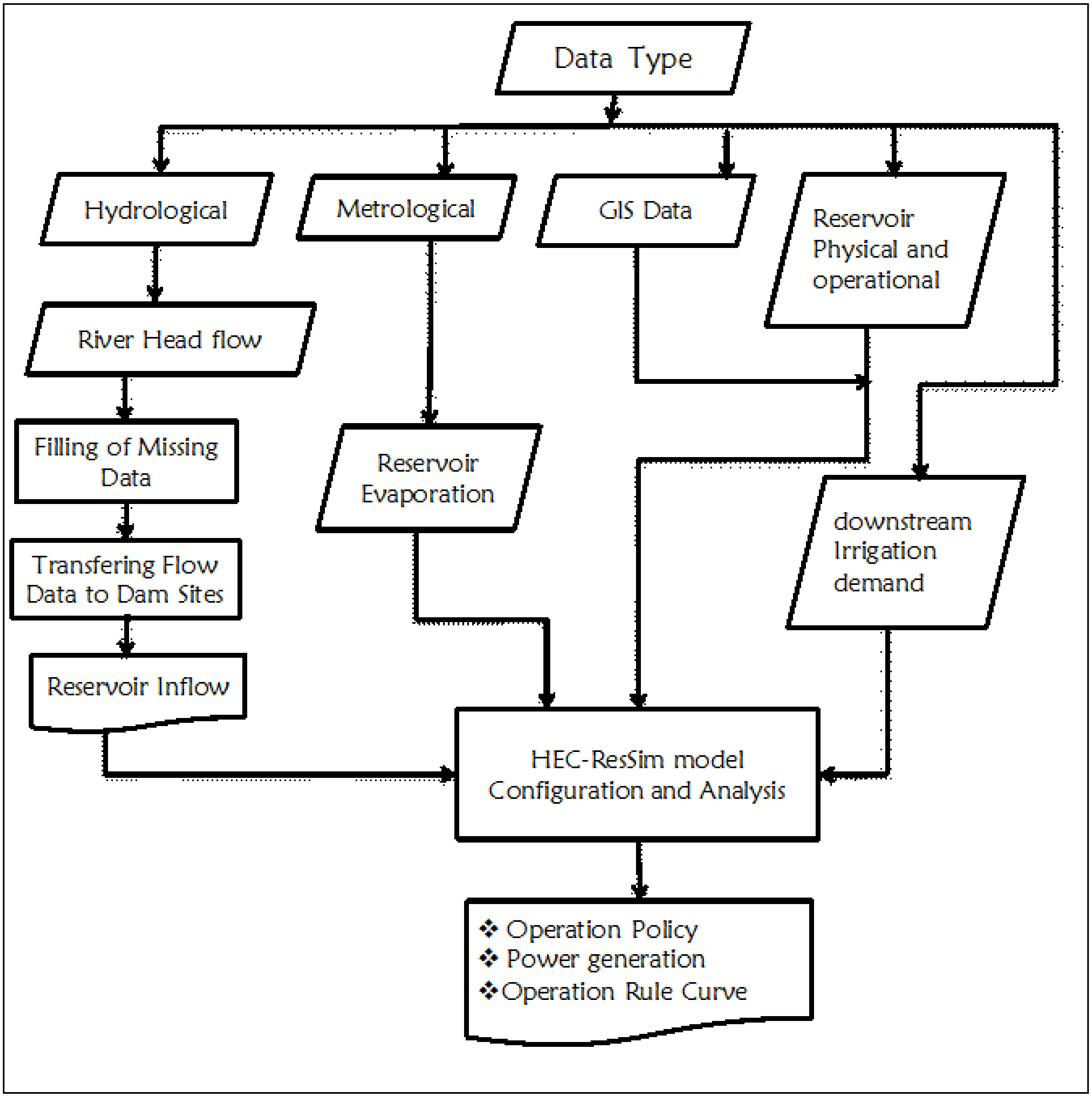


Figure 4-1 Frame work Methodology used

4.2 Data Collection and Analysis

4.2.1 General

It is an indispensable step to collect adequate and quality data before undertaking and processing of any research. Therefore, the primary assignment of the study was getting relevant information and data of the study area. This section identifies and discusses the types and source of data required for the study, and their analysis.

Before starting hydrological and metrological data analysis and simulation, it is important to check whether the data are homogenous, correct, sufficient and complete with no missing data. It is because erroneous data resulting from lack of appropriate recording, shifting of station location and processing are serious as they lead to inconsistency and ambiguous results that may contradict to the actual situation (Maidment, 1992).

4.2.2 Meteorological Data

The meteorological data have been collected from National Meteorological Agency (NMA). The availability and quality of meteorological data such as rainfall, temperature, sunshine hours, wind speed, and relative humidity are vital for any water resource study.

There are number of Meteorological stations in the river basin, however, due to limitation of data only nine station were considered out of which only four of them are found in and on the border of Genale basin. The criterions for the selection of the metrological data were based on the availability of data, the data quality and possibly whether the station is within the watershed or not? And if not it is within the sub-basin or nearby. The data collected covers a period of 1991-2005.Except few of the station most of the station data are incomplete and short. Table 4-1 below shows of selected meteorological station with their respective location and sub basin.

Table 4-1 List of Selected Meteorological Stations in Genale Dawa River Basin

S.No	Station name	Sub Basin	UTM Location	
			Easting	Northing
1	Bore	Dawa	458151	702828
2	Genale Donota	Genale	559201	630819
3	Hagereselam	Dawa	447342	716983
4	Harekelo	Dawa	542990	614068
5	Negele	Genale	563910	589736
6	Nensebo	Genale	511826	727985
7	Kibremengist	Dawa	498470	649433
8	Wadera	Dawa	533821	638600
9	Yirbamuda	Genale	467572	686170

In regard to rainfall regimes and seasons, a standard self-explanatory nomenclature for Ethiopia has been compiled by NMSA, namely “mono-modal”, “bi-modal” and “diffuse”. The entire Genale river basin falls under the “bi-modal” rainfall regime with two wet seasons. There are two sub- divisions of the “bi-modal” regime. Type I in which the rainfall continues for a period of some 7 months from April to October with less pronounced peaks at the beginning and end, and Type II in which pronounced rainfall peaks occur in April and October with little rainfall between these peaks. Some 80% of the Genale catchment area draining to the GD-3 project site is within the “bi-modal” Type I rainfall regime with prolonged wet season. Only some 20% of the catchment is within the “bi-modal” Type II rainfall regime. This Type II regime begins upstream of the project components (dam and powerhouse) of GD-3, in the region just north of Kibremengist and extends downstream to the middle and lower reaches of the Genale River. (Feasibility study of GD-3, 2007)

Spatial distribution of meteorological stations is sparse and uneven. Only four stations lie within the Genale basin. The sparse metrological stations and spatial variation of rainfall over the Genale project area is shown in the isohyetal map produced in the Feasibility study of GD-6 (Norplan and Norconsult, 2009).

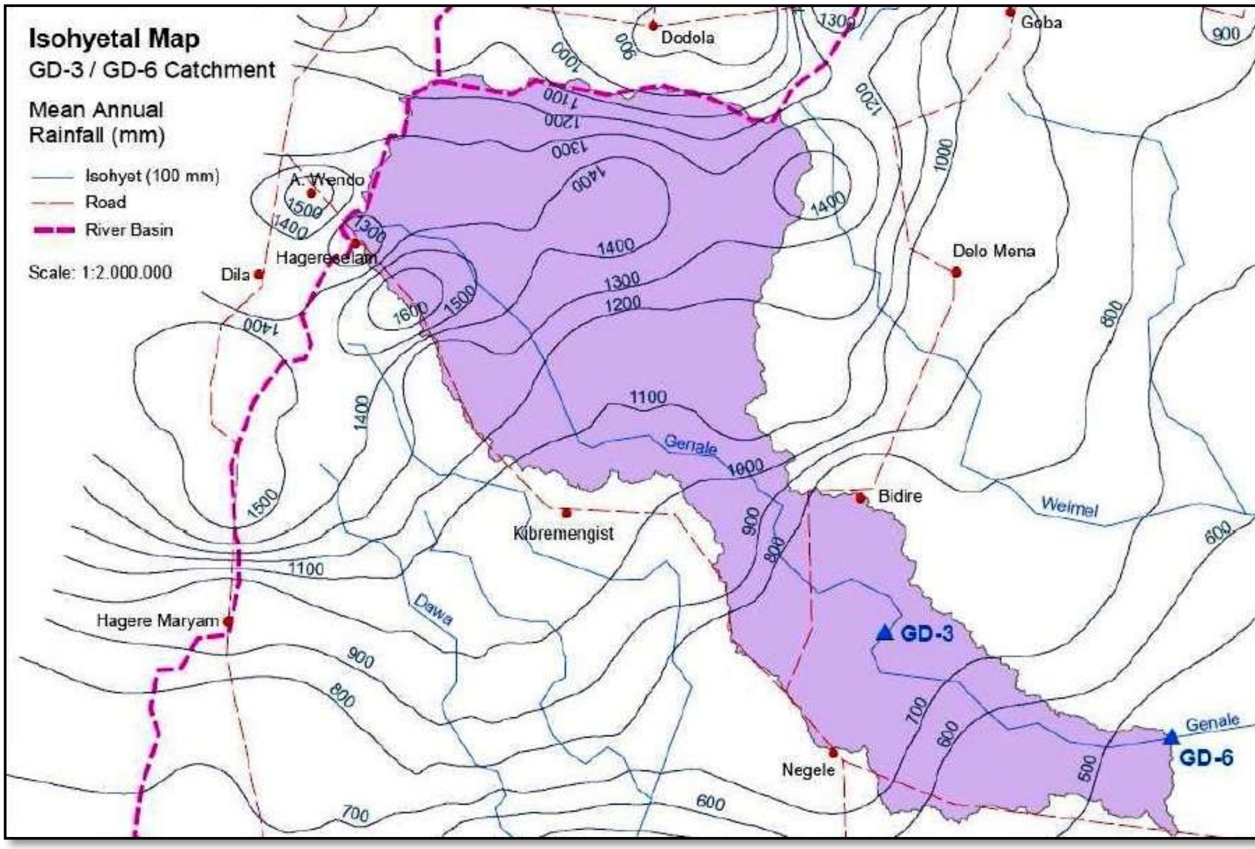


Figure 4-2 Map of mean annual rainfall over the Genale basin, source- PFS (2006)

4.2.2.1 Test for Homogeneity of Selected stations

For a meteorological station to be selected representative to the analysis of aerial precipitation on a reservoir of the dam sites of this study and filling of missing rainfall data, homogeneity of the group stations need to be checked. Therefore to test the homogeneity of the selected gauging stations monthly precipitation records were non-dimensionalized using equation 4-1 (Linsely, 1983) and plotted to compare the stations with each other as shown in figure 4-2 (nearest station to the hydropower plants under this study).

$$P_i = 100\% * \frac{(\overline{P_i})}{\overline{P}} \quad \cdots\cdots 4.1$$

Where, P_i =is non-dimensional value of rainfall for month i,

$\overline{Pi}$ = Over year-averaged monthly rainfall at the station i,

$\overline{P}$ = The over year -average yearly rainfall of the station

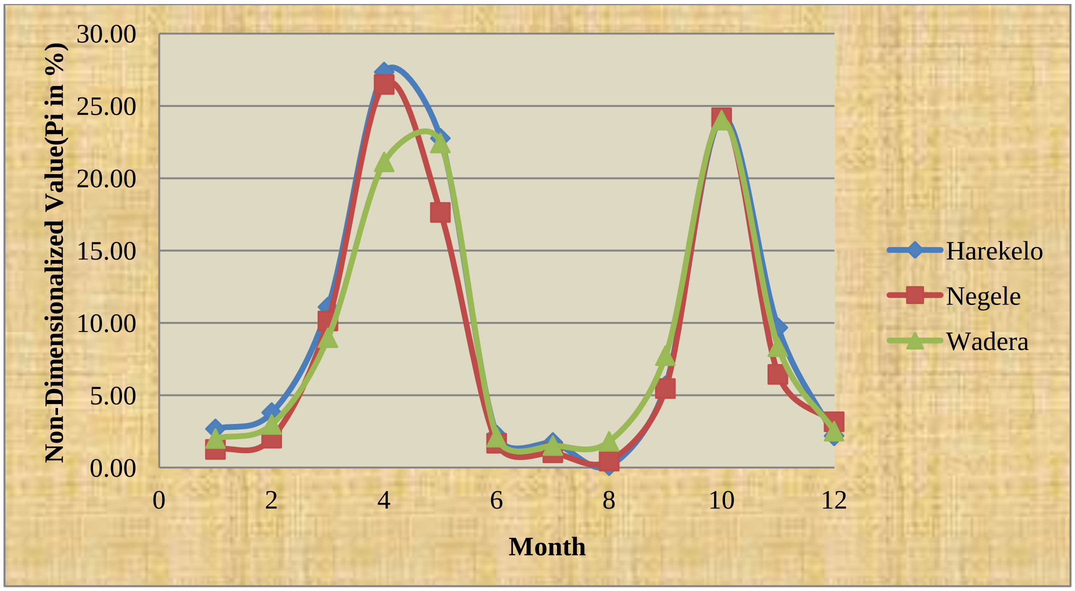


Figure 4-3 Non-dimensionalzed stations for middle Genale sub-basin

Thus the homogeneity test graph shows that all have homogenous characteristics of “bi-modal” Type II rainfall regime, as these stations are closer to the project sites.

4.2.2.2 Test for Consistency of Record

If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. Shifting of rainguage station to a new location, the neighbourhood of the station undergoing a marked change, change of ecosystem due to calamites and occurrence of observational error from a certain date are some of the most common causes of inconsistency of records. The checking for inconsistency of the record is done by the double-mass curve technique. This technique is based on the principle that when each recorded data comes from the parent population, they are consistent (Subramanya, 1994).

In the double-mass curve analysis the graph is plotted between the cumulative rainfall of a single station as ordinate and the cumulative rainfall of the group of stations as abscissa. The base stations used in the double mass analysis were Harkelo, Negele and Wadera which are located in the middle Genale sub-basin closer to the project site. The double mass curve analysis of these station shows that there is no significant break in the slope which implies that the datas on these stations are consistent, Figure 4-3.

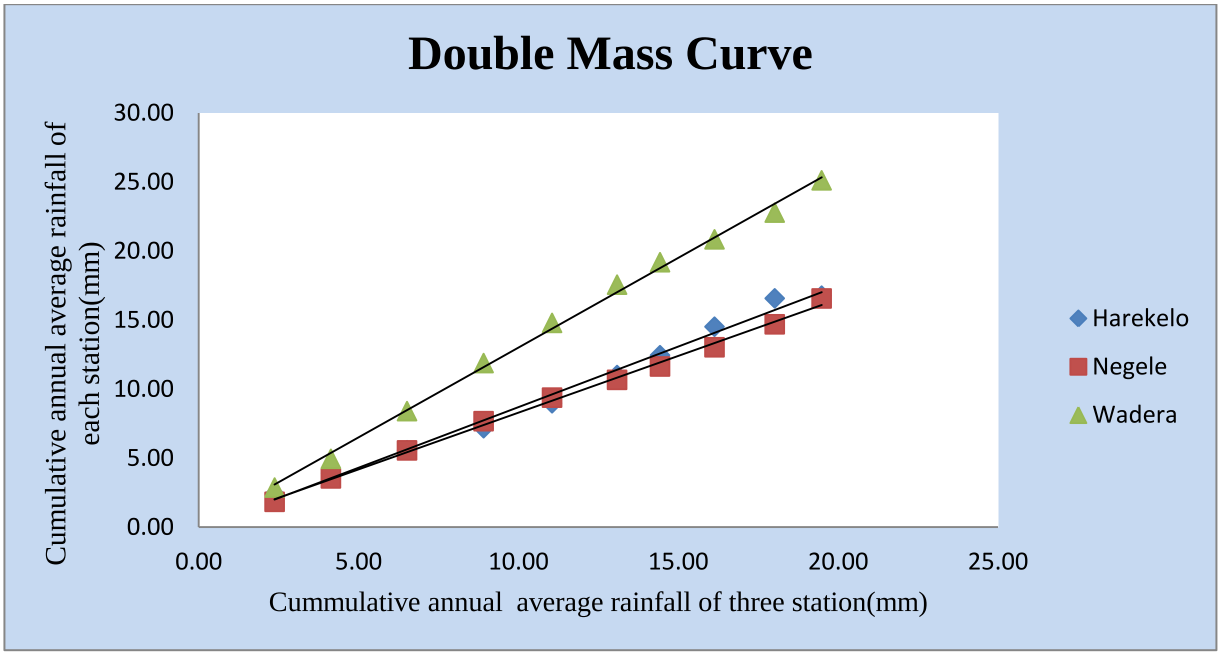


Figure 4-4 Double mass curves for selected meteorological stations

4.2.2.3 Estimating Missing Rainfall Data

Measured precipitation data are vital to many problems in hydrologic analysis and design. Since there are costs related to data collection, it is imperative to have complete records at every station. However the actual condition in most of the data records this is not satisfied for different reasons. For gauges that require periodic observation, the failure of the observer to make the necessary visit to the gauge may result in missing data. Vandalism of recording is another problem that results in incomplete data records, and instrument failure because of mechanical or electrical malfunctioning can result in missing data. Any such causes of instrument failure reduce the length and information content of the precipitation record(McCuen, 1989). A number of methods have been proposed for estimating missing rainfall data. The most common methods are the simple Arithmetic Mean Method and Normal-Ratio Method and these methods are used for filling of missing data in this study.

Normal – Ratio Method

The normal ratio method is preferred to be used where the mean annual precipitation of any of the adjacent stations exceed the station in question by more than 10% and it is Normal ratio methods are expressed by the following relationship:

$$P_x = \frac{N_x}{N}\left(\frac{P_1}{N_1} + \frac{P_2}{N_2} + \cdots\cdots\cdots\cdots + \frac{P_n}{N_n}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .4.2$$

Where,

P_x =Missing value of precipitation to be computed.

N_x = Average value of rainfall for the station in question for recording period.

N_1 ,N_2………Nn= Average value of rainfall for the neighboring station 1,2,…n..

P_1,P_2....P_n = Rainfall of neighboring station 1,2,…n during missing period

N= Number of stations used in the computation.

4.2.3 Hydrological Data Analysis

Due to human and intrinsic errors in data readings and complex relationship of hydrological processes that cannot be expressed explicitly, exact prediction of hydrological variables are impossible. As a result of this disadvantage, it is crucial that statistical analysis is conducted to allow a better understanding of the statistical trends and relationships existing within the data, thereby resulting in better model development (Burton, 1998).

An accurate assessment of the water resources in the Genale basin has historically and to some degree is still constrained by a limited hydrological database. For the hydrological analysis, the present study used most of the available hydrological data related to the Genale basin. These data have been collected by different institutions and projects. The majority of the historical hydrological data comes from the Hydrology Department of MoWIR which is responsible for the operation of the hydrometric network throughout Ethiopia.

There are about 11 hydrometric stations in Genale basin. However most of them are far from the hydro plant sites under study and with very low catchment area, in which seven of the gauging stations are about 20% of one of the main gauge station found nearest to the project sites, Chenemsa. Records of tributaries stream flow are of great value for description of the Genale River flow formation but might only be used and as a supplementary information for estimation of hydrological parameters of the planned projects. In practice, the only station in Genale basin, which supplies data that can be used directly for estimation of hydrology of the proposed hydropower projects, is the Chenemsa gauging station (Norplan and Norconsult, 2009). Chenemsa site has long and continuous record with in the flow period this study is conduct, from 1991 to 2005, except gaps for some months.

4.2.3.1 Filing of Missed Data

In order to make use of partially recorded data, missing values need to be filled in sequence. To fill the missing recorded stream flow gauging data various methods are available. The missing values were filled with regression. In this study as the station located at Chenemsa located at 39^{0}32’6’’E and 5^{0}42’29’’N covering about 88% , 71% and 69% of the area draining to the GD-3, GD-5 and GD-6 dam sites respectively, is selected as key station. Filling of missing data is therefore carried out only for this station.

4.2.3.2 Flow Data Transfer to the Dam Sites

Though gauging stations are available in a river basin, it is unusual for these gauges to be located precisely at rivers confluence and dam sites. The most commonly method used to transfer stream flow data to the point of interest is to use area ratio methods as described by eq.4.3. This method uses the drainage areas to interpolate flow values between or near gauged sites on the same stream. Flow values are transferred from a gauged site, either upstream or downstream to the ungauged site.

This method is most valid in situations where watersheds are of similar size, landuse, soil type and experience similar precipitation patterns and be on the same stream (Knapp et al., 2001). The case of this study has similar situation as described above. Chenemsa station is located at 40Km from GD3 site and 145Km from the last downstream site GD-6 having similar precipitation pattern and all being located on Genale Main River. Hence, the area – ratio method is considered appropriate to generate inflow data at the ungauaged dam sites from the gauged station chenemsa.

$$Q_{Site} = \left[\frac{A_{Site}}{A_{gauge}}\right]^n Q_{gauge} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 4.3$$

Where, Q_{site}-discharge at the site of interest,

Q_{gauge}- discharge at the gauge site,

A_{site}-drainage area at site of interest,

A_{gaug}-drainage area at the gauge site and n-varies between 0.6 and 1.2.

If the A_{site} is within 20% of the A_{gauge} ($0.8 \leq [A_{site}/A_{gauge}] \leq 1.2$), then n = 1 to be used. The estimated discharge at the site will then be within 10% of actual discharge. When A_{site} is within 50% of the A_{gauge} two station data are considered for data transferring. Relation can be developed to estimate a weighted average flow at a site lying between upstream and downstream gauges(Daniel, 2011).

$$Q_{site} = \frac{(A_{gauge1} - A_{gauge2}) Q_{gauge1} + (Asite - Agauge2) Q_{gauge2}}{(Agauge1 - Agauge2)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 4.4$$

Where: - Gauge1 upstream gauging site and gauge2 downstream gauging site.

4.2.4 Evaporation from Reservoir

The key parameter dependent on climatic data used in reservoir simulation studies is evaporation loss from the reservoir area. Among the several phases in the hydrological cycle, evaporation is one of the most difficult to quantify. Certainly it is difficult to define the unseen amounts of water stored or moving underground, but above the ground surface, the great complexities of evaporation.

There are several methods for evaporation determination; water balance, energy balance, Aerodynamic, penman and pan evaporation methods being the most common (Chow, 1998). In the absence of pan evaporation data in the region, potential evaporation from free water surface at the dam location can be calculated by Penman method. Fortunately, mean monthly evaporation data for the reservoir was obtained from their respective feasibility study documents.

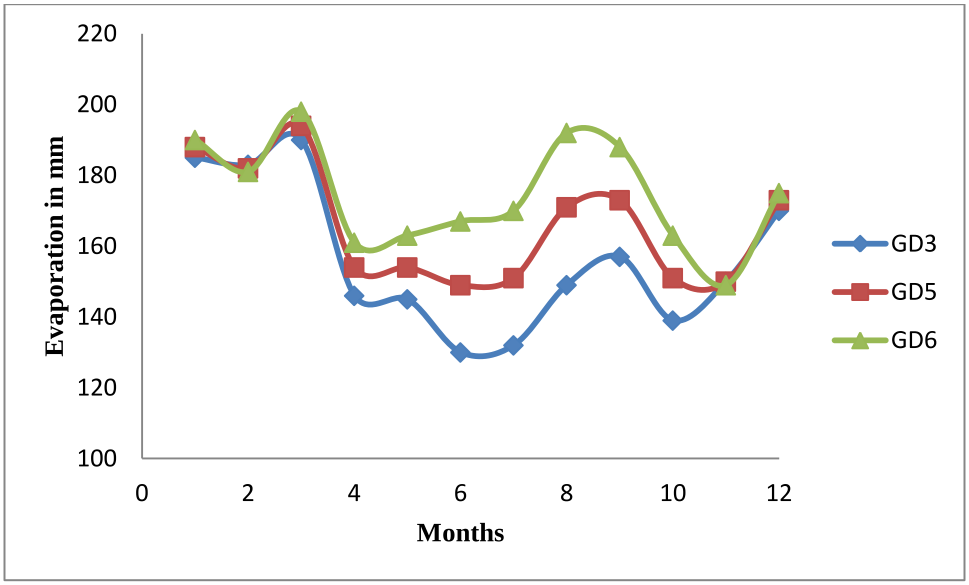


Figure 4-5 Mean Monthly Reservoir Evaporation for GD3, GD5 and GD6.

5. DEVELOPMENT OF HEC- ResSim FOR GENALE- DAWA RIVER BASIN

5.1 General

HEC-ResSim is a planning and real time decision-support tool for single and multi-reservoir system management. This software performs hydrologic routing and determines reservoir releases based on a rule curve approach plus user-specified operating rules to meet multipurpose, seasonal, at-site and downstream operational goals, including flood reduction, water supply, hydropower generation and stream flow generation.

Hec-ResSim comprises three separate sets of functions called Modules that provide access to specific types of data within a watershed. These modules are Watershed Setup, Reservoir Network, and Simulation. Each module has a unique purpose and an associated set of functions accessible through means, toolbars, and schematic elements. The Hec-ResSim model setup is done for Genale-Dawa River basin, specifically for the study area, and modules will sequentially be discussed in the following sections.

5.2 Watershed Setup

The watershed setup for Genale- Dawa River basin is done by importing first the geo-referenced GIS data map of the study area. This helps to draw the stream alignment properly following the background map and put the reservoir dams and its computation points at the appropriate positions. The watershed setup for the study area, Genale – Dawa river basin GD-3, GD-5 and GD-6 reservoir system, is shown in figure 5-1. All the three reservoirs lie in the Genale main river stream with GD-3 being upstream reservoir for GD-5 which is located upstream of GD-6.

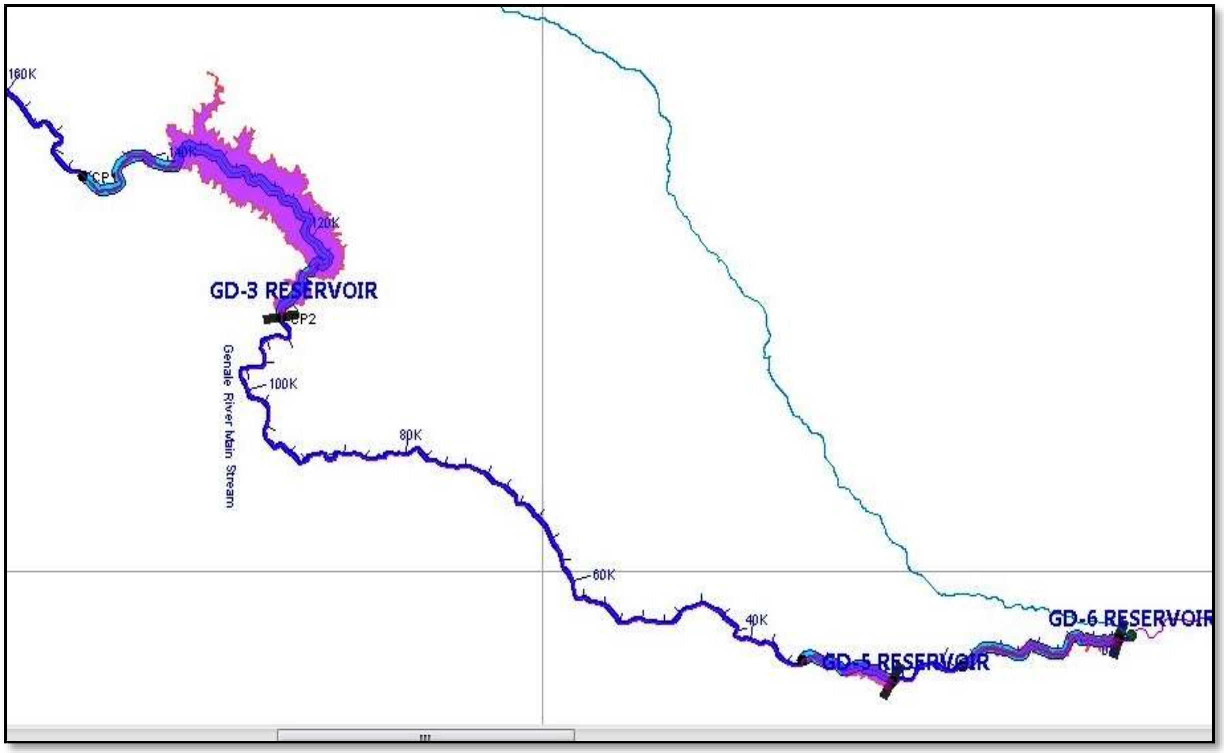


Figure 5-1 Watershed Setup for Genale Dawa reservoir system

5.3 Reservoir Network Setup

After the watershed setup is complete, In the Reservoir Network module, the routing reaches and other network elements have been added to complete the connectivity of the network scheme. Once the schematic is complete, physical and operational data for each network element are incorporated. Alternatives were also created that specify the Reservoir Network, operation set(s), initial conditions and assignment of DSS pathnames (time-series mapping). In the Reservoir Network module, one will build the river system schematic, describe the physical and operational elements of the reservoir model, and develop the alternatives that are to be analyzed. Using configurations that are created in the Watershed Setup Module as a template, the basis of a Reservoir Network has been created.

The network components that are represented by Hec-ResSim for Genale Dawa river basin are of three types: junctions, routing reaches and reservoirs. Each element is defined with enough information to be physically realistic without requiring excessive detail that would bog down computation time.

By network system developing the reaches, junctions, and reservoirs are combined and interconnected system Genale-Dawa River Basin network is prepared (Figure 5-2).

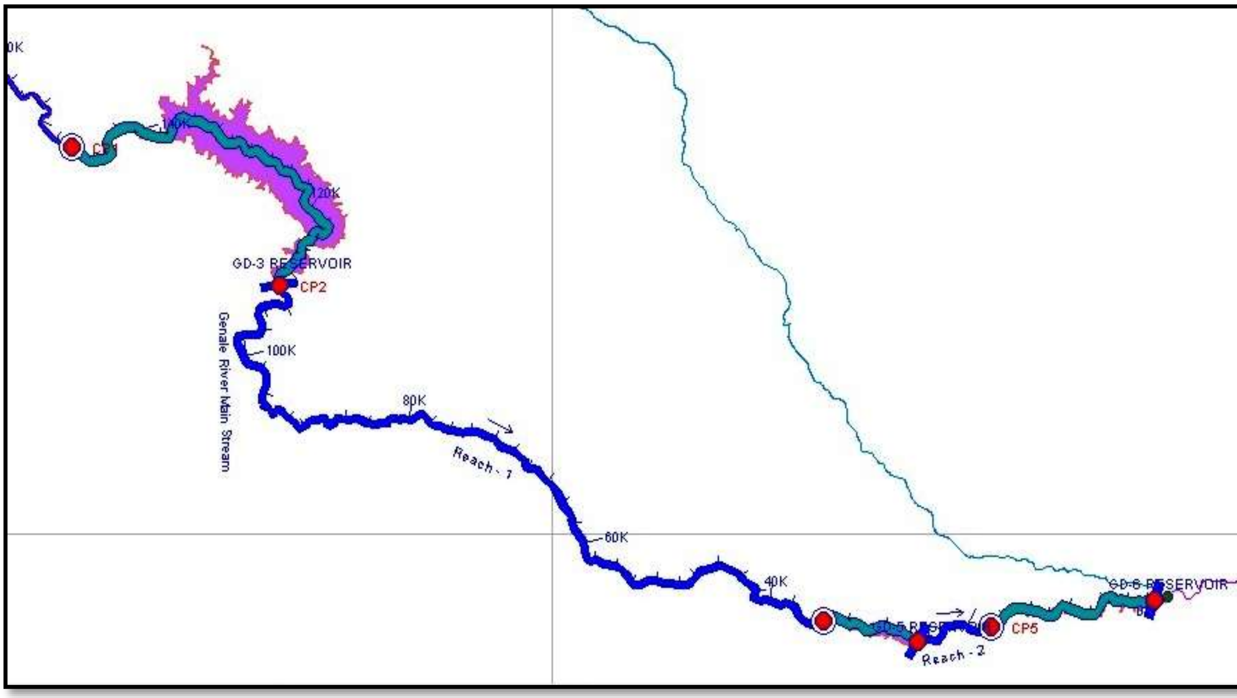


Figure 5-2 Reservoir Network setup for GD-3, GD-5 and GD-6 Reservoir System

The modeling elements that make up the reservoir network for this study include: reservoirs, reaches, junctions, reservoir systems, and state variables. Each of these elements consists of one or more sub-elements. The following sections will describe each element type beginning with the simplest elements, the junctions, and working up to the most complex, the reservoirs and reservoir systems.

5.3.1 Junctions

The junction elements serve four functions: 1) they link model elements together, 2) they are the means by which flow (headwater or incremental) enters the network, 3) they combine flow, the outflow of a junction is the sum of the inflows to the junction, and 4) when provided with an optional rating curve, they calculate stage using the computed junction outflow. The focus area in this study of Genale-Dawa river basin has 6 junctions. Each reservoir has 2 junctions. One is for inflow and the other for outflow or release water.

Once a reservoir network is assembled, the connection between network elements is taken for granted, however a good model design includes junctions at key locations to identify and manage inflow data effectively across various alternatives.

Depending on the inflow locations, junctions can fall into two categories: boundary junctions and interior junctions. Boundary junctions have no reaches or reservoirs above them in the network and typically identify a single upstream gage or inflow representing the total headwater inflow. Interior junctions combine inflow routed from upstream with incremental local flow before passing the total flow on to the downstream element. Hence, junction CP1 is the only boundary junctions the rest are interior junctions Figure 5-2.

5.3.2 Reaches

Routing reaches represent the natural streams in the system that route water from one junction to another in the network. Routing is performed in HEC-ResSim using one of a handful of hydrologic routing methods. The lag and attenuation of flow in a reach is computed by one of a variety of available standard hydrologic routing methods, such as Muskingum, Modified Puls, Coefficient, or Muskingum-Cunge. Losses through seepage can be specified for each routing reach. The Muskingum method is used for this study

The Muskingum routing method requires three parameters, the Muskingum K, Muskingum X, and the number of subreaches. The K parameter is the travel time of the flood wave through the reach, the X parameter is used to model the attenuation of the flood wave due to channel and overbank storage, and the number of subreaches is an additional parameter that affects the amount of attenuation through the reach. The X parameter is dimensionless and can vary from 0.0 – 0.5. A value of 0.0 maximizes attenuation of the flood wave and a value of 0.5 does not attenuate the flood wave, indicates a “direct translation” of the hydrograph through the reach. K is approximated using the kirpich’s formula:

$$K=0.0078L^{0.77}S^{-0.385} \qquad \ldots\ldots 5.1$$

Where K=travel time for drop of water to travel from the remotest point outlet (minute)

L-Length of channel/ditch from head water to outlet in ft and S- average watershed slope, ft/ft. The computed (K) in hr, X and the number of sub-reach values have been entered as an inputs to reach editor of the reservoir network model.

There are two routing reaches in this study that routes the flow from GD-3 to GD-05(Reach-1) and GD-05 to GD-06(Reach-2). The reach parameter for the reach-2 is shown in Figure5-4.

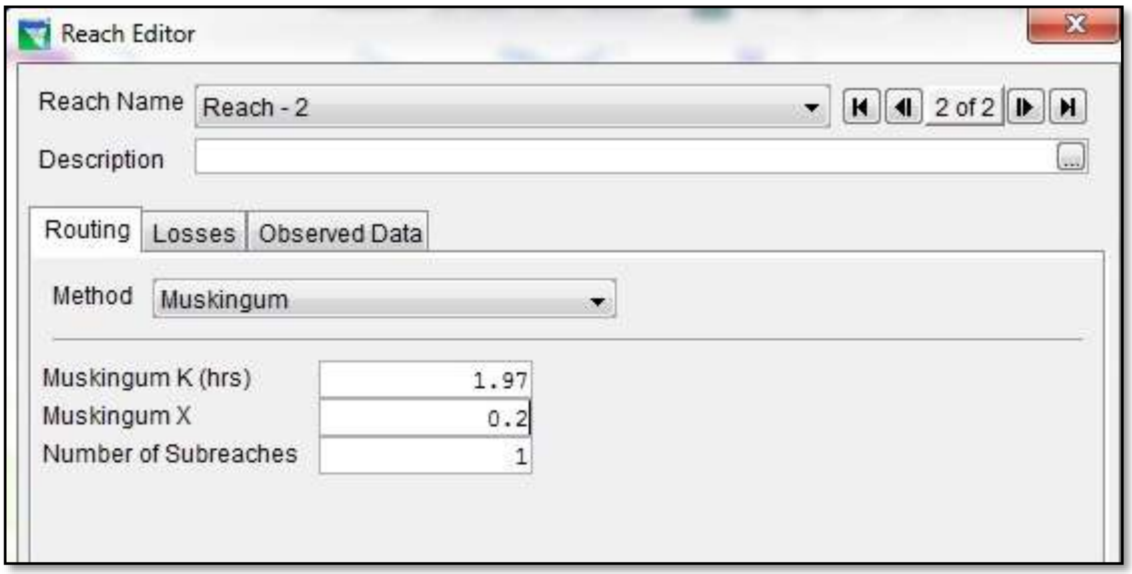


Figure 5-3 Reach Parameter

5.3.3 Reservoirs

A reservoir is the most complex element of the reservoir network and is composed of a pool and a dam. HEC-ResSim assumes that the pool is level (i.e., it has no routing behavior) and its hydraulic behavior is partly defined by an elevation-storage-area table. The real complexity of HEC-ResSim's reservoir network begins with the dam(Wakena, 2006).

The pool is described by the reservoir's elevation-storage-area relationship and can optionally include evaporation and seepage losses. The dam represents both an uncontrolled outlet and an outlet group – the top of dam elevation and length specifies the minimum parameters for an uncontrolled spillway and the dam may contain one or more controlled or uncontrolled outlets. The advanced outlet types are power plant and pump, both of which are controlled outlets with additional features to represent their special purposes. The power plant adds the ability to compute energy production to the standard controlled outlet. Reservoir elements also hold the operational data for a reservoir. The operational data represents the goals and constraints that guide the release decision process. The operation data is grouped as a unit called an operation set. A reservoir can hold multiple operation sets, but only one operation set per reservoir may be used in an alternative. The operation set is made up of a set of operating zones, each of which contains a prioritized set of rules. Rules describe a minimum or maximum constraint on the reservoir releases.

Once the Reservoir Network elements are added to the watershed set up, the reservoir network is developed. Each reservoir characteristics has to be carefully provided with the appropriate physical and operation data for the proper and realistic simulation of the Reservoir system.

5.3.3.1 Physical Components

Definition of physical parts is one of the most important parts in HEC model. Even small changes affect significantly the system behavior and the impacts deteriorate or meliorate the result in the simulation part. Input that should be considered for the physical part consists of the reservoir pool characteristics which are defined by the storage-elevation-area curve and the dam properties that consist of uncontrolled and controlled outlets along with tail water elevation and the downstream control.

a) Storage-Elevation-Area

The elevation storage area curve is the main characteristics of the reservoir pool defining the surface area and the volume of storage at the respective elevation. Elevation –storage-area curves are shown in section 3.7. However, the input of elevation storage area from a spread sheet for the GD-3 Reservoir in ResSim is shown in Figure 5-3.

b) Spillway

Spillways are structures constructed to provide safe release of floods pass a dam to a downstream river stretches. Every reservoir has a certain capacity to store water. If the reservoir is full and high flows enter the same, the reservoir level increases and may eventually result in over-topping of the dam. To avoid this situation, the flood has to be passed to the downstream side and this is done either through the spillway or turbine intakes. A spillway can be a part of a concrete or connected to an embankment dam.

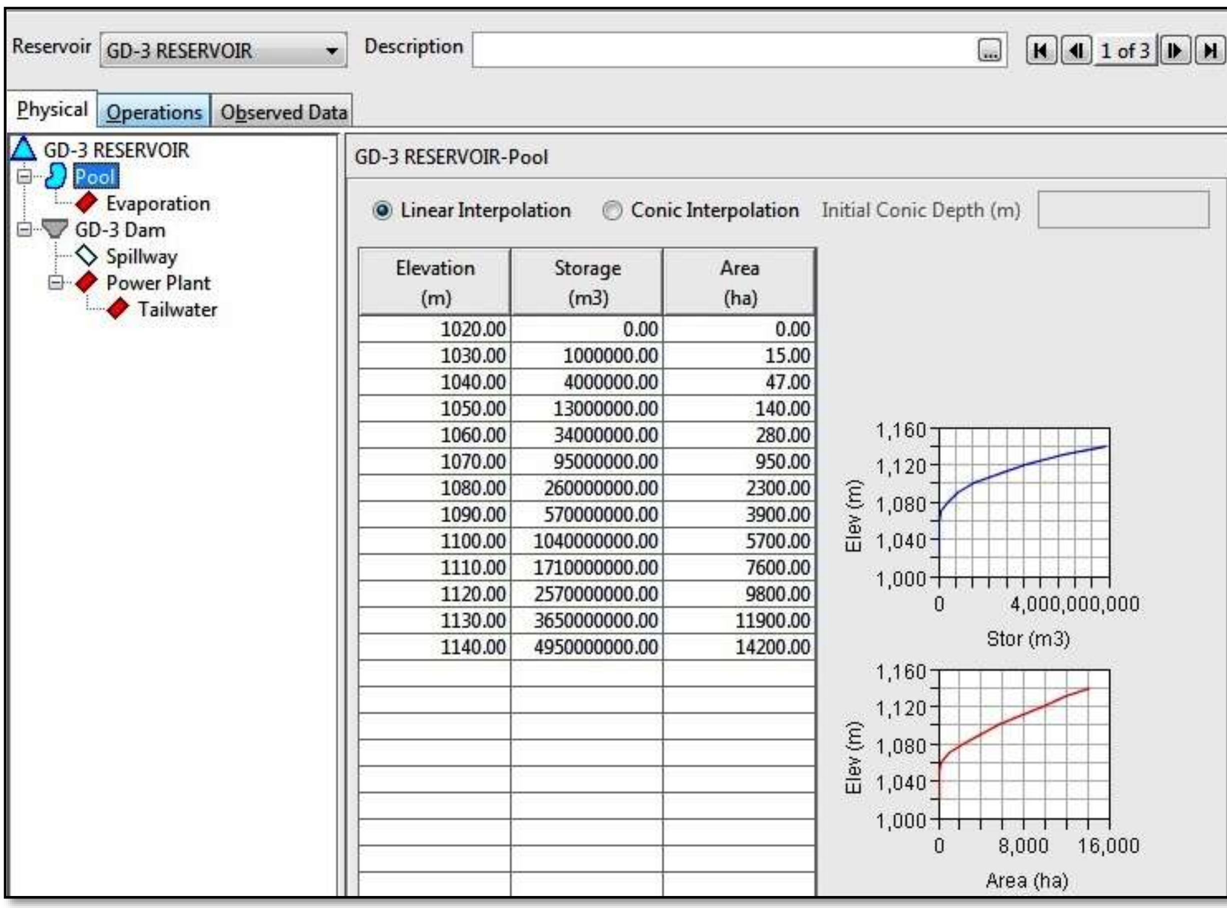
The elevation versus maximum capacity relation for the spillway of reservoirs will be computed for the various elevations above the spillway crest from the well known broad crest weir formula, equation 5.2. ResSim has two way of data entry for the uncontrolled outlet. The first is using weir equation that requires the wearing coefficient, outlet elevation and crest length of the spillway. The second option is using a rating curve of elevation versus outflow. The first option is used in this study.

$Q=CL_eH^{1/2}$ --5.2

Where Q=discharge in the spillway in m^3/sec

C=discharge coefficient which is taken as 2.05

Le=effective length of spillway in meter



Elevation (m)	Storage (m3)	Area (ha)
1020.00	0.00	0.00
1030.00	1000000.00	15.00
1040.00	4000000.00	47.00
1050.00	13000000.00	140.00
1060.00	34000000.00	280.00
1070.00	95000000.00	950.00
1080.00	260000000.00	2300.00
1090.00	570000000.00	3900.00
1100.00	1040000000.00	5700.00
1110.00	1710000000.00	7600.00
1120.00	2570000000.00	9800.00
1130.00	3650000000.00	11900.00
1140.00	4950000000.00	14200.00

Figure 5-4 Elevation –Storage-Area relationship for GD-3

c) Penstock data input

For the penstock outlet the orifice formula (equation 5.3) is used to fill the head versus maximum capacity data as the flow is pressurized

$$Q=CA\sqrt{2gH} \quad \text{--} \quad 5.3$$

Where A is cross sectional area of conduit, g –acceleration due to gravity, H is the pool level above the center of power intake and C is the contraction coefficient.

d) Tail water

Tail water arises both due to hydropower outlets and spillways but in a different elevation and location according to dam topography. It can be natural channels or concert channels. Design of the tail water is important because of the risk for cavitations that can damage the system when sub critical water condition arises. The tail water elevations are adopted from the feasibility study reports of the hydro plants.

5.3.3.2 Operation Component

In a manner similar to the methods an operator may use, each reservoir in ResSim network must determine the quantity of water to release at each time step of a simulation run. For this to happen, scheme upon release decisions can be made or an operation plan should be described. This plan is called an Operation Set. (HEC, 2013)

An operation set consists of three basic features: Zones, Rules and the identification of the Guide curve.

Zone

Zones are operational subdivisions of the reservoir pool. Each zone is defined by a curve describing the top of the zone. When an operation set is created, ResSim establishes a default set of zones within the operation set. These zones are Flood Control, Conservation and the Inactive. However additional zone could be added when necessary. A Minimum Operation zone is added in between the conservation and Inactive zone for this study. Flood zone is the storage between the full supply level of the pool to the top dam crest, Conservation zone is between the Minimum operating level and full supply. Minimum operating zone is storage between top of the inactive zone and the minimum operating level.

Rule

One of the important parts in reservoir simulation models are operation rules. Operating rules describe the logic used to make decisions on storing or releasing water. Dam planning and operation requires decisions to be made about the magnitude and timing of releases. Rules are applied to selected zones of the reservoir to describe the different factors influencing the release decision when the reservoir elevation is within each zone. Determining optimum reservoir storage capacities and operating regime has been a major focus of water agencies, responsible for the planning, design and operation of dams for many years (Yeh, 1985).

HEC-ResSim uses an original rule-based approach to mimic the operational decision-making process that reservoir operators follow in setting release schedules. Just as operators must, the HEC-ResSim release decision-making process for a reservoir takes into account time of year, hydrologic conditions, water temperature, and simultaneous operations by other reservoirs in a system (Klipsch and Hurst, 2007).

The release decision process in ResSim has three basic steps. The first step is to identify the maximum and minimum physical limits on the release, which is the allowable release range. The maximum of the range is the total maximum capacity of the outlets for the current pool elevation, the minimum of the range is the minimum release capacity of the outlets, usually zero. The second step is to narrow the allowable release range by applying the rules in the current zone starting with the highest priority rule. If two rules contradict each other, the higher priority rule applies. The final step is to evaluate the desired release for the basic guide curve operation. This is the release needed to get the reservoir to the guide curve in the current time step (computation interval) based on the starting pool elevation, the prior release and the current inflow. (HEC, 2013)

If the desired release falls within the allowable release range, then the release decision will be the desired released determined by the last step. However, if the desired release is outside the allowable release determined in the first two steps above, the release will be set to the limit closest to the desired value range (HEC, 2013).

The Tandem operation and Release function are the rules used for the reservoir pools of this study. Tandem rules are considered for the upstream reservoirs, GD-3 and GD-5, while the release function is used for the downstream reservoir GD-6. Figure 5-5 and 5-6 shows the tandem and release rules respectively.

As per the technical note of Hec-ResSim, upon the release of the latest version of this software (Version3.1) which is used for this study, Logic has been added to the tandem operation algorithm to see the tandem chain or cascade and to balance the full set of the reservoir together as a single system even if one or more of the reservoirs in the system was constrained by higher priority objectives. This modification affects the result of tandem cascade reservoir as in the case of this study significantly providing with the better output result. (HEC, 2013)

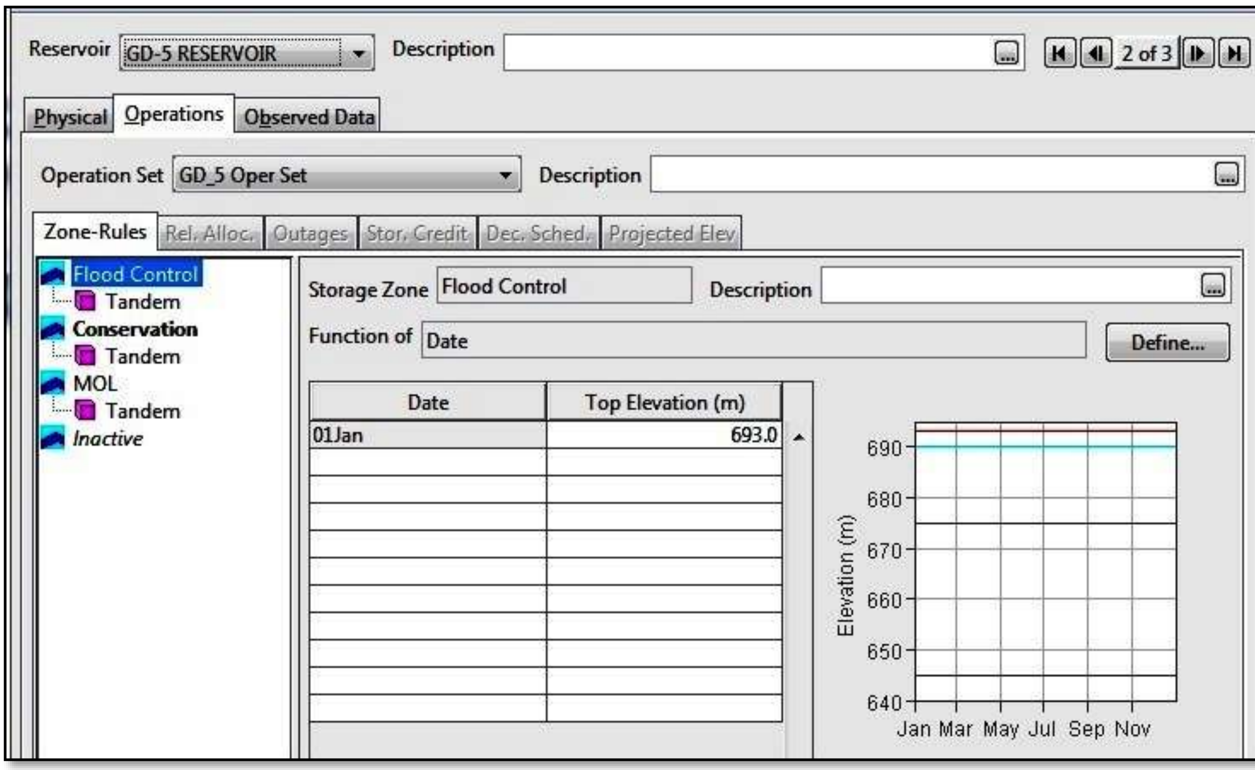


Figure 5-5 Tandem rule for GD-5 Reservoir

The release function rule type is one of the most powerful rule types available. This rule allows specifying the maximum, minimum, or specified flow to be released through the release element. In this study, Release rule function is applied for the downstream reservoir (GD-6). The release rule is also used to fulfill the monthly average water requirement for the proposed irrigation project downstream of the GD-6 hydropower plant, which is taken as minimum release from

GD-6 Figure 5-6. The monthly average water requirement of the proposed downstream irrigation is taken from the feasibility study of GD-6 Hydropower project.

Table 5-1: Monthly average water requirement for Lower Genale Irrigation plant

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q(m^3/s)	13.2	7.2	1.6	21.2	22.2	13.8	9.8	15.0	24.7	28.6	26	20.4

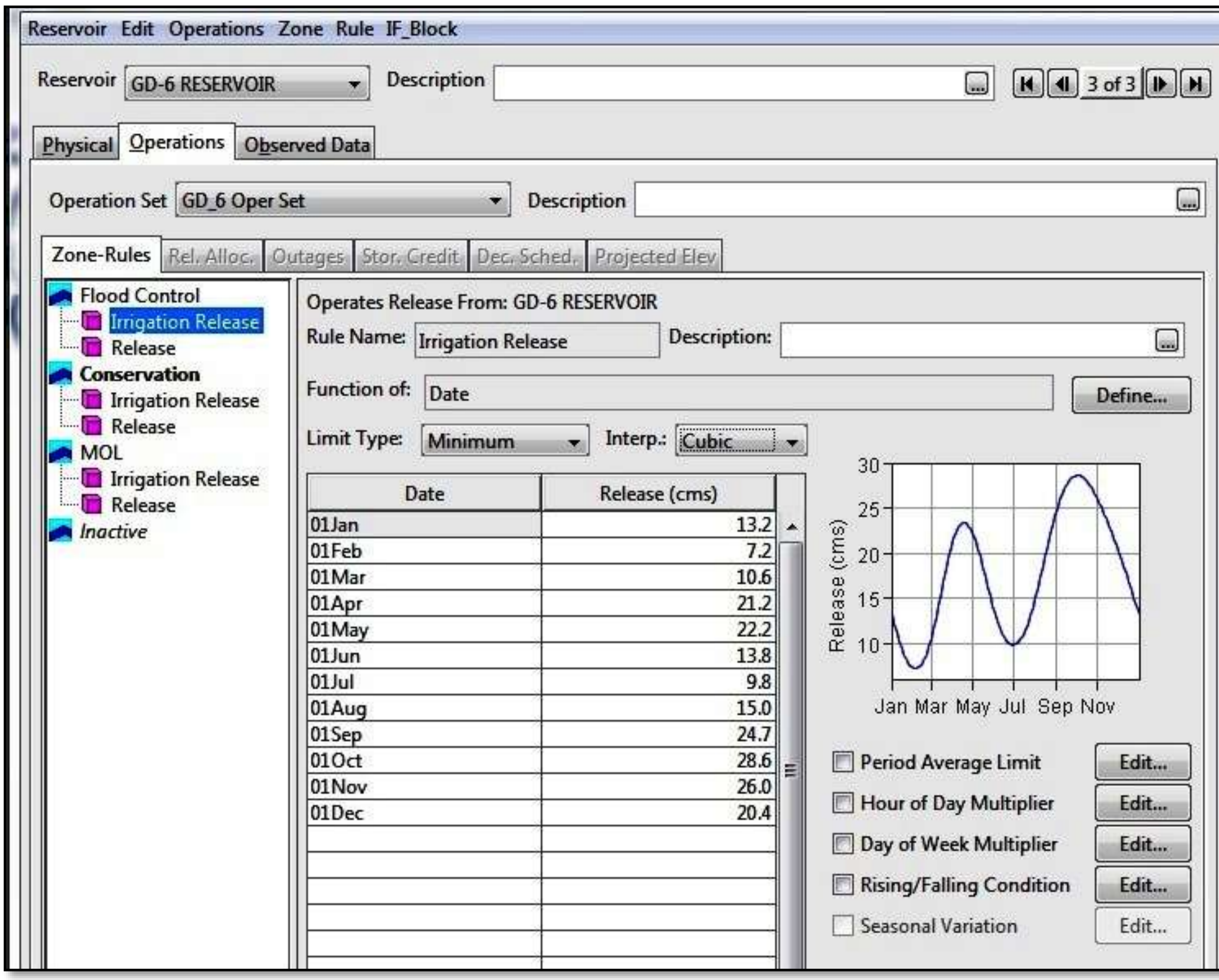


Figure 5-6 Release Rule for the downstream Reservoir, GD-6

To summarise with, the reason for rule definition is to keep the water on desired guide curve. Below of desired guide curve hydropower (conservation) zones and conservation rules was used and when elevation and water level raised up over the desired guide curve, flood controlling zone is operated and rules in this part are applied(Madani, 2013).

Guide Curve

A reservoir in HEC-ResSim must have a target elevation. A reservoir's target elevation, represented as a function of time, is called its Guide Curve. It is the dividing line between the upper zones of the reservoir (typically called the flood-control pool) and the lower zones (typically called the conservation pool). Guide Curve specifies the reservoir level between the flood and hydropower pools. Guide curve operation oversees releases to maintain that storage level. The general release operation is to (i) release water as quickly as possible when high inflows encroach into the flood pool and raise storage above the guide curve, or (ii) curtail releases to the minimum required amounts necessary to satisfy buffer, conservation, or hydropower requirements when inflows are low and storage level is drawn-down below the guide curve. As inflows decrease (after flood pool encroachment) or inflows rise (after draw-down into the hydropower or conservation pools), guide curve operations tends to guide storage level back towards the "Guide Curve."

The release decision logic in HEC-ResSim starts and ends with the guide curve. When the reservoir's pool elevation is above the guide curve, the reservoir wants to release more water than is entering the pool; when below guide curve and the reservoir wants to release less water than is entering the pool. All operating rules and physical limitations act as constraints upon the reservoir's ability to meet the goal of returning the pool to its guide curve elevation. Without rules, the reservoir will be constrained only by physical capacity of the outlets to get to and stay at the guide curve elevation.

In this study, search of the optimal power and/or energy for the system has been done by dropping the top of the conservation zone, guide curve, of each reservoir up to the Minimum operation level. In doing so, significantly different power and energy results has been found for each reservoir in each scenario. However the main goal of the study is to get the optimal power or Energy for the system, the alternative that results a maximum power is selected to be the best alternative.

5.4 System Storage Balance

In HEC-ResSim, multi-reservoir system constraints are orchestrated using a storage balancing approach. The system storage balance specifies the weighting or allocation of the total release from all the reservoirs to each reservoir in the system. By default, HEC-ResSim will try to maintain an even percent-of-storage balance between the reservoirs that are operating as a system. This default balance is referred to as the implicit storage balance. If the implicit balance is not appropriate, the user can enter an explicit description of the storage balance between the reservoirs. Several factors including relative size of the reservoirs and the proximity to the control point make it in inappropriate for the reservoirs in this system of to balance evenly to meet the constraints (Madani, 2013).

Both the implicit and explicit system storage balance methods are used for this study as discussed in the subsequent section.

5.4.1 Implicit System Storage Balance Method

The implicit system storage balance scheme take into account the System Storage, the total storage from GD-3, GD-5 and GD-6 reservoirs in the system. The system storage ranges from empty (0Mm^3) to full (3457.6Mm^3). Moreover the default scheme considers only one system zone, the system Guide Curve storage, which amounts to the sum of all reservoirs conservation storage (2884.04Mm^3). The desired storage for each reservoir is determined through an implicit "balance line".

For system storage less than the system guide curve storage, the balance line has lower limit that corresponds to empty storage at the reservoir versus empty system storage, and the upper limit corresponds to guide curve storage at the reservoirs (2570Mm^3 at GD-3, 130.4Mm^3 at GD-5 and 183.6Mm^3 at GD-6) versus system guide curve storage (2884.04Mm^3).

For system storage greater than the system guide curve storage, the lower limit of the balance line corresponds to guide curve storage at the reservoirs (2570Mm^3 at GD-3, 130.4Mm^3 at GD-5 and 183.6Mm^3 at GD-6) versus the system guide curve storage (2884.04Mm^3). The upper limit corresponds to full storage at the reservoirs (3087.2Mm^3 at GD-3, 143.4Mm^3 at GD-5 and 227.1Mm^3 at GD-6) versus system guide curve storage (3457.6Mm^3), Figure 5-7.

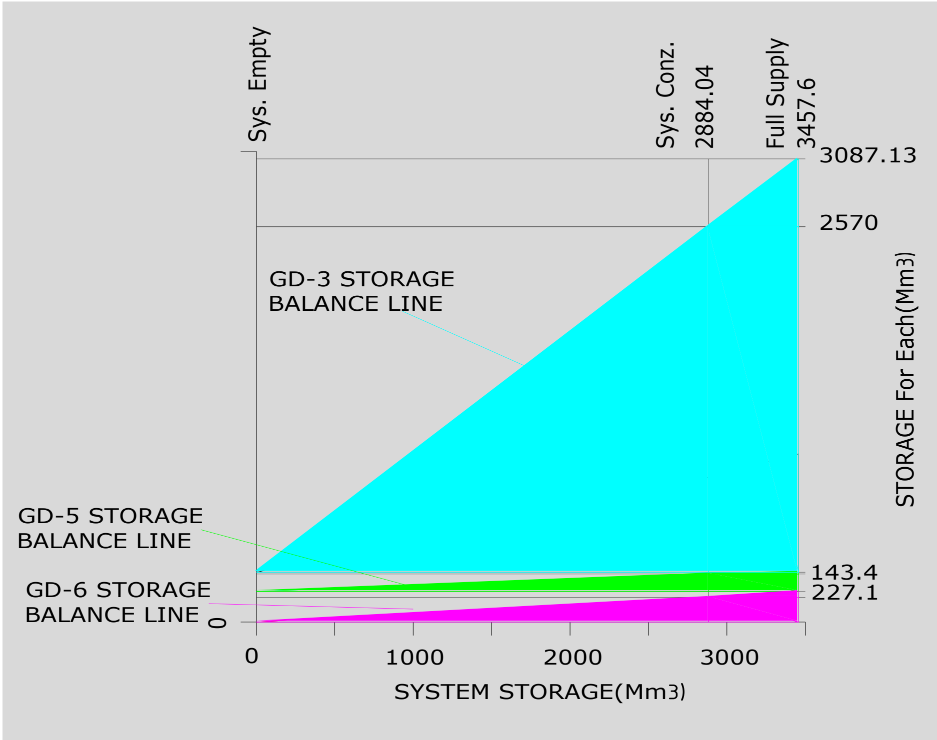


Figure 5-7 Implicit Storage Balance Line

At the end of each decision interval (i.e., end of period), the desired storage for a reservoir corresponds to a point on the balance that coincides with the sum of the estimated storages for both reservoirs.

When the total estimated storage from the reservoirs is less than the system guide curve storage, the corresponding desired storage represents an equal percentage of the storage below the guide curve at each reservoir. When the total estimated storage from the reservoirs is greater than the system guide curve storage, the corresponding desired storages represent an equal percentage above the guide curve at each reservoir.

5.4.2 Explicit System Storage Balance Method

Explicit system storage balance is the user defined system storage balance. The user can modify the implicit balance lines explicitly to characterize the desired storage distributions using one or more system zones and placing inflection points along the balance line.

In addition to the three default zones created by Hec-ResSim, this study has added a minimum operation zone between the conservation and inactive zone of each reservoirs in the system which results one additional system zone for the reservoir system.

A number of inflection points have been used from each zone of each reservoir to search for the best alternative inflection coordinate that generates a maximum power. Table 5-2 shows some of the inflection points used for the study in each zone of their respective reservoirs.

Table 5-1 Inflection points of GD-3, GD-5 and GD-6 Reservoirs

GD3 - Reservoir	Flood Control Zone	Elevation	1120	1121	1122	1123	1124	1125
		%age of Flood Control	0.00	20.00	40.00	60.00	80.00	100.00
	Conservation Storage Zone	Elevation	1080	1090	1100	1110	1120	
		%age of Conservation storage	0.00	25.00	50.00	75.00	100.00	
	Minimum Operation Zone	Elevation	1060	1065	1070	1075	1080	
		%age of MOP storage	0.00	25.00	50.00	75.00	100	
GD5 - Reservoir	Flood Control Zone	Elevation	690	691	693	694	695	
		%age of Flood Control	0.00	25.00	50.00	75.00	100.00	
	Minimum Operation Zone	Elevation	672	676.5	681	685.5	690	
		%age of MOP storage	0.00	25.00	50.00	75.00	100.00	
	Conservation Operation Zone	Elevation	645	650.4	655.8	661.2	666.6	672
		%age of Conservation storage	0.00	20.00	40.00	60.00	80.00	100.00
GD6 - Reservoir	Flood Control Zone	Elevation	586.00	587.00	588.00	589.00	590.00	592.00
		%age of Flood Control	50.00	58.33	66.67	75.00	83.33	100.00
	Conservation Storage Zone	Elevation	580	581	582	583	584	585
		%age of MOP storage	0.00	20.00	40.00	60.00	80.00	100.00
	Minimum Operation Zone	Elevation	566.0	569.5	573.0	576.5	580.0	
		%age of Conservation storage	0.00	25.00	50.00	75.00	100.00	

A number of combinations of inflection points from table 5-4 are used for different scenarios of the trial and error iteration of the simulations. The iteration aims at getting the optimal coordinate of inflection that result the maximum power output of the multi-reservoir system. Detail of the iteration selection of the optimal coordinate will be discussed in the next result and discussion chapter.

6. RESULT AND DISSCUSION

6.1 General

As mentioned previously, main objective of the study is to simulate and get optimal power generation for the cascaded reservoir system of the three major hydropower projects, GD3, GD5 and GD6, and prepare a rule curve to attain the optimized power and energy.

After the watershed setup and reservoir network is completed different decision rules has been used and the two methods of system storage balance, implicit and explicit, were adopted to attain objective of the study. Hence, from the three modules of Hec-ResSim simulation module is the one where the simulation results are viewed with a number of trial and error iteration.

6.2 Simulation in HEC-ResSim

The purpose of the Simulation module is to separate output analysis from the model development process. Since the reservoir model is completed and the alternatives have been already defined, the simulation module will subsequently perform the computation and shows the results in different form. All the output results are incorporated in the HEC-DSSVue (HEC's data storage system) in which data may be plotted, tabulated, edited and manipulated with over fifty mathematical functions. During the creation of the simulation model it is must to specify a simulation time window, a computation interval, and the alternatives to be analyzed.
Moreover, the simulation module of ResSim has an interesting option to edit the reservoir physical and operational characteristics, reaches, system operations and alternatives within the separate simulation window without affecting or applying the changes in the reservoir network module which makes it flexible and user friendly.

6.2.1 Simulation Assumptions

The simulation made a number of assumptions to simplify the complexity of the actual Operation system and river basin simulations. Some of the basic assumptions made are:
1. Seepage through the reservoir and the body of the dam is assumed to be zero.
2. Seepage and evaporation through the reaches are assumed to be zero.
3. Only free water surface evaporation losses were assumed.

6.3 Implicit System Storage Balance Result

The simulation result using both the Explicit and Implicit system storage balance is discussed here under in order to compare the results and take the best result. Of the two system storage balance, the result using implicit storage balance is discussed in this section. Simulation for Implicit system storage balance is done by setting 100% inflection point in each zone and selecting none from the reservoir system balance. The average power potential generated in the system is the summation of the average power in each reservoir.

HEC-ResSim uses an original rule-based approach to mimic the actual decision-making process that reservoir operators must use to meet operating requirements for flood control, power generation, water supply, and environmental quality. The predetermined rules consist of setting the guide rule curve and the specific rules given under each zone of each reservoir.

6.3.1 Effect of Guide rule curve position on the result

By default the guide rule curve of the reservoir is set at the top of conservation. However, according to user manual of ResSim, the guide curve can be assign to any level above the inactive level (HEC-2013). Thus in the study the power generated has been calculated assigning the guide curve at different position. It has been seen from the simulation result that the power/energy generated from the system is increasing while the guide curve of GD3 has been set from the top of conservation level down to the minimum operation level (Table 6-1). However there is minor increase to the overall system power/energy generation when the guide curve of the downstream reservoirs, GD5 and GD6, is assigned at the top of conservation zone than at the minimum operation level. This is true for the implicit storage balance methods.

Thus with respect to the guide curve position the optimal result using the implicit storage balance is found assigning the guide curve at the minimum operating level for GD3 reservoir and at the top of conservation zone for GD6 and GD5 reservoirs. Table 6-1 lists some of the average power generated by each reservoir and the total reservoir system by assigning the guide rule curve at different position above the inactive level using the default implicit system storage balance.

Similar to Gray, the probable reason for increasing generation of overall energy of the multi-reservoir system by setting the guide curve between the top of conservation and inactive level is that more water is released through the outlet, where the maximum capacity of the outlet is a constraint to the flow, while the system tries to approach the guide curve level of each reservoir.

Table 6-1 Power and Energy Generated assigning the Guide curve in different position

Hydropower Plants	Power and Energy Generated	Guide Curve position in GD3, GD5 and GD6 Reservoir Respectively							
		COZ (1120), COZ (690), COZ (585)	COZ (1115), COZ (690), COZ (585)	COZ (1095), COZ (690), COZ (585)	MOP (1080), COZ (690), COZ (585)	MOP (1080), MOP (675), MOP (580)	MOP(1080), MOP (675), COZ (585)	FC (1125), COZ (690), COZ (585)	FC (1125), FC (695), COZ (585)
GD-3	Energy Generated per Time Step (MWh)	773.24	4587.53	5340.38	4228.15	4229.33	2427.03	3776.09	1498.25
	Power Generated (MW)	32.22	191.15	222.52	176.17	176.22	101.13	157.34	62.43
GD-5	Energy Generated per Time Step	1852.55	881.49	312.4	2061.15	2060.15	2258.2	1098.05	1678.82
	Power Generated (MW)	77.19	36.73	13.02	85.88	85.84	94.09	45.75	69.95
GD-6	Energy Generated per Time Step (MWh)	4942.43	5157.78	5678.87	5801.7	5792.63	5803.25	4906.39	5056.11
	Power Generated (MW)	205.93	214.91	236.62	241.74	241.36	241.8	204.43	210.67
System Average Energy Generated		**2762.40**	**3878.78**	**4136.05**	**4413.22**	**4409.97**	**3828.30**	**3569.89**	**3005.11**
System Average Power Generated		**315.34**	**442.79**	**472.16**	**503.79**	**503.42**	**437.02**	**407.52**	**343.05**

As discussed in the section above position assignment of the guide curve which is the predetermined rule for the simulation of the multi-reservoir system has an effect on the output result of the power/energy generation. Thus the results obtained by setting the guide curve above the inactive level of each reservoir is shown in table 6-1 to compare the results and take the optimal maximum power generated. The result from the table shows the optimal power/energy generated when the guide curve is set at the minimum operation level for GD-3 and at top of conservation for GD-5 and GD-6.

The maximum average annual energy and power generated using implicit system storage balance is 1,543.3GWh and 176.17MW for GD3, 752.9GWh and 85.88MW for GD5 and 2,117.6GWh and 241.74 for GD6 respectively. The reservoir system will have an average energy and Power 4413.22GWh/yr and 503.79MW respectively.

6.4 Explicit System Storage Balance Result

The explicit system storage balance is mainly characterized by inflection points that modify the implicit balance lines explicitly to the desired storage distribution. However in ResSim position of the guide curve assigned as predetermined rule for the simulation has significant effect to get the optimal power/energy that the reservoir system can generate using the time-series flow data and physical characteristics of the reservoirs satisfying the constraints. , explicit system storage balance operation depends on placing of inflection points to the balance line within each system zone.

6.4.1 Effect of Guide rule curve position on the result

Similar to the implicit system storage balance the result of the power generated using the explicit system storage balance has been tested setting the guide curve on different level above the inactive zone. The best result, maximum power generation, is found when the guide curve is assigned to the minimum operation level for GD3 and GD5 reservoirs and at the top of conservation zone for GD6 reservoir.

6.4.2 Inflection Points

Inflection points transform the implicit balance line in to explicit curve. The inflection points allow the slope of the lines, or the relationship between individual reservoir storage and system storage, to vary. An unlimited number of balance line inflection points could be added within each system zone to further refine and shape the desired balance distribution.

Similar to the implicit system operation, the explicit system operation is carried out each time period when system rules are in effect. The process of determining desired storages is repeated every decision interval in order to assign the priority for release to the reservoir that is farthest above the desired storage. A release decision made for a particular time period may not necessarily achieve the desired balance. The reservoir are considered “in balance” when both reservoir have reached their guide curve or are operating at the desired storages levels along their balance line curves prescribed in the explicit storage balance scheme.

Number of inflection points has been taken to get optimal system storage balance line with minimum spill and maximum power or total energy. Out of the number of trials undertaken to get the optimal inflection point, three sample trials including the optimal co-ordinate are selected to show the average power generated for each reservoir and annual energy and power generated from the system storage (Table 6-2).

Table 6-2 Summary of Energy Generated (daily) and power generation for system reservoirs

Zone (GD3%, GD5% and GD6%)	Storage (GD3,GD5,GD6) in Mm^3	Elevation (GD3,GD5,GD6) in m a.s.l	System Storage in Mm^3	GD3 Average Power Generated (MW)	GD5 Average Power Generated (MW)	GD6 Average Power Generated (MW)	System Average Power Generated (MW)	System Average Energy Generated per year (GWh/year)
Alternative 1								
Flood Control	(3087.13,167,241.7)	(1125,695,591.5)	3495.8	83.15	92.22	239.98	**415.35**	**3638.47**
Flood Control Inflection(40,50,66.67)	(2776.9,149.9,222.4)		3149.1					
Conservation	(2570,132.7,183.6)	(1120,690,585)	2886.3					
Conservation Inflection (50,50,40)	(1415,87.9,159.6)		1662.5					
Minimum Operation	(260,43,143.6)	(1080,672,580)	446.6					
Minimum Operation Inflection (50,40,50)	(147,17.98,102.65)		267.63					
Inactive	(34,1.3,61.7)	(1060,645,566)	97					
Alternative 2								
Flood Control	(3087.13,167,241.7)	(1125,695,591.5)	3495.8	162.81	94.86	241.98	**499.65**	**4376.93**
Flood Control Inflection(20,75,83.33)	(2673.4,158.4,232.0)		3063.9					
Conservation	(2570,132.7,183.6)	(1120,690,585)	2886.3					
Conservation Inflection (25,75,100)	(837.5,110.3,183.6)		1131.4					
Minimum Operation	(260,43,143.6)	(1080,672,580)	446.6					
Minimum Operation Inflection (75,75,80)	(203.5,32.6,127.22)		363.3					
Inactive	(34,1.3,61.7)	(1060,645,566)	97					
Alternative 3								
Flood Control	(3087.13,167,241.7)	(1125,695,591.5)	3495.8	176.38	86.01	241.97	**504.36**	**4418.14**
Flood Control Inflection(0,100,100)	(2570,167,241.7)		2978.7					
Conservation	(2570,132.7,183.6)	(1120,690,585)	2886.3					
Conservation Inflection (0,100,100)	(260,132.7,183.6)		576.3					
Minimum Operation	(260,43,143.6)	(1080,672,580)	446.6					
Minimum Operation Inflection (100,100,100)	(260,43,143.6)		446.6					
Inactive	(34,1.3,61.7)	(1060,645,566)	97					

6.4.3 Explicit System Storage Balance Optimal Reservoir Operation

As can be seen from the result the optimal inflection point is alternative 3. The storage balance line for this optimal inflection point is plotted in Figure 6-1.

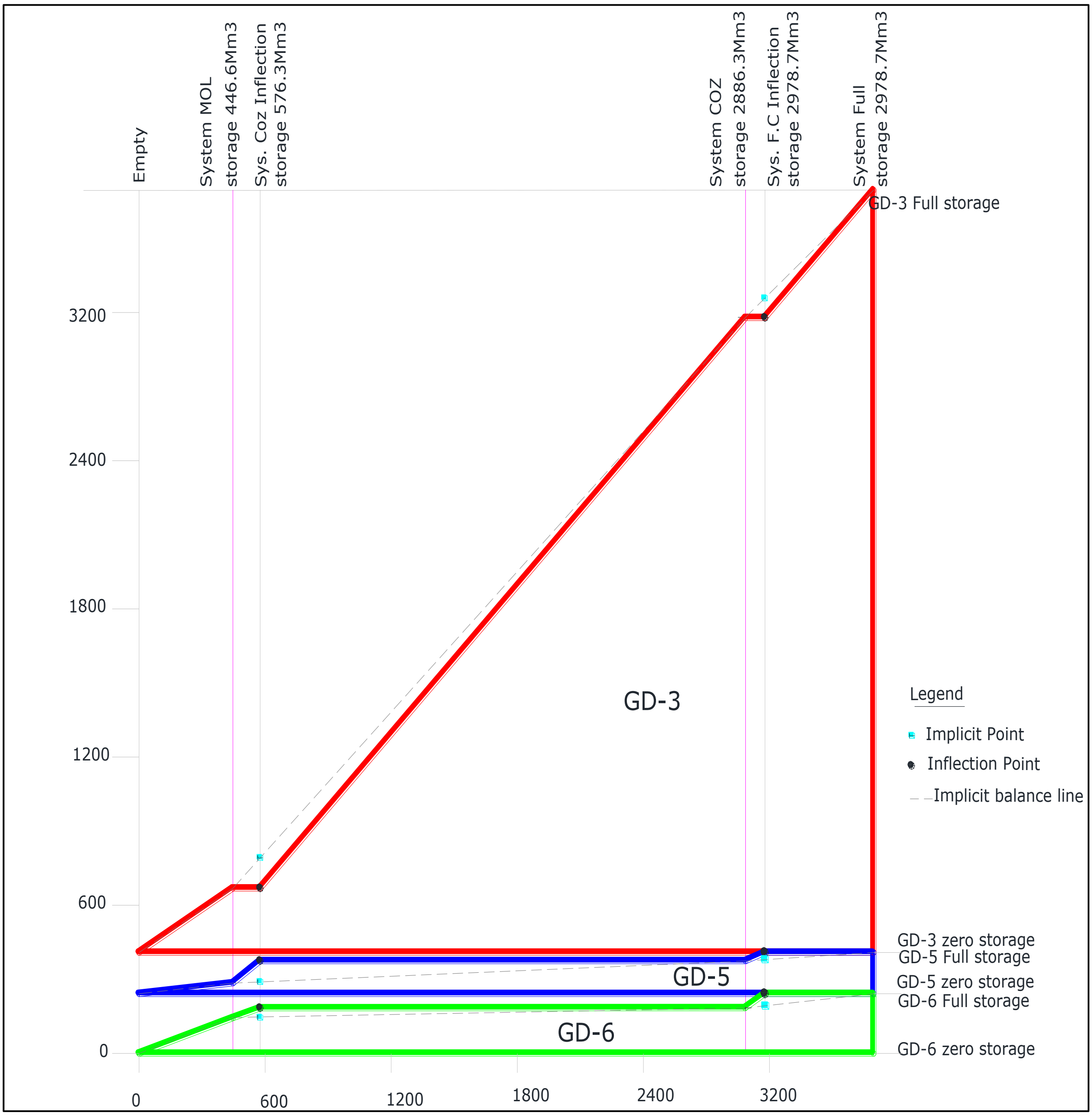


Figure 6-1 Explicit System Storage balance line

The explicit storage balance diagram consists of the implicit balance line which is drawn with broken line to show the influence of inflection points, in each zone, on the storage balance diagram converting the implicit storage balance line to explicit. Generally it can be seen from the plot that due to the inflection point insertion the storage of the upstream GD-3 Reservoir is reduced and the storage requirement of downstream reservoirs, GD3 and GD5, are increased.

Without provision influence point in the conservation zone each reservoir, when the available total volume of the storage in the system is $576.3Mm^3$, the distribution of the water to be available in reservoirs GD3, GD5 and GD6 were expected to be $382.92Mm^3$, $47.82Mm^3$ and $145.56Mm^3$ respectively. However due to the inflection point provided (0,100,100) the distribution of water storage that will be available in reservoirs GD3, GD5 and GD6 will be $260Mm^3$, $132.7Mm^3$ and $183.6Mm^3$ respectively. This result shows that the inflection point provided at the conservation zone has gave the chance for the downstream reservoirs, GD5 and GD6, to fill their conservation zone at faster rate and filling of the conservation GD3 reservoir is detained from the minimum operation storage of the system up to this inflection point rather it will release the water to the downstream reservoirs.

Similarly in the Flood control zone when the available storage of water in the system is $2978.7Mm^3$, the implicit storage balance would have a desired storage of $2648.05Mm^3$, $137.90Mm^3$ and $167.90Mm^3$ for GD3, GD5 and GD6 respectively. However due to the inflection point (0,100,100) in the Flood Control zone the desired storage at each reservoir has changed explicitly to $2570.0Mm^3$, $167.9Mm^3$ and $241.70Mm^3$ for GD3, GD5 and GD6 reservoirs respectively. This also shows the tendency of emptying the upstream reservoir, GD3, and filling the downstream reservoirs, GD5 and GD6 there by preparing the upstream (GD3) reservoir to control the flood during peak flood flow which is one of the purposes of the plant. Moreover while emptying the flood zone by release of more water through the outlet, the power generated by the hydropower plant gets increased and the regulated flow for the downstream hydro power plants, GD5 and GD6 is secured.

6.5 Selection of the Optimal Power for the System.

From the discussion of section 6.3 and 6.4 the average optimal power and energy result of the reservoir system using implicit system storage balance is 503.79MW and 4413.22GWh/yr and using explicit system storage balance is 504.36MW and 4417.7GWh/yr.

Hence, the optimal power result of the system is 504.36MW that is found using an explicit system storage balance. This agrees with the studies done for cascade reservoir systems on different river basins referred for the preparation of this study. (Genet, 2008), (Mulu Sewinet, 2009).

6.5.1 Power Vs Release Plots for the Optimal System Power Operation

All the output results of the simulation can be retrieved from the Hec-DSSVue found under the tool command on the menu bar of the simulation window. The results can be viwed in tabular form and as plots. Since it is easy to see and understand than the tabular output some of the plots of the results are discussed in this section.

The plots of the explicit system storage balance optimal power plant operation including power at the upper plot position, inflow and outflow to the power plants in the lower portion are presented in Figures 6-4 to 6-6.

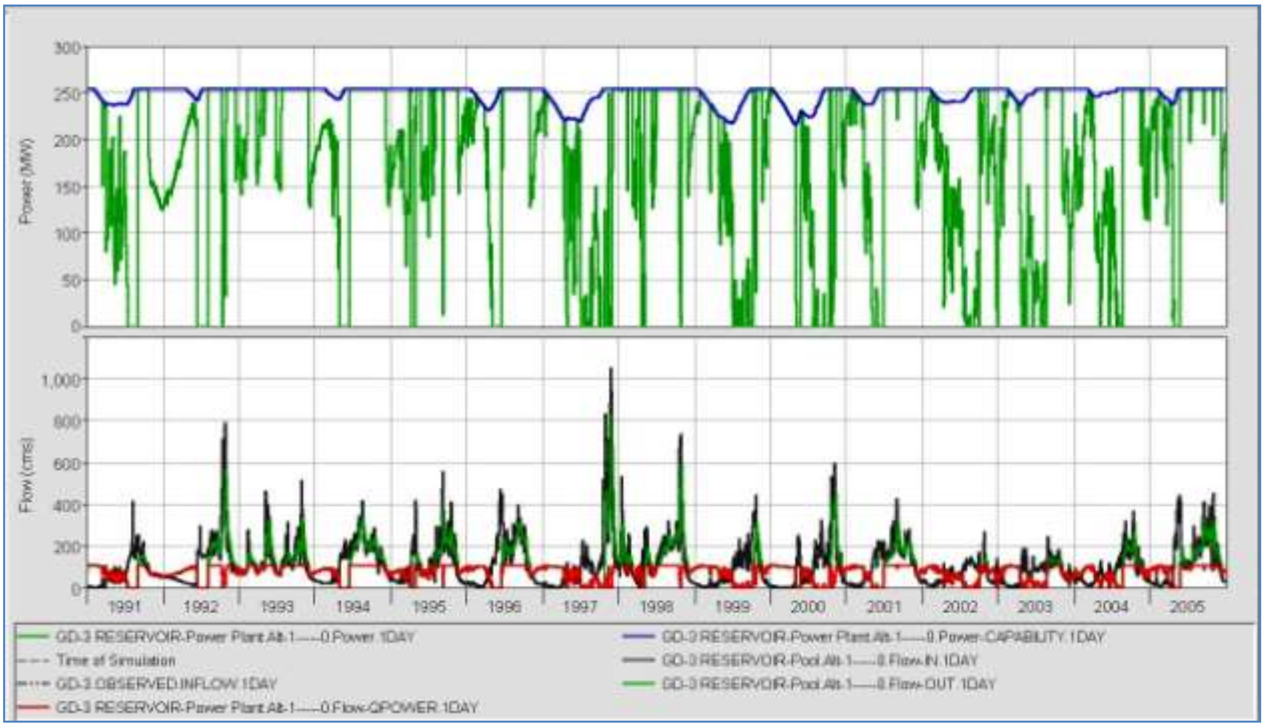


Figure 6-2 GD-3 Power generated, inflow and outflow

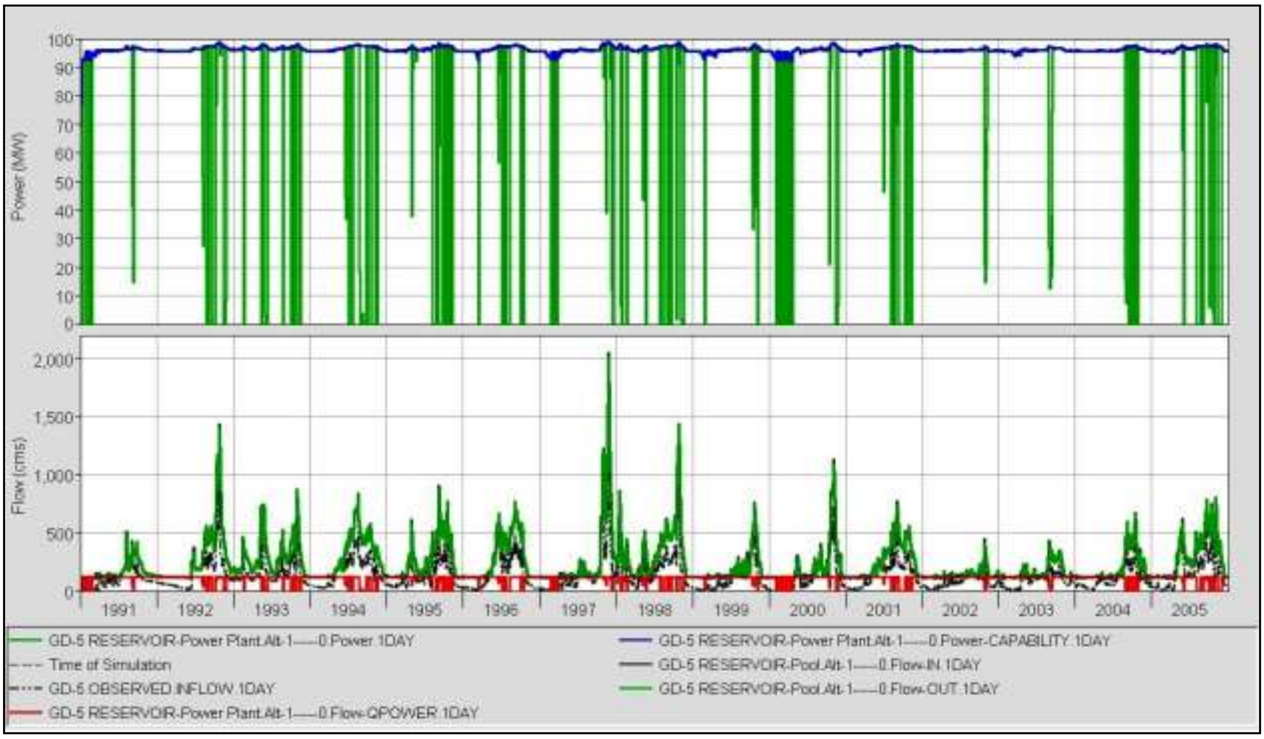


Figure 6-3 GD-5 Power generated, inflow and outflow

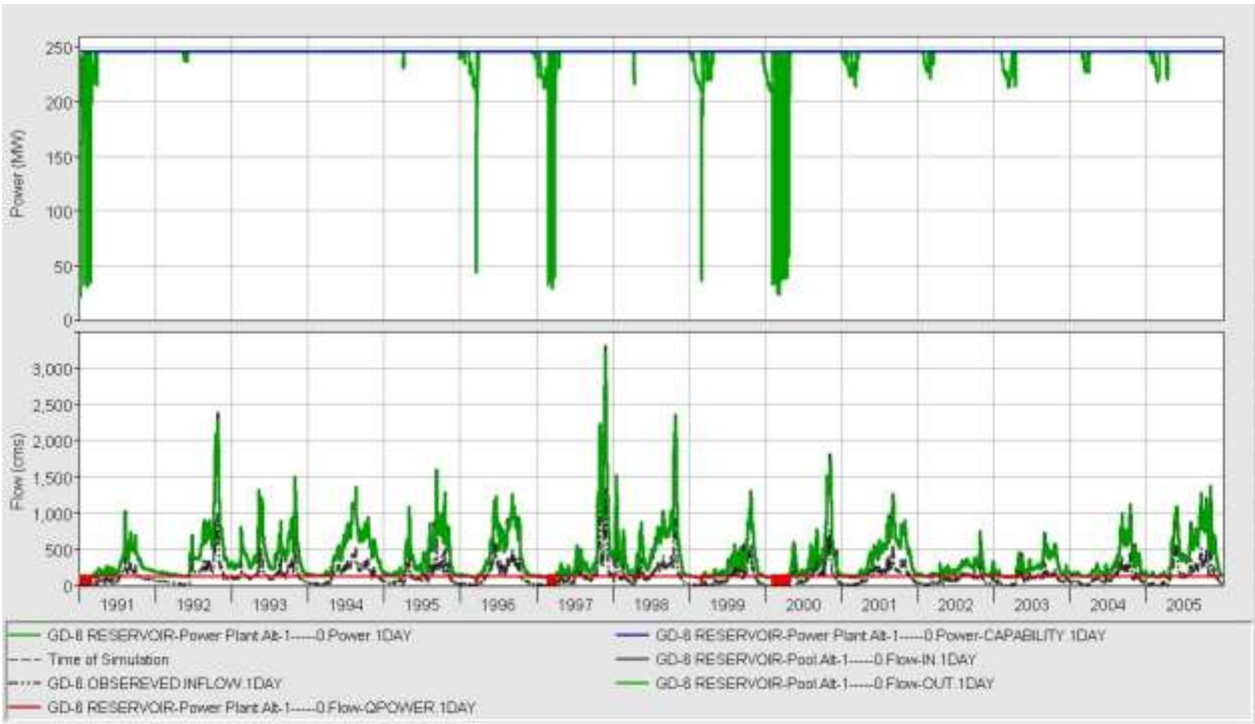


Figure 6-4 GD-6 Power generated, inflow and outflow

6.5.2 Firm and Secondary Power and Energy

Firm power and energy are by definition the power and energy that could be supplied by the station with a high reliability, not less than 95%, on a continuous basis. A 95% degree of reliability is assumed for this study which means partial or total failure to produce firm energy in 5% of all months, on average.

Secondary power is the power generated in excess of primary power by which its magnitude for a desired percentage of time is quantified by subtracting the firm power from the corresponding available power, average power in the Hec-ResSim output context.

The Firm and secondary power are computed from the power duration curve plotted in the excel spread sheet using output power result from the Hec-ResSim model, Figure 6.7 to 6.9.

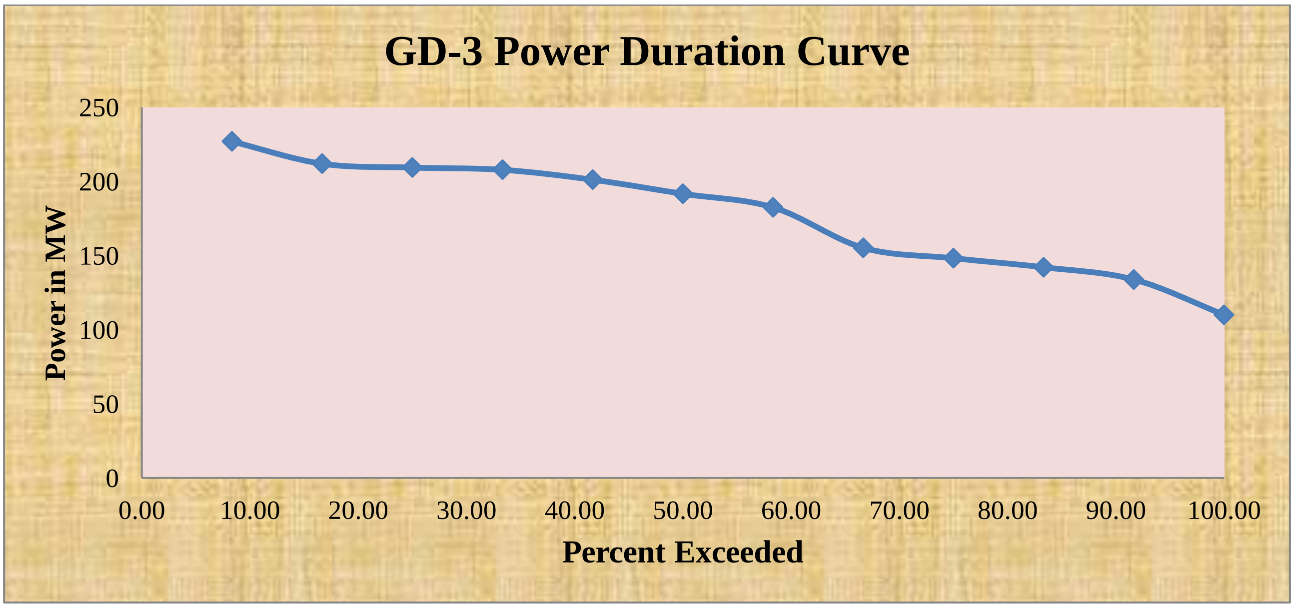


Figure 6-5 Power Duration Curve

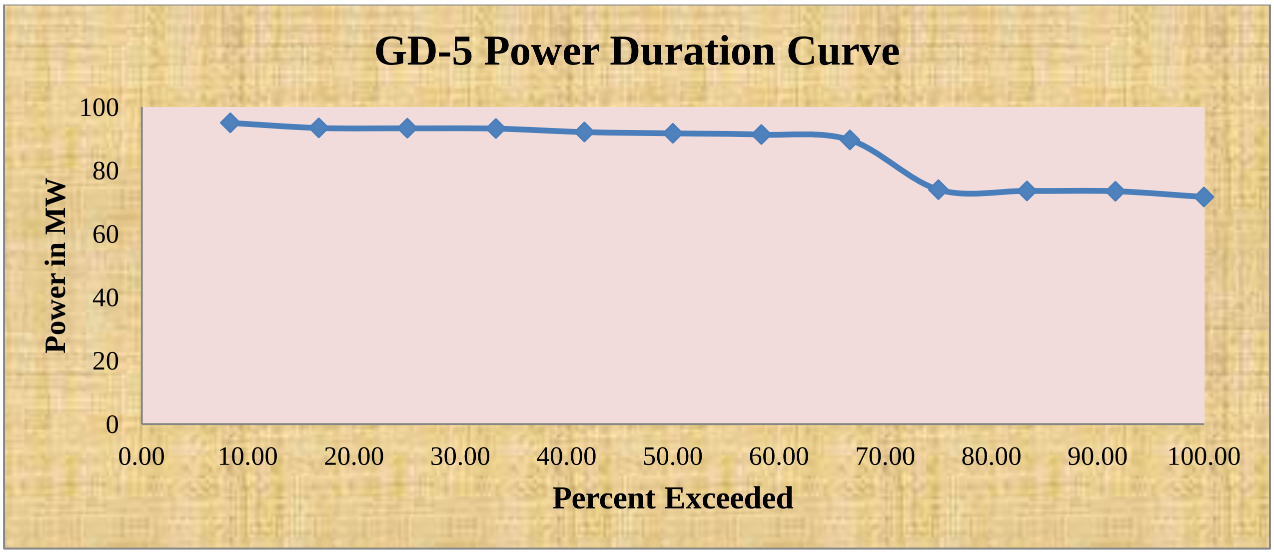


Figure 6-6 GD-5 Power Duration Curve

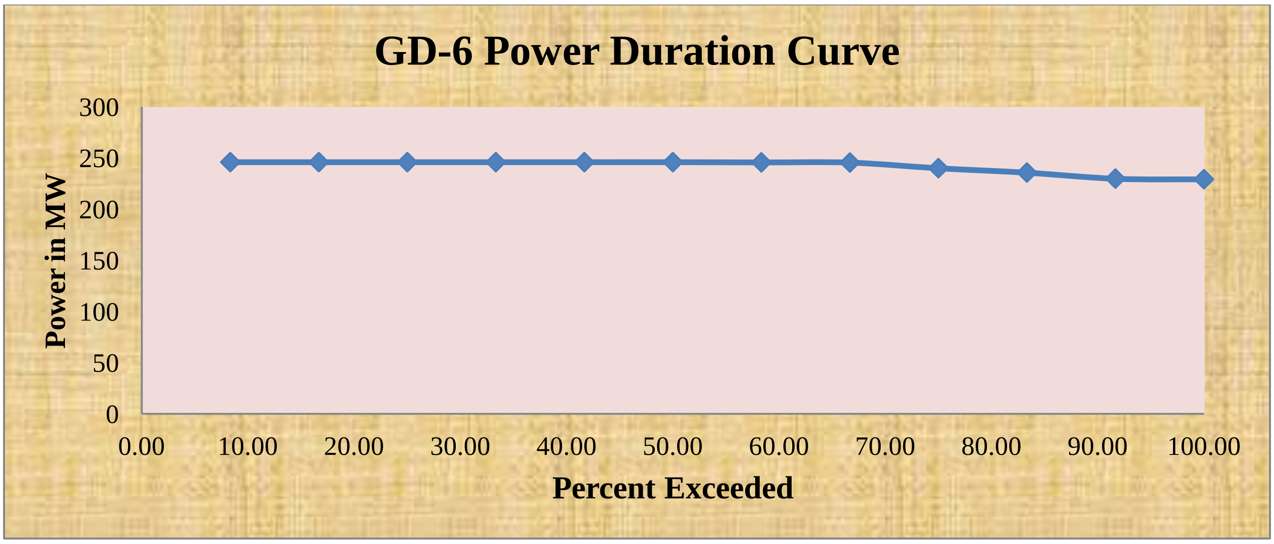


Figure 6-7 GD-6 Power Duration Curve

The above power duration curve result shows that the regulated flow from GD-3 results in an almost firm power to the downstream hydropower plants GD-5 and GD-6.

The Average, Firm and secondary power and energy are summarized in table 6-3.

Table 6-3 Summary of Average, firm and secondary power and energy

Location and Parameter	Average	Firm	Secondary
GD-3 Energy Generated Per Year (GWh/yr)	1545.3	1129.2	416.1
GD-3 Power Generated (MW)	176.4	128.90	47.50
GD-5 Energy Generated Per Year (GWh/yr)	753.4	636.7	116.7
GD-5 Power Generated (MW)	86	72.68	13.32
GD-6 Energy Generated Per Year (GWh/yr)	2119.0	2011.8	107.2
GD-6 Power Generated (MW)	241.9	229.66	12.24
System Energy Generated Per Year (GWh/yr)	4417.7	3777.7	640.0
System Power Generated (MW)	504.3	431.2	73.1

The result in the Table 6-3 reveals that the average energy generated by GD3 plant, 1,545.3GWh/yr, is less than the average energy in the feasibility study for GD-3 hydropower plant, 1640.0 GWh/yr by an amount 94.7GWh/yr. The average energy generated at GD-5 power plant by this study is 753.4GWh/yr which is greater by 38.4GWh/yr than the average energy estimated at the Pre-feasibility study (715GWh/yr). Similarly, the average energy generated by GD-6 in this study (2119GWh/yr) is some 544GWh/yr greater than the feasibility study result (1575GWh/yr).

The overall average energy of the system in this study is 4417.7GWh/yr which is some 487.7 greater than the feasibility study result, 3930Gwh/yr. As per the result of this study the firm energy for the system is 3777.7GWh/yr some 17.7 greater than the Feasibility study result which sum up to 3760GWh/yr.

6.5.3 Guide Curve

Setting an appropriate guide curve is the core target to achieve optimal reservoir operation. Figure 6-10 to 6-12 shows the guide curve output plot of Hec-ResSim model for GD3, GD5 and GD6. The upper plot region is the computed reservoir pool elevation and the lower region shows the computed pool inflow and outflow.

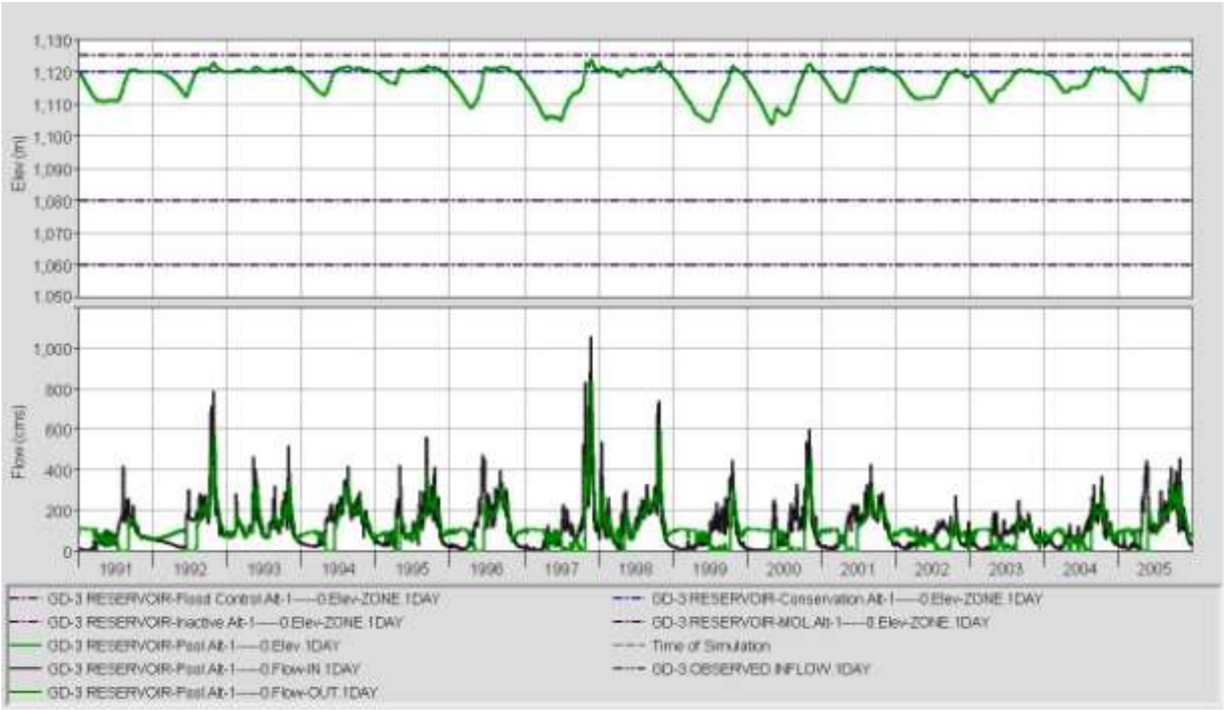


Figure 6-8 GD-3 Pool Level, Inflow and outflow

This plot shows that the level of water in GD-3 Reservoir is mostly in the conservation zone.

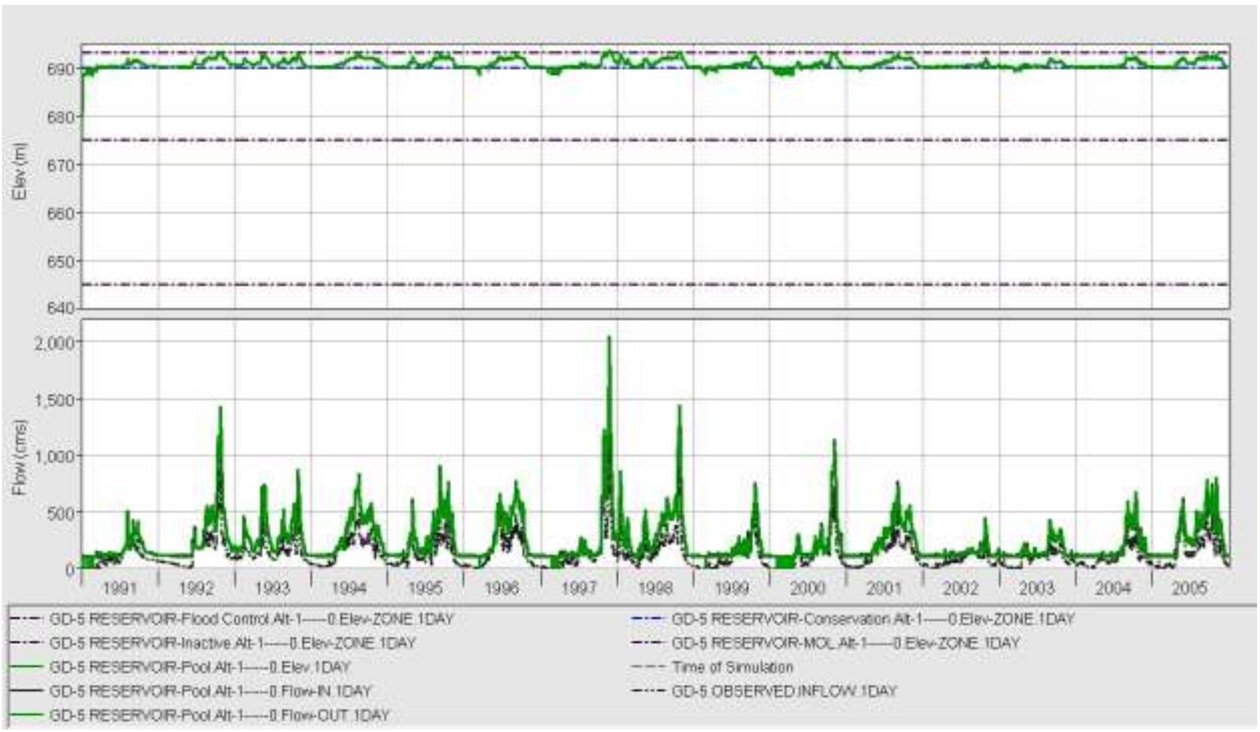


Figure 6-9 GD-5 Pool Level, Inflow and outflow

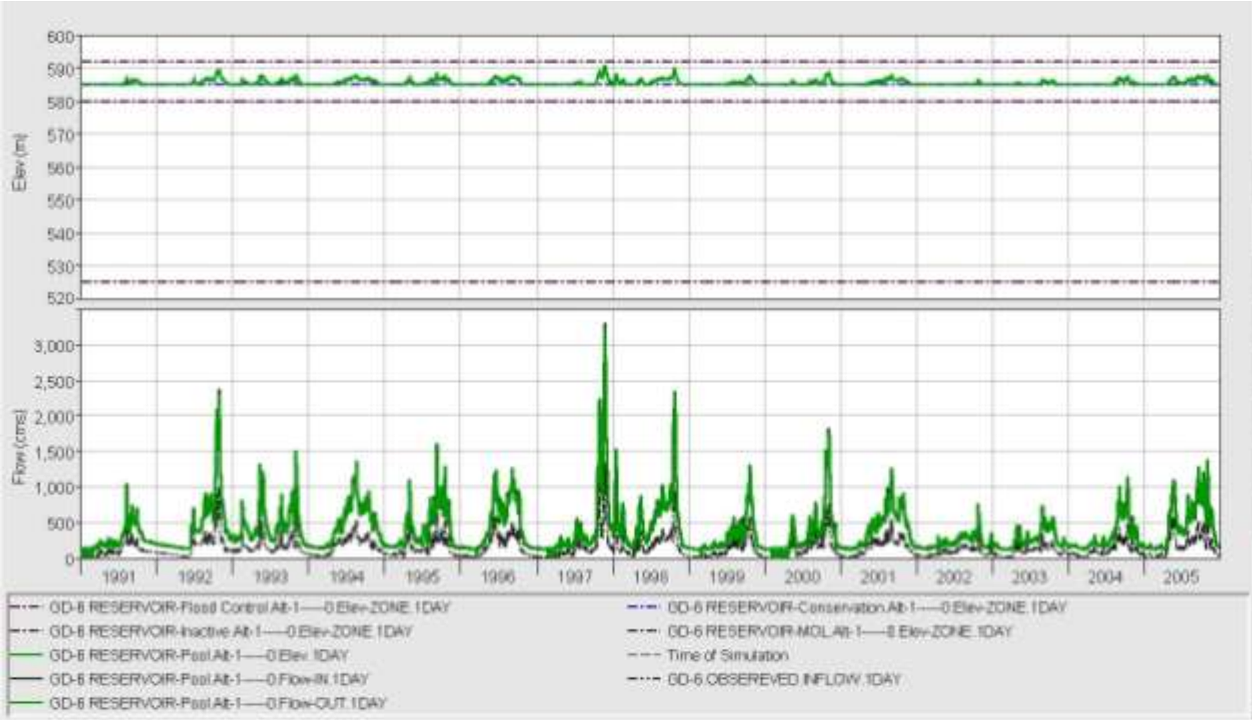


Figure 6-10 GD-6 Pool Level, Inflow and outflow

The plot in Fig 6-12 shows that the pool level is almost in the flood zone and this shows that the reservoir of GD-6 has a regulated full flow almost within the whole simulation period so that if the physical characteristics of the hydro plant are improved the plant can generate more reliable power.

Using the output result retrieved from the HecDssVue, the monthly average (Guide) curve of the aforementioned reservoirs is plotted in an Excel spreadsheet (Figure 6-13 to 6-15).

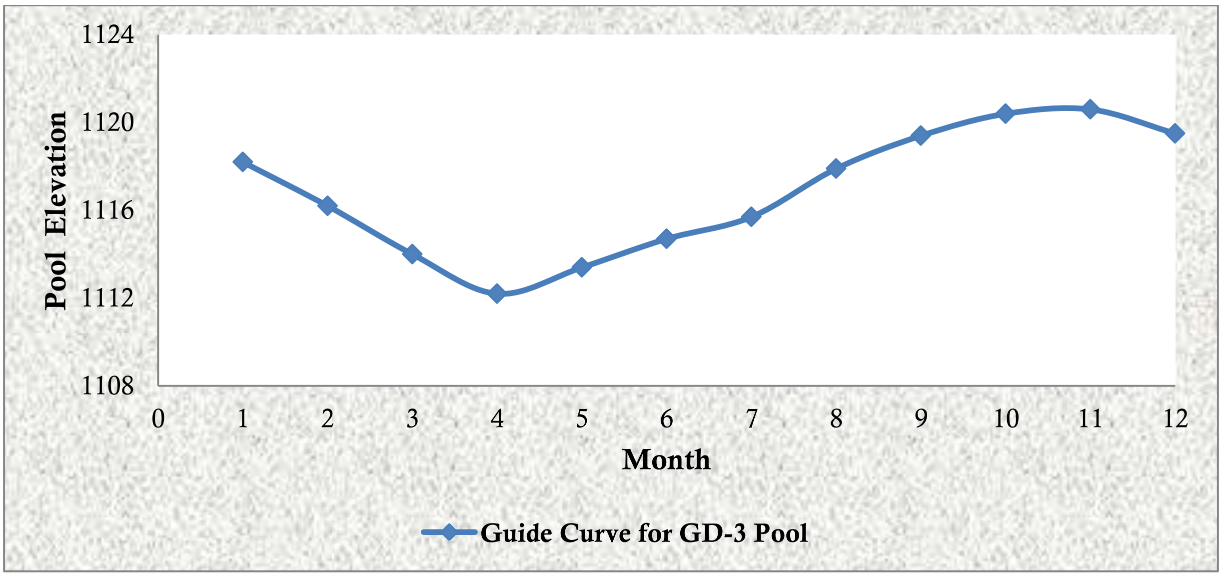


Figure 6-11 GD-3 Guide Curve operation Level

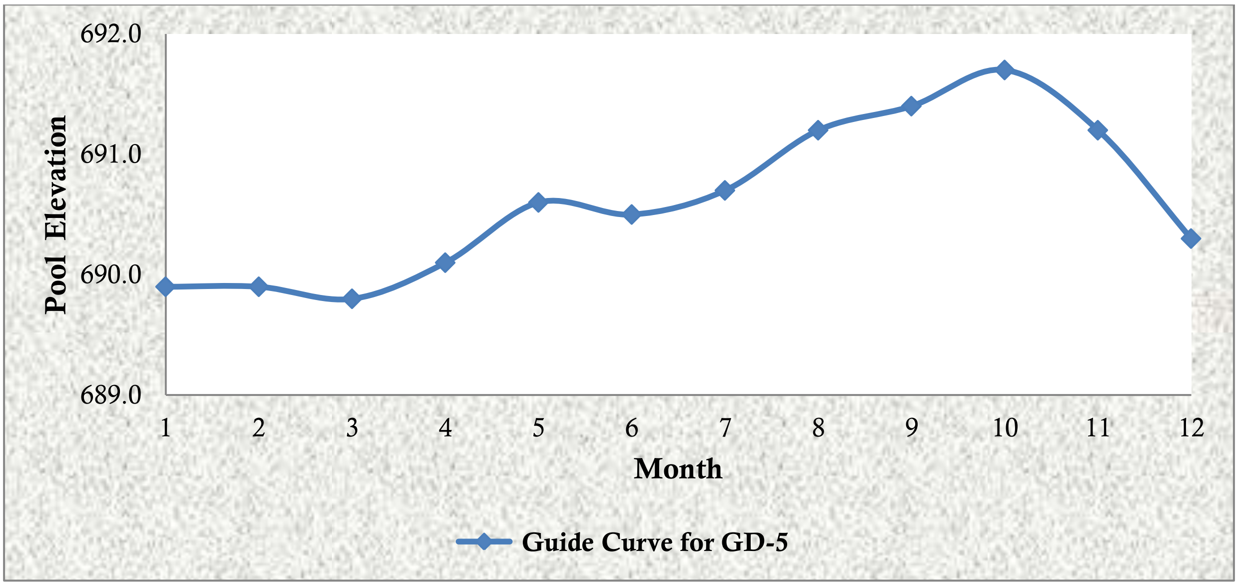


Figure 6-12 GD-5 Guide Curve operation Level

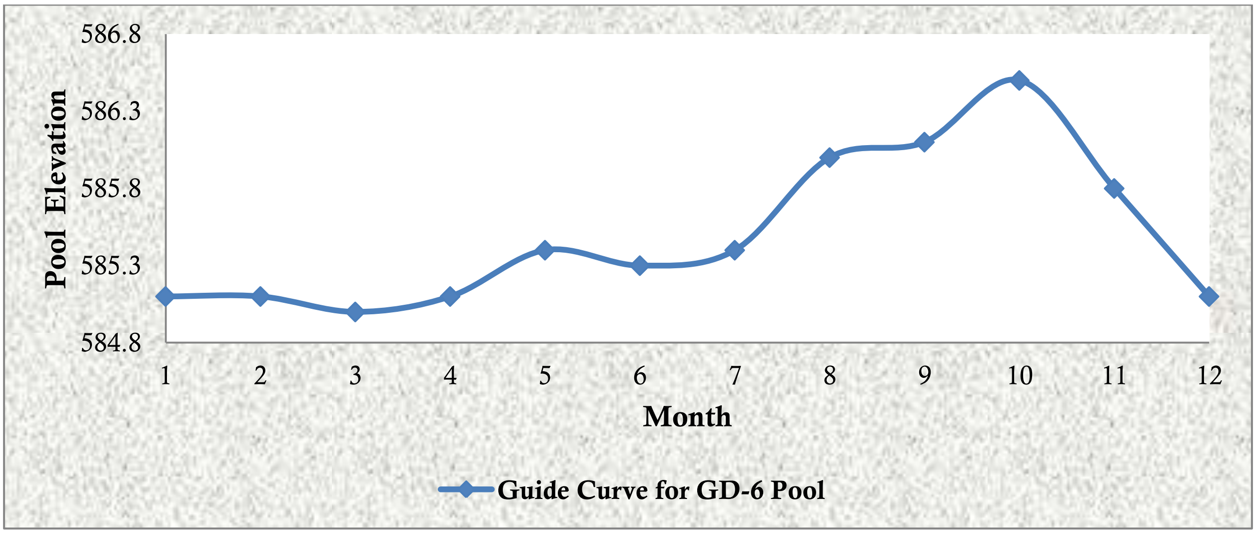


Figure 6-13 GD-6 Guide Curve Operation Level

In addition to the above plots, the guide curve, maximum and minimum operating levels chart of the GD-3 reservoirs is plotted as shown in Figure 6-16. Charts of GD-5 and GD-6 are shown in Appendix D Fig D-1 and Fig D-2. Values in the chart show the optimal monthly maximum, minimum and guide curve (maximum and minimum) level, 1122.4, 1104.7, 1120.6 and 1112.2ma.s.l respectively for GD-3.

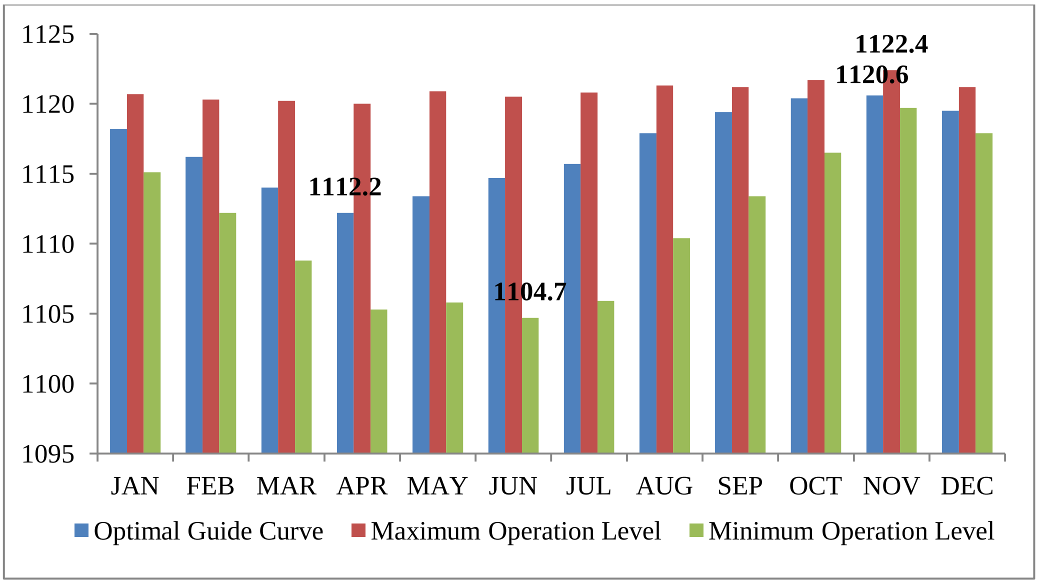


Figure 6-14 GD-3 Monthly maximum, minimum and average (guide) curve chart

7. CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The principal aim of the study is to increase the power and energy generation of Genale – Dawa cascade hydropower projects (case study GD-3, GD-5 and GD-6) by operating the reservoirs of the plants jointly as a system using new release Hec-ResSim3.1 model, considering annual and seasonal hydrological variations contained in the inflow series, reservoir characteristics and operation rules, evaporation losses and downstream water requirements.

All the three hydropower plants are found on the main stream of Genale River. GD-3 hydropower plant, which is situated at the upstream of the two, is a storage type hydropower plant. The other two GD-5 and GD-6 plants rely on the regulated perennial flow from the upstream GD-3 hydropower plant.

All the physical and operation data has been taken from concerned governmental offices and the feasibility study of GD-3 and GD-6 and the prefeasibility study of GD-5. Since the upstream Reservoir is operating for the function of the downstream ResSim was configured for tandem operation with daily requirement of the power plant.

The computation has been done using both the implicit and explicit system storage balance. In both storage balance types alternatives has been analyzed by assigning the guide curve at different position above the inactive zone in the operation tab of the reservoir module which result a significant impact in the output result. From the system storage balance, the explicit system storage balance has outcome the optimum result. The results of implementing the inflection points under different alternative strategies demonstrate that, the explicit system balance can be used efficiently to optimize operation in reservoirs. The conclusions are then set as follows,

Power and Energy

From the discussion of the result in section 6.9.1, it can be summarized that the average energy generated from each plant (GD-3, GD-5 and GD-6) when the reservoirs are in tandem operation is 1545.3, 753.4 and 2119GWh/yr respectively. The average energy of the upper most power plants (GD-3) is decreased by 94.7GWh/yr and the average energy of the downstream power plants (GD-5 and GD-6) is increased by 38.4 and 544GWh/yr respectively.

Moreover, the plant factor of GD-3 power plant is 0.69 which is less than the value estimated in the feasibility study (i.e. 0.72) while the plant factor of GD-5 and GD-6 results 0.59 and 0.98 respectively which is some higher than the estimated value in prefeasibility study of GD-5 and feasibility study of GD-6, 0.56 and 0.73 respectively.

The overall average energy of the system in this study is 4417.7GWh/yr which is some 487.7 greater than the feasibility study result, 3930Gwh/yr and the firm energy of the system is 3777.7GWh/yr some 17.7 greater than the feasibility study result which sum up to 3760GWh/yr.

The decrease of the energy generated by GD-3 and increase of the two downstream power plants in this study, considering the tandem operation of the three plants as a system, shows that the downstream power plants are benefited from the regulated flow the upper GD-3 power plant and GD-3 is operating for the benefit of the downstream plants. However decrease of energy at GD-3 (94.7GWh/yr) is much more less than the overall energy increase of the system (487.7GWh/yr).

Thus, it can be seen from the result of this study, that the overall energy to be generated from the system can be increased by tandem operation of the reservoirs using explicit system storage balance.

Guide curve

From the guide curve plotted in sec 5.6.2 it can be seen that pool level of GD-3 reservoir fluctuates within the active conservation zone between1112 and 1120 except on October and November where the pool level is in the flood zone (1120.4 and 1120.6 on October and November respectively). Emptying the flood zone of GD-3 is useful to the control the flood during peak flood times, which is one of the purposes of the project.

The optimal guide curve denotes that there is a tendency, in the optimal explicit system storage, to leave more water from GD-3 reservoir and prepare the storage to hold more water during high flood seasons. The water released from this reservoir can generate additional power at the downstream power plants. The reverse is true for the operation of the downstream power plants

The pool level of GD-5 is almost in the flood zone except for the first three months, January to February, where the pool level is in the active live storage zone. In GD-6 the reservoir pool level is in the flood zone throughout the year, that is why the plant factor is 0.98 which is nearly 1.

This clearly shows that the downstream hydropower plants are guaranteed to generate even more energy if the physical characteristics of the reservoirs are improved, considering the adverse effect that might result economically and environmentally.

Downstream Irrigation Requirement

Due to full condition of the reservoir almost throughout the year, the irrigation project found downstream of GD-6 power plant is guaranteed to get the minimum flow requirement throughout the year.

7.2 Recommendation

The study has recommended the following points to be included in the future reservoir operation and studies for better water based development plan in the basin.

In order to keep the reservoir pool level at optimal guide curve it is recommended to release more water from the GD-3 until both the downstream power plant fill their conservation and flood zone when the pool level of is in conservation and flood level respectively. It is also recommended to releases more water from GD-5 after it fills its conservation and flood zone.

The work conducted in this thesis was by employing HEC-ResSim 3.1 which still does not have ability to simulate the rainfall runoff process in the catchment, as a result outputs for reservoir and power plant simulation was dependent on the discharge inflow into the reservoirs. Hence, it is recommendable to use a stochastically generated time series of rainfall and stream flow instead observed historic hydrological data.

The Hec-ResSim optimal result is based on a successive trial and error procedure that is not fully guaranteed for the optimal value. Hence it is recommendable to recheck using optimization models.

Nowadays climate change and its impact is becoming a hot issue on different natural and manmade systems in different ways. Therefore, it is recommended to include further refinement of scenarios considering climate change impact for further analysis.

In practice, the only station in Genale basin, which supplies data that can be used directly for estimation of hydrology of the proposed hydropower projects, is the Chenemasa gauging station. Thus it is recommended to establish more number of gauging stations on Genale Main River for continuous and reliability of the data on the stream.

This study doesn’t consider the upstream proposed hydropower plant GD-2, in the master plan study. It is recommended to further study the optimal reservoir operation including this power plant.

Continuous and accurate monitoring at all gauging station especially key station like Chenemasa is strongly recommended.

APPENDIX - A POTENTIAL DAM SITES IN GENALE DAWA BASIN

Table A-0-1 Potential Dam Sites as Identified by MoWIR

Sub-Basin	River	Lat. D	Lat. M	Lon. D	Lon. M	Purpose	Proposed	Code (GDH-)	WAPCOS Coincidence
Genale	Wabera	3	39	40	39	Irrigation		11	
	Welmel	6	28	39	37	Irrigation	*	12	
	Iya	6	25	39	22	Irrigation		13	
	Dumel	6	43	40	16	Irrigation		14	
	Genale-D	4	36	41	40	Multi-purpose	*	15	
	Genale-C	4	56	41	30	Hydropower		16	GD-8
	Genale-A	5	43	39	34	Multi-purpose		17	
	Genale-B	5	37	39	42	Hydropower		18	GD-3
	Wabe Mena	6	39	40	46	Irrigation		1	
Dawa	Awata-C	5	44	39	10	Multi-purpose		19	
	Awata-B	5	50	38	54	Multi-purpose		20	
	Awata-A	5	58	38	43	Multi-purpose	*	21	
	Melka Guba	4	43	39	28	Multi-purpose	*	22	GD-14
	Dawa-C	4	51	39	21	Hydropower		24	
	Dawa-B	5	0	39	8	Irrigation		24	GD-13
	Dawa-A	5	7	38	58	Multi-purpose		25	GD-12
	Momora	5	47	38	45	Multi-purpose		26	
	Kilkile	5	4	38	43	Hydropower		27	
	Afelata	5	36	38	27	Hydropower		28	
	Didiga	5	17	38	15	Irrigation	*	29	
Weyb	Shaya	7	9	39	57	Irrigation		2	
	Upper Weyb	7	6	40	24	Irrigation		3	
	Middle Weyb	6	46	40	58	Irrigation		4	
	Lower Weyb	5	28	41	47	Irrigation	*	5	GD-29
	Wabe Gastro-A	6	32	41	10	Irrigation		6	GD-23
	Wabe Gastro-C	5	45	41	43	Irrigation		7	GD-28
	Wabe Gastro-B	5	54	41	37	Irrigation		8	
	Tebel	6	57	41	0	Irrigation		9	
	Togona	7	9	40	6	Irrigation		10	

Table A-2 Competitive Candidate Hydropower Plants in the Genale-Dawa Basin

Project GIS Code	MoWR Code	Alternative	Guaranteed Maximum Capacity (MW)	Average Energy Generation (GWh/a)	Primary Energy Output (%)	Basic Project Cost (mUS$)	Spec Generation Cost 10% Discount Rate		Remarks
							Average (USc/kwh)	Weighted (USc/kwh)	
HYGEN40	GD-3	A	240	1115	89	279	3.19	3.47	
HYGEN20	GD-5	S	146	715	82	186	3.33	3.84	Regulation by HYGEN40
HYGEN10	GD-6	S	244	1195	81	317	3.36	3.91	Regulation by HYGEN40/20
HYGEN08	GD-7	S	185	830	83	245	3.75	4.29	Regulation by HYGEN40/20/11
HYMOR05	LI-01	I	67	305	91	123	4.85	5.2	Project identified by LI-YBC
HYGEN50	GD-2	E	130	598	89	226	4.79	5.24	
HYAWA10	Awata-C	L	68	317	93	127	5.1	5.38	
HYWEY40	GD-19	I	123	373	78	154	5.29	6.32	Powerhouse in Wabi Shebele
HYGEN06	GD-8	T	82	378	77	172	5.78	6.99	Regulation by HYGEN50/40/20/11/08
Total w/o HYWEY40			1161	5452		1674			Note: for Installed Capacity Factor of 1.75
Total with HYWEY40			1284	5825		1828			Equivalent to Plant Factor of about 50%

Table A-3: Details of Identified Hydropower Sites in Genale-Dawa Basin (WAPCOS)

Code	Latitude			Longitude			Levels (m a.s.l.)		L-Dam	Q	Head	Pcont	Tot.Energy	Tech.Pot.
(GD-)	Deg	Min	Sec	Deg	Min	Sec	River	FSL(NWL)	(m)	(m^3/s)	(m)	(MW)	(GWh/a)	(GWh/a)
Genale sub-basin														
1	6	10	35	38	57	40	1370	1500	1000	19.2	200	37.7	330	231
2	5	58	0	39	22	0	1210	1300	350	47.9	200	94.0	823	576
3	5	37	20	39	42	40	1000	1100	300	54.9	200	107.7	944	661
4	5	27	0	39	50	30	830	900	500	53.7	200	105.4	923	646
5	5	21	0	40	11	0	630	700	700	54.3	100	53.3	467	327
6	5	22	40	40	21	30	500	600	400	59.7	100	58.6	513	359
7	5	20	20	41	20	0	250	400	400	127.9	100	125.5	1099	769
8	4	55	0	41	30	0	200	250	400	105.9	50	51.9	455	319
9	4	19	40	41	59	0	180	200	300	82.5	20	16.2	142	99
									Sub-total Genale:			650.2		3987
Dawa sub-basin														
10	5	19	30	38	49	20	1100	1200	350	12.6	200	24.7	217	152
11	5	11	40	38	50	20	920	1000	350	39.5	100	38.7	339	238
12	5	5	20	38	58	20	860	900	250	43.2	50	21.2	186	130
13	5	0	20	39	7	30	820	850	1000	104.5	50	51.3	449	314
14	4	43	20	39	27	40	720	800	750	82.5	100	80.9	709	496
15	4	44	30	39	59	45	550	700	500	91.9	200	180.3	1579	1106
16	4	47	34	40	21	30	400	500	1250	94.3	100	92.5	810	567
17	4	39	40	40	34	0	350	400	1000	87.1	50	42.7	374	262
18	4	17	30	40	46	0	310	350	400	64.3	50	31.5	276	193
30	5	20	30	38	58	35	1310	1000	1000	17.0	400	66.7	584	409
31	5	8	30	39	8	40	860	600	600	38.4	100	*37.7*	330	231
									Sub-total Dawa:			668.3		4098
Weyb sub-basin														
19	7	16	45	40	7	0	2200	2300	1000	12.3	100	12.1	106	74
20	6	57	40	40	45	35	1400	1500	500	14.0	100	13.7	120	84
21	6	50	40	41	52	20	1100	1200	750	15.3	100	15.0	131	92
22	6	44	0	41	0	0	1000	1100	500	16.1	140	22.1	194	136
23	6	33	0	41	10	43	815	900	750	19.0	100	18.6	163	114
24	6	25	30	41	15	0	700	800	750	21.6	100	21.2	186	130
25	6	15	35	41	23	10	600	700	750	23.2	100	22.8	199	140
26	6	15	0	41	29	25	550	750	750	24.1	100	23.6	207	145
27	6	0	25	41	33	40	470	500	500	24.8	20	4.9	43	30
28	5	45	0	41	47	40	325	500	500	25.9	50	12.7	111	78
29	5	29	30	41	42	0	300	1250	1250	28.9	50	14.2	124	87
									Sub-total Weyb:			180.9		1109
									Total for Basin			1499		9270

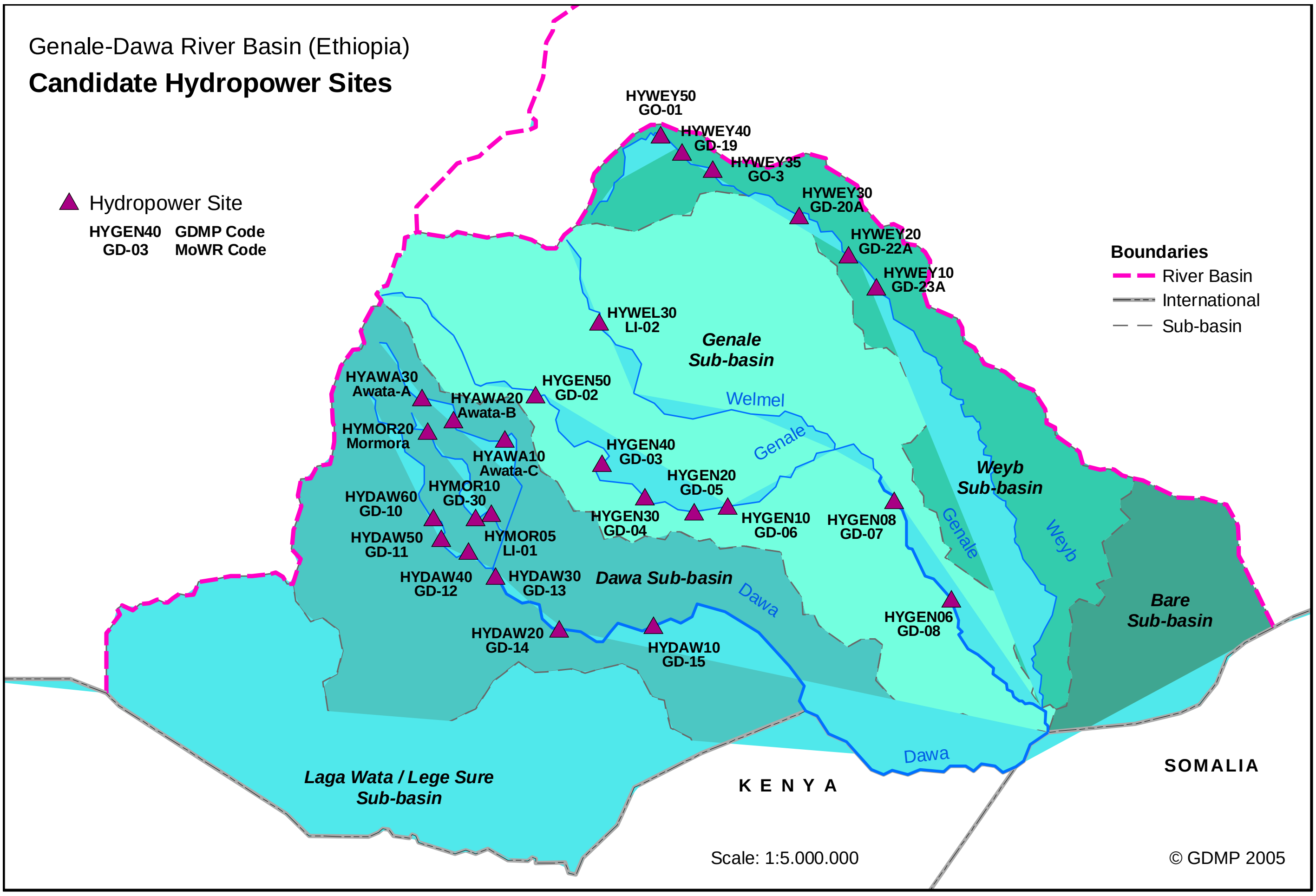


Figure A-1 Location of Candidate Hydropower Sites (Source Master plan Study)

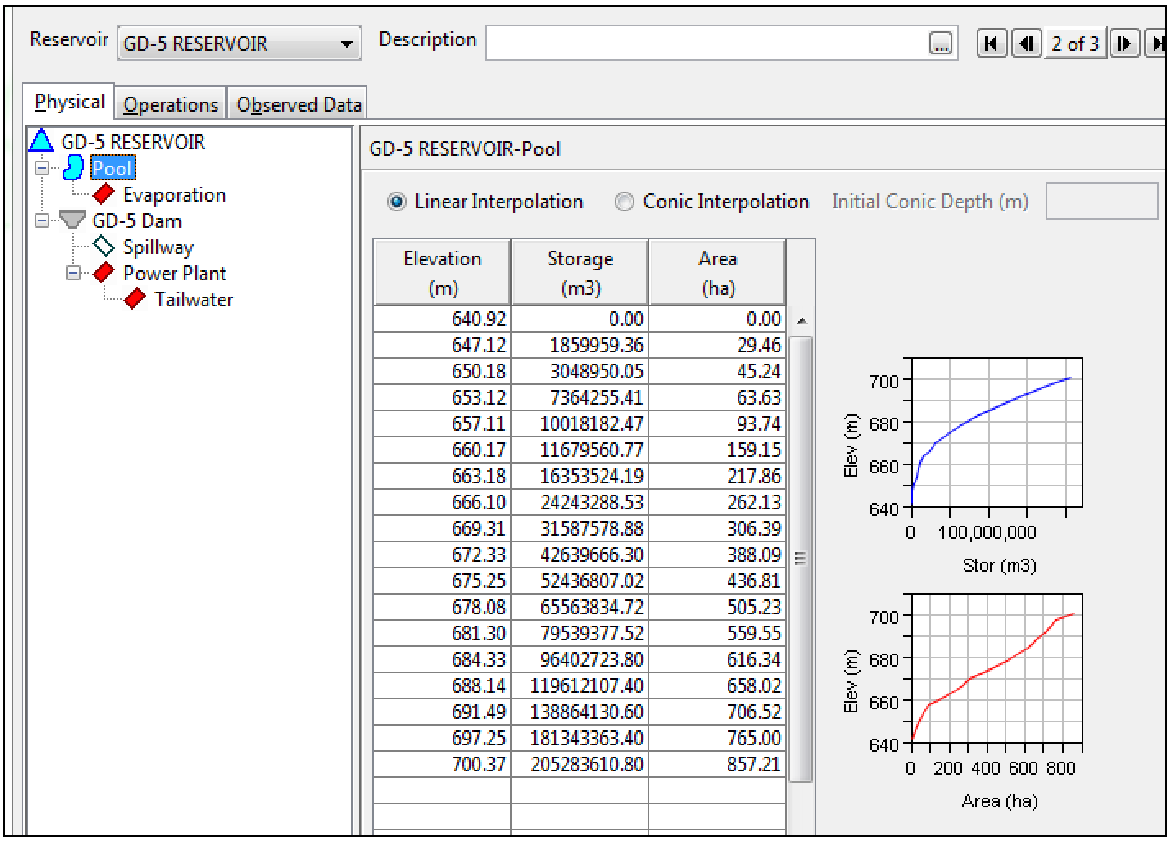
APPENDIX - B SUMMARY OF SALIENT FEATURES OF THE POWER PLANTS

Table B-1: Summary of the Salient features of the three proposed Projects

Parameter	Dimension	GD-3	GD-5	GD-6
Main Dam Type		RCC Gravity	RCC Gravity	RCC Gravity
Full Supply Level	m asl	1120	690	585
Reservoir Area at FSL	km²	98	7	8.15
Reservoir Volume	Mm³	2570	132	183.6
Dam Height	m	110	59	60
Length of Headrace Tunnel	m	12,402	4650	4700
Tailwater Level	m asl	831.9	585	351
Average Flow	m³/s	92.6	97	102
Rated Head	m	254.5	83	182
Installed Capacity	MW	254	146	246
Average Energy	GWh/year	1640	715	1575
Primary Energy	GWh/year	1600	620	1540
Note: GD-5 and GD-6 are only feasible if they can benefit from regulation by GD-3				

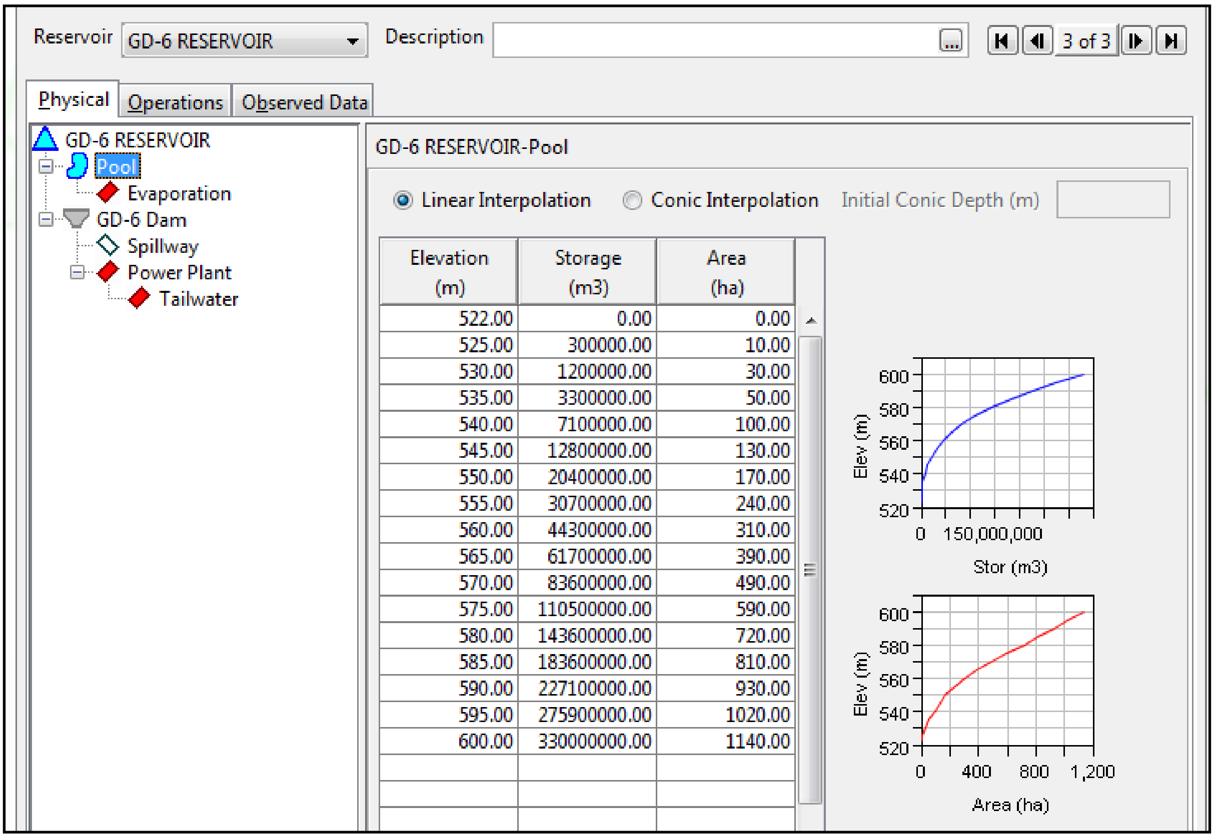
(Summarized form the feasibility and Prefeasibility and Master Plan Study of Genale-Dawa River Basin)

APPENDIX – C INPUT FOR HEC ResSim



Elevation (m)	Storage (m3)	Area (ha)
640.92	0.00	0.00
647.12	1859959.36	29.46
650.18	3048950.05	45.24
653.12	7364255.41	63.63
657.11	10018182.47	93.74
660.17	11679560.77	159.15
663.18	16353524.19	217.86
666.10	24243288.53	262.13
669.31	31587578.88	306.39
672.33	42639666.30	388.09
675.25	52436807.02	436.81
678.08	65563834.72	505.23
681.30	79539377.52	559.55
684.33	96402723.80	616.34
688.14	119612107.40	658.02
691.49	138864130.60	706.52
697.25	181343363.40	765.00
700.37	205283610.80	857.21

Figure C-1 Elevation –Storage – Area of GD-5



Elevation (m)	Storage (m3)	Area (ha)
522.00	0.00	0.00
525.00	300000.00	10.00
530.00	1200000.00	30.00
535.00	3300000.00	50.00
540.00	7100000.00	100.00
545.00	12800000.00	130.00
550.00	20400000.00	170.00
555.00	30700000.00	240.00
560.00	44300000.00	310.00
565.00	61700000.00	390.00
570.00	83600000.00	490.00
575.00	110500000.00	590.00
580.00	143600000.00	720.00
585.00	183600000.00	810.00
590.00	227100000.00	930.00
595.00	275900000.00	1020.00
600.00	330000000.00	1140.00

Figure C-2 Elevation –Storage – Area of GD-6

APPENDIX – D OUTPUT RESULTS

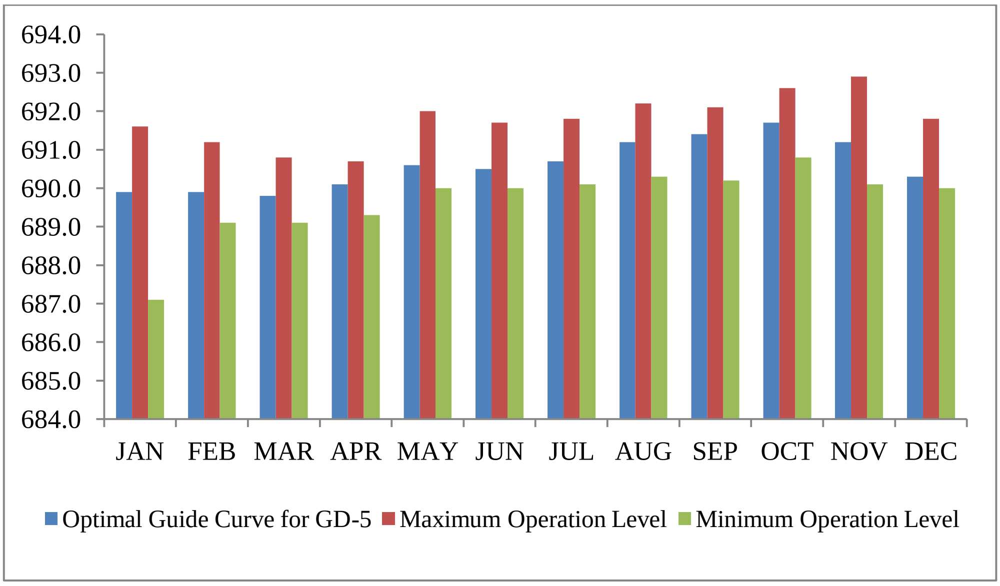


Figure D-1 GD-5 Monthly maximum, minimum and average (guide) curve chart

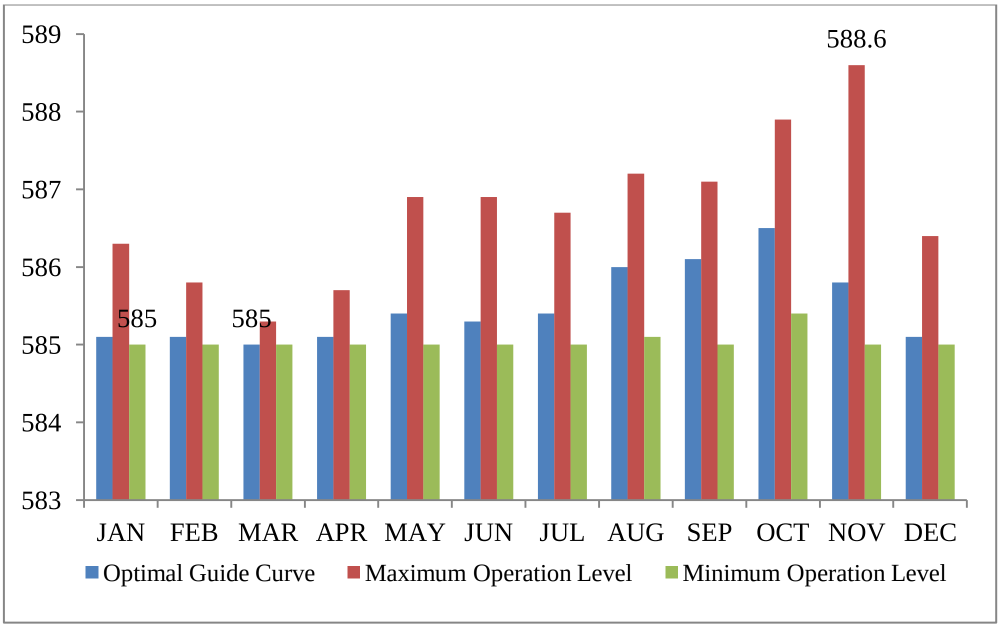


Figure D-2 GD-6 Monthly maximum, minimum and average (guide) curve chart

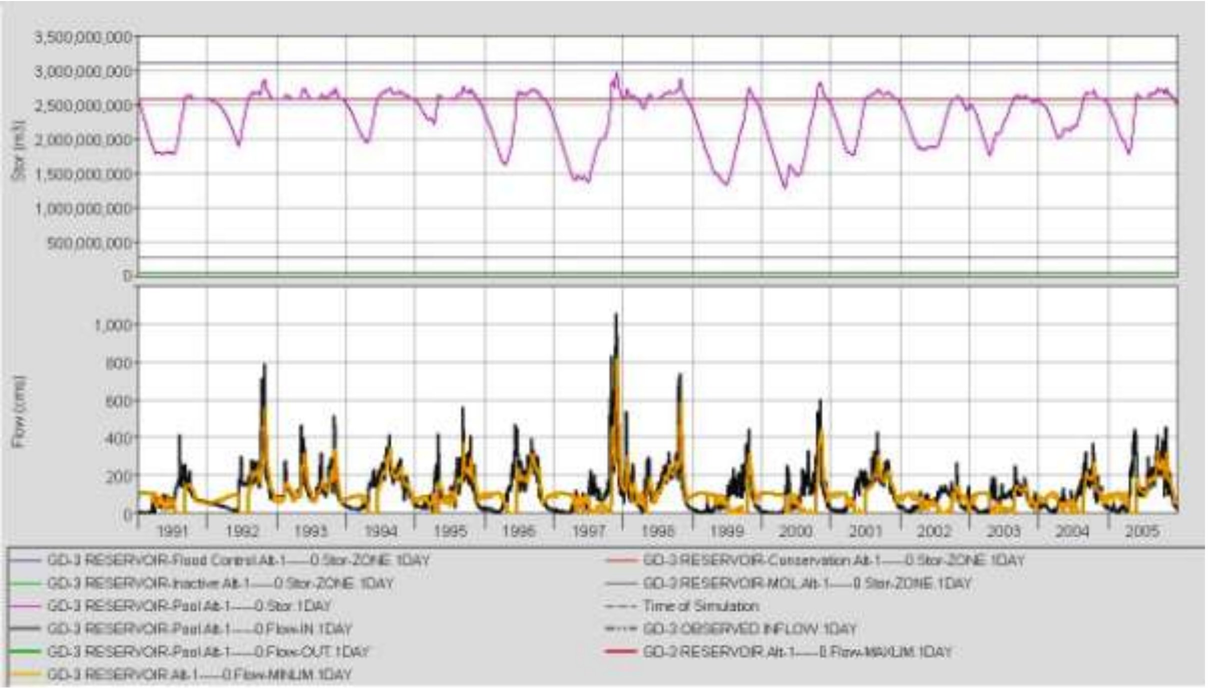


Figure C-3 Operation plot for GD-3

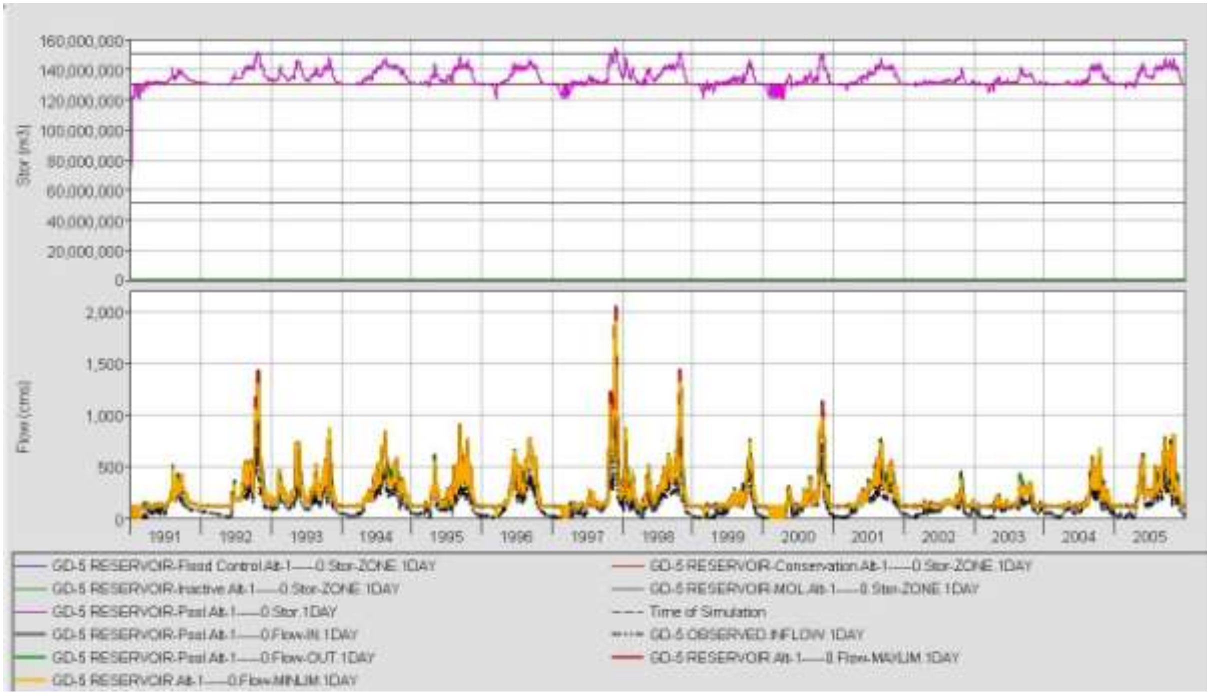


Figure C-4 Operation Plot for GD-5

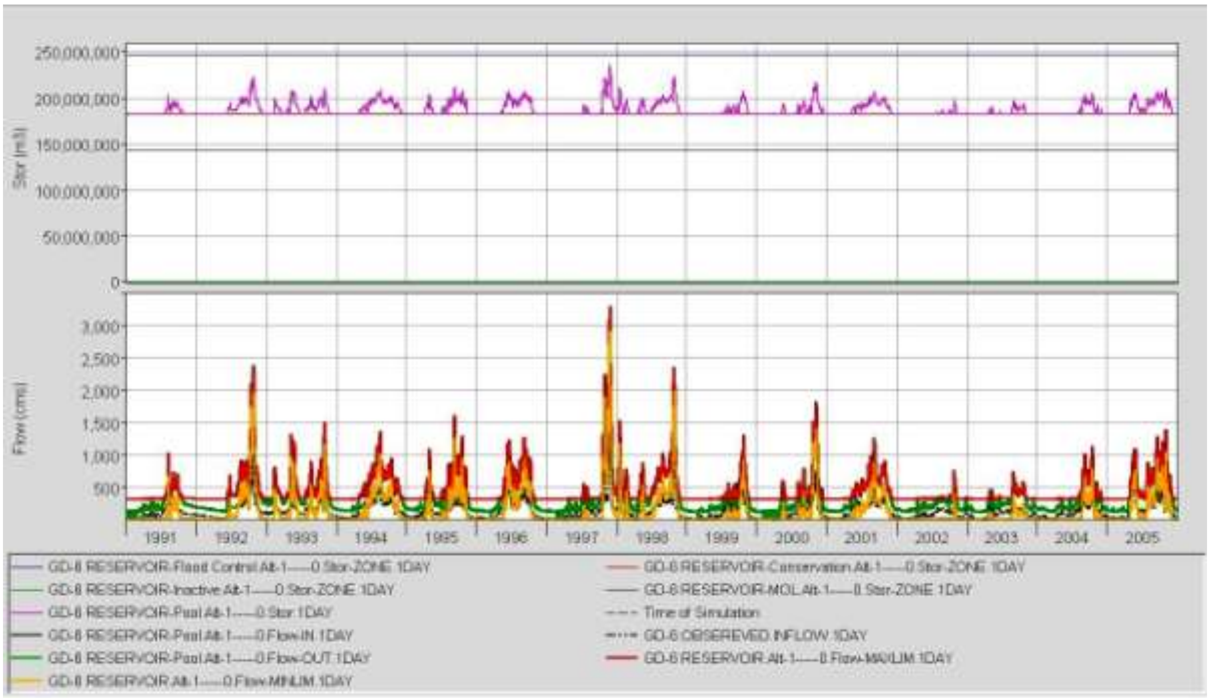


Figure C-5 Operation Plot for GD-6

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