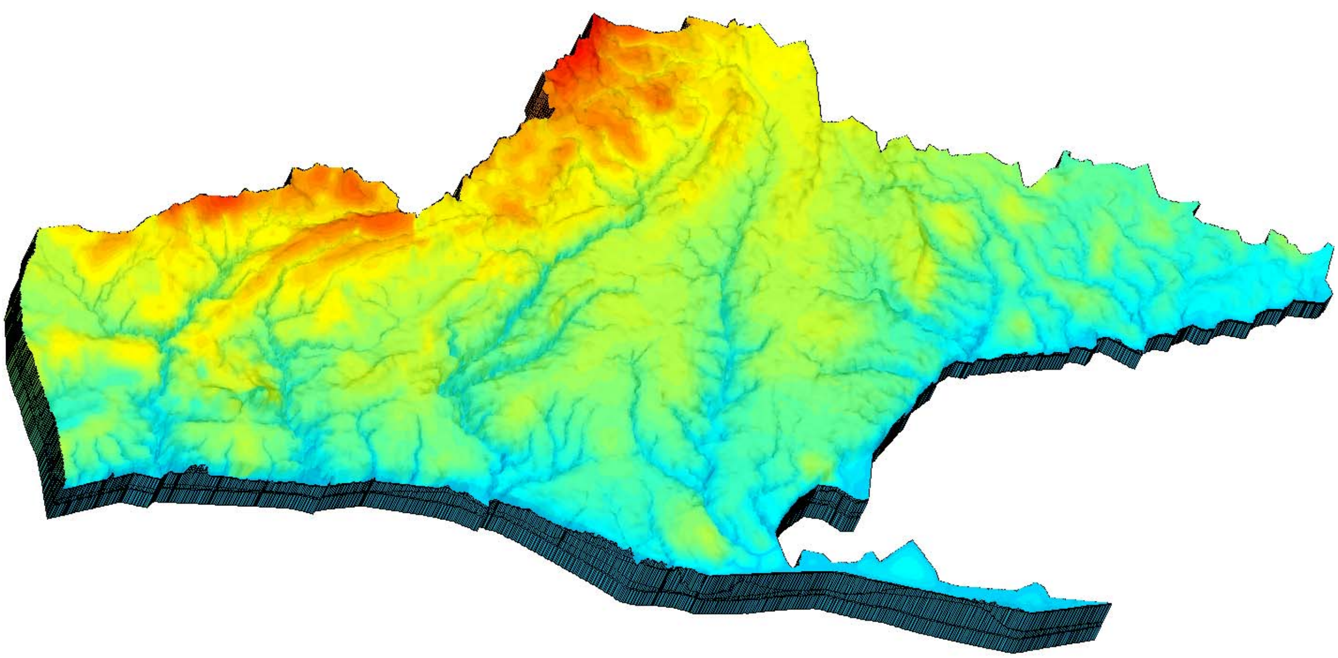
Long Point Region, Kettle Creek and Catfish Creek Integrated Water Budget

Final Report



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Prepared by

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Executive Summary

For the purposes of the Clean Water Act (MOE, 2006), a partnership was formed in 2004 between the Grand River Conservation Authority (GRCA), Long Point Region Conservation Authority (LPRCA), Catfish Creek Conservation Authority (CCCA) and Kettle Creek Conservation Authority (KCCA) to form the Lake Erie Source Protection Region. The four Conservation Authorities agreed to jointly undertake research, public education, and watershed planning and management for the advancement of drinking water source protection for the respective watersheds.

This report documents the approach and findings of the Integrated Water Budget for the Long-Point Region, Catfish Creek and Kettle Creek Conservation Authority (LPRCA / CCCA / KCCA) Study Area. The Integrated Water Budget outlined in this document is meant to partially fulfill the requirements of the Province of Ontario's Clean Water Act (2006), and follows the guidelines developed by the Province (MOE, 2007).

A water budget, as described by the Province's Water Budget Guidance Document (MOE, 2007), is an understanding and accounting of the movement of water and the uses of water over time, on, through, and below the surface of the earth. This Report implements the use of two coupled models, a continuous streamflow-generation model (GAWSER) and a steady-state groundwater flow model (FEFLOW), as well as a rigorous water demand estimation process. It provides an extensive and integrated understanding of hydrologic processes and water use in the Long Point Region, Catfish Creek, and Kettle Creek Conservation Authorities.

The integrated manner in which the FEFLOW and GAWSER models have been calibrated to two independent data sets (1, total streamflow and baseflow and 2, water well levels) provides enhanced confidence in the model-predicted flow volumes. When assessing model performance, the use of multiple, but separate, datasets increases the confidence that the modelling system is accurately representing the hydrologic processes. Based on the overall performance of the modelling system in replicating these observed conditions, the modelling system is considered to be accurately replicating surface and groundwater flow volumes, and is thus appropriate to provide realistic water budget estimates for the Study Area.

The Study Area was designated a "High Use Watershed" area by the Ontario Ministry of the Environment (MOE) in 2005 (AquaResource, 2005), based on a preliminary, regional assessment. The assessment contained within this current Integrated Water Budget Report, provides a more detailed and rigorous evaluation of water budget components throughout the Study Area. Subsequent watershed-wide studies included a Water Use study for each Conservation Authority (Bellamy and Wong, 2005), a draft Watershed Characterization study for each Conservation Authority (Lake Erie Source Protection, 2008), and a draft release of the Water Budget Report for the Study Area (AquaResource, 2008). Numerous other studies have examined individual areas and creeks within the Watersheds.

The Integrated Water Budget Report was completed using a set of water budget tools (groundwater flow and streamflow numerical models). To simulate surface water flows and partitioning of precipitation, continuous hydrologic modelling was employed using the GAWSER models constructed for each Conservation Authority (Schroeter & Associates, 2006a, b, c). As part of this Integrated Water Budget Report, the GAWSER modelling included an enhanced approach to incorporating water takings and is able to simulate streamflows that reflect all seasonal hydrologic processes. By incorporating agricultural demand, the hydrologic modelling has provided improved characterization of that demand. To simulate groundwater flows, a regional-scale FEFLOW model was developed and calibrated to available water level and

streamflow data. The original groundwater flow models (WHI, 2003 & 2007) were built upon in this Report to enhance modelling of key regional-scale features in the Study Area and to better represent bedrock characteristics. The FEFLOW model is designed to represent average annual groundwater flow conditions, with particular focus on volumetric flow from one subwatershed to another. Together these modelling tools provide a physical means of quantifying flows through the system for determining available water resources in the Study Area.

Significant efforts were also undertaken to better quantify and characterize the consumptive water demand throughout the Study Area. The water demand characterization completed in this study included efforts to verify Permit-To-Take-Water (PTTW) information, gathering “actual pumping” data, estimating agricultural demand based on discussions with the farming community, validating actual use information through calibration of the surface water model, and gathering relevant information contained within MOE’s PTTW paper files. The improved understanding of water demand provides an enhanced ability to characterize the water demand throughout the Study Area.

The Tier 2 Water Quantity Stress Assessment was prepared as a companion document to this report (AquaResource, 2009a) as a structured means of evaluating the degree of potential water quantity stress throughout an area by comparing the volume of water demand to that which is practically available for use. The results of streamflow and groundwater flow modelling and water demand estimates from this Integrated Water Budget were incorporated into the Tier 2 Water Quantity Stress Assessment to fulfill the requirements of the MOE’s Technical Rules (2008). Using predetermined thresholds for hydrologic stress, subwatersheds were classified as having a Low, Moderate, or Significant potential for stress. As per the Clean Water Act Technical Rules (MOE, 2008), municipal water systems located within a Tier 2 potentially stressed subwatershed meet the requirements to proceed with a Tier 3 Water Quantity Risk Assessment.

Integrated Water Budget

The continuous streamflow model (GAWSER) and the steady-state groundwater flow model (FEFLOW) used for this Report were integrated using the groundwater recharge parameter and through calibration to the same baseflow discharge data. The GAWSER model was initially calibrated / verified to streamflow observations, with estimated groundwater recharge values subsequently provided to the groundwater flow model as input. The groundwater flow model was then calibrated to observed water levels and baseflow estimates. Having such a coupled modelling system, calibrated to two independent data sets (streamflow and groundwater levels), increases the level of confidence in both models and allows an integrated set of water budget parameters to be produced, as given in the following Table.

Water Budget Parameter	Value (m^3/s)	Value (mm/year)
Precipitation	115.6	953
Evapotranspiration	67.3	555
Runoff	23.5	194
Recharge	24.8	204
SW Taking	0.9	7
Net Groundwater Discharge to Surface Water Features	20.0	164
GW Taking	1.7	14

The numeric models developed for this Study are regional in nature. They provide an improved understanding of the flow characteristics for both surface water and groundwater flows at that scale and discussion on a subwatershed basis in the Report details the enhanced understanding derived from the models. Local-scale features may not be well represented in the models and, therefore, results of the models should be interpreted at the scale for which they were designed.

Beyond the water budget, this report provides an enhanced understanding of the flow system using forward particle tracking, which illustrates the linkages between recharge areas and discharge areas. This knowledge will help water managers to better understand potential impacts of future changes to the landscape throughout the Study Area.

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1.0 Introduction

In an effort to share knowledge and resources, a partnership was formed in 2004 between the Grand River Conservation Authority (GRCA), Long Point Region Conservation Authority (LPRCA), Catfish Creek Conservation Authority (CCCA) and Kettle Creek Conservation Authority (KCCA) to form the Lake Erie Source Protection Region. For the purposes of Source Water Protection, the GRCA acts as the lead authority for the region. Map 1.1 shows the territory covered by the Lake Erie Region, including municipal boundaries and main rivers and tributaries. The four CAs agreed to jointly undertake research, public education, and watershed planning and management for the advancement of drinking water source protection for the respective watersheds. The watersheds have a long history of partnership and cooperation, and also have a natural association by containing most inland rivers and streams flowing from Ontario directly into Lake Erie.

Combined, the region represents a diverse area, ranging in land use from intense agricultural production to large and rapidly expanding urban areas. The region spans an area from the City of St. Thomas in the west, to Halton Hills on the east, and from Lake Erie to as far north as Dundalk. The area includes, in whole or in part, 49 upper and lower tier municipalities, as well as two First Nations communities.

This document summarizes the development and application of a water budget framework for the portion of the Region contained within three watersheds: Long Point Region, Catfish Creek and Kettle Creek. This framework is closely based on the Grand River Integrated Water Budget Report (AquaResource, 2009b), which relied upon the integration of a continuous surface water flow model (GAWSER) and a three-dimensional groundwater flow model (FEFLOW) to represent the conceptual hydrology and hydrogeology of the Study Area. GAWSER models have recently been developed for all three watersheds and are able to simulate the many hydrologic processes which occur above and below the ground surface. To understand the complexities of groundwater flow through the three watersheds, the Norfolk County FEFLOW model has recently been extended into Catfish and Kettle Creek.

With the surface water models and the groundwater flow model in place, the Conservation Authorities are able to better characterize hydrological processes above and below the ground throughout the three Conservation Authorities, to evaluate the water budget for subwatersheds within the Conservation Authorities, and estimate the impacts of current and future water demands on the hydrologic system.

1.1 THE CONSERVATION AUTHORITIES

1.1.1 Long Point Region Conservation Authority

The Long Point Region Conservation Authority (LPRCA) covers an area of approximately 2,900 km^2 in Southern Ontario and is shown in Map 1.2a. The area includes a number of watercourses, including Big Otter Creek, Big Creek, Lynn River, and Nanticoke Creek, as well as a number of smaller watercourses which all drain into Lake Erie. The LPRCA watershed is almost 100 km at its widest point and 60 km running north to south. It includes the urban centers of Tillsonburg, Delhi, Simcoe, Nanticoke, Port Dover, Port Rowan, and a number of smaller villages. Municipalities within LPRCA include Haldimand County, Norfolk County, Oxford County and Elgin County.

1.1.2 Catfish Creek Conservation Authority

The Catfish Creek Conservation Authority (CCCA) is located in the heart of the Carolinian zone in southwest Ontario, sandwiched between Long Point Region and Kettle Creek Conservation Authorities, as can be seen on Map 1.2b. In addition to the area drained by Catfish Creek, the CCCA also includes Silver Creek and a number of small watercourses that drain directly to Lake Erie, for a total of 490 km^2. Portions of Elgin and Oxford Counties, as well as the urban centers of Aylmer and Port Bruce are located within CCCA.

1.1.3 Kettle Creek Conservation Authority

The Kettle Creek Conservation Authority (KCCA) is located just south of the City of London, on the north shore of Lake Erie. As shown on Map 1.2c, the watershed is hourglass in shape and drains 520 km^2 of land. In addition to Kettle Creek, KCCA also includes a number of small watercourses that drain directly into Lake Erie. The KCCA area includes the south-central portion of Middlesex County/City of London and the central portion of Elgin County, including the City of St. Thomas.

1.2 SIGNIFICANCE OF WATER USE IN THE WATERSHEDS

A significant portion of the Study Area is located within the physiographic unit known as the Norfolk Sand Plain. This extensive deposit of sandy materials is particularly well suited to growing a variety of cash crops, most notably tobacco, and to a lesser extent, sod, vegetables and ginseng. However, due to the sandy nature of the soils, and the high water requirements of common crops, extensive irrigation is required. This high irrigation requirement has resulted in the area having the highest concentration of Permits To Take Water in Southern Ontario, as is displayed in Map 1.3. This concentration has led to numerous low water conditions, particularly during the dry period of 1998-1999, and is reflected by the MOE designation of the area as a "High Use Watershed" (AquaResource, 2005).

In addition to the significant agricultural water takings, there are also a number of communities that are reliant upon groundwater or inland surface water supplies for drinking water. These communities include Dereham Centre, Norwich, Otterville, Springford, Tillsonburg, Delhi, Courtland, Simcoe, Waterford, Brownsville, and Belmont. In many cases, the aquifers or watercourses that these communities depend on for water are also the same sources that supply water for agricultural irrigation.

1.3 SCOPE OF CURRENT ASSESSMENT

The development of the LPRCA/CCCA/KCCA water budget modelling framework is being carried out to meet the needs of the Province of Ontario's Clean Water Act (2006). The Ontario government has introduced this legislation to protect drinking water at the source, as part of an overall commitment to human health and the environment. A key focus of the legislation is the production of locally-developed, science-based source water assessment reports and protection plans. A significant component of this science-based approach is the development of a subwatershed-based water budget. A water budget, as described by the province's Water Budget Guidance Document, is an understanding and accounting of the movement of water and the uses of water over time, on, through, and below the surface of the earth. The analysis should address some or all of the following four main questions:

1) Where is the water? (i.e., where are the various subwatershed hydrologic elements (e.g., soils, aquifers, streams, lakes) located?)

2) How does the water move between these elements? (i.e., what are the pathways through which the water travels?);
3) What and where are the stresses on the water? (i.e., where are the takings?); and
4) What are the trends? (i.e., are levels or streamflows declining, increasing, or remaining constant over time?).

With the water budget model in place, the province requires the completion of a Water Quantity Stress Assessment. The Water Quantity Stress Assessment is documented within a companion to this report (AquaResource, 2009a). The Stress Assessment methodology is used initially to estimate the level of potential for stress in each subwatershed. This estimate is completed by comparing the existing and future water demands against the available surface and groundwater supply for each subwatershed. Depending on the level of potential stress estimated by the Water Quantity Stress Assessment, the water budget developed in each subwatershed will be refined to better represent local conditions and to better understand the possible stressors that may be occurring due to water withdrawals.

The purpose of this document is to describe the LPRCA/KKCA/CCCA water budget modelling framework with respect to its ability to meet internal objectives of better characterizing and understanding the subwatersheds' hydrology.

1.4 SCALE OF ASSESSMENT

Both the FEFLOW and GAWSER numerical models that are to be used within this assessment are regional tools, constructed from regional scale datasets. Local complexities are not represented within these tools, and therefore cannot be used to describe the local hydrologic conditions, or to determine the specific level of hydrologic or ecological stress an individual water taking may have on local scale features.

For the purposes of this assessment, the definition of *regional scale* are areas that are between 50 and100 km^2 and are equivalent to "*subwatersheds*", which this analysis will focus on. Areas that are between 1-5 km^2, are considered to be *local scale*, and are typically referred to as "*subcatchments*". "*Watersheds*" are groupings of subwatersheds, and are also used to describe the entirety of lands under a particular Conservation Authority's jurisdiction.

Due to limitations in both input data and available calibration points, hydrologic processes that are significant at the local scale may not be well represented within the regional scale numeric models. Because of this, subwatershed-scale water budget information presented in this Report should not be used to support local scale decision making, but rather identify where additional characterization and more detailed modelling is required to better understand and manage water resource issues.

1.5 METHODOLOGY

The entirety of the Study Area has continuous surface water models (GAWSER) and a steady-state three-dimensional groundwater model (FEFLOW) from previous modelling studies. The original Big Creek GAWSER (2002) model was subsequently expanded to the entirety of LPRCA (2006). The CCCA GAWSER model was completed in 2006, along with an update of the KCCA GAWSER model. All three models have been calibrated to a long-term period of record (1961-2004) as water budget assessment tools and are documented by Schroeter and Associates (2006 a, b, c). The FEFLOW model, developed by Waterloo Hydrogeologic Inc (WHI), was constructed as part of the Norfolk Groundwater Study (WHI, 2003), and was recently extended to include CCCA and KCCA (WHI, 2007). Prior to the Integrated Water Budget, the groundwater and surface water models were not coupled via groundwater recharge rates. Within the current study, the updating of FEFLOW recharge to estimates predicted by GAWSER is a critical step. This loose coupling of models is essential to be able to combine the predictions made by the two models into a single water budget framework.

1.5.1 Water Use Estimates

Water Use Inventories have previously been completed for Long Point, Catfish Creek and Kettle Creek (GRCA, 2005a, b, c) and water use estimates have been completed. These studies incorporated data from a variety of sources, including Permits-To-Take-Water, municipal pumping information and Statistics Canada data. This provides the foundation for quantifying the demand side of the Water Budget.

1.5.2 Continuous Surface Water Model (GAWSER) - Background

The Guelph All-Weather Sequential-Events Runoff (GAWSER) model is a physically-based deterministic hydrologic model that is used to predict the total streamflow resulting from inputs of rainfall and/or snowmelt. It can operate in both continuous and event-based mode, and can be used to model recharge ponds and predict pollutant accumulation, wash-off and transport. The climate input data required for continuous modelling includes daily maximum and minimum temperatures, daily total precipitation and hourly rainfall.

There are eight main hydrologic processes represented in GAWSER:

1. Accumulation and Ablation of Snow;
2. Filling and Emptying of Interception and Depression Storage;
3. Infiltration;
4. Evapotranspiration {beyond that included as part of (1) and (2)};
5. Generation and Routing of Overland Flow;
6. Generation and Routing of Subsurface Storm Runoff;
7. Filling and Emptying of Groundwater Storage (Recharge and Baseflow)
8. Routing of Streamflow in Channels
9. Routing of Streamflow through Reservoirs.

These procedures are fully documented in the GAWSER Training Guide and Reference Manual (Schroeter & Associates, 1996).

Seasonal changes in model parameters (e.g., soil hydraulic conductivity) can either be specified on a monthly basis or automatically shifted based on air temperature. Evapotranspiration is calculated by either specifying monthly potential evapotranspiration rates (for vegetated terrestrial surfaces) or allowing the model to generate potential evapotranspiration rates using the Linacre equation, a simplification of Penman's equation.

Variability in infiltration characteristics are accounted for by conducting separate calculations within each subcatchment for one impervious and up to eight pervious combinations of soil and land use. The Green-Ampt equation is used in the infiltration calculations with allowance for the recovery of infiltration between events, and reductions in infiltration caused by high soil water conditions.

Overland runoff routing uses area/time versus time relationships, whose travel time relationships are based on channel rating tables developed from stream cross-section measurements. Channel routing is completed using the Muskingum-Cunge method. Reservoir routing is handled using the Puls method with controlled releases allowed. Diversions of water flow from channels and reservoirs can be directed to other channels or groundwater storage. The routing method is stable over a range of channel slopes, allowing the application of GAWSER in watersheds with large variations in both channel slope and geometry.

For further information on GAWSER and its application as a water management tool see GAWSER: A Versatile Tool For Water Management Planning, Schroeter H.O., et al. (2000).

1.5.3 FEFLOW Model – Development and Implementation

The groundwater flow model for the Study Area was developed by Waterloo Hydrogeologic, Inc using FEFLOW. This model originated from the Norfolk Groundwater Study (WHI, 2003), and included the entirety of LPRCA. The Norfolk FEFLOW model was then extended to include Catfish and Kettle Creeks by completing the following steps (WHI, 2007):

1. Identify, acquire and review all available data including previous studies, and previous groundwater models;
2. Develop a spatially referenced database of information on the hydrogeology of the Study Area and complete mapping using GIS to characterize the aquifers and aquitards across the watershed;
3. Develop a 3D conceptual hydrogeological model with a seamless connection to the existing Norfolk model;
4. Extend the numerical model domain into Catfish and Kettle Creek, and incorporate the geological understanding into the Norfolk layer structure;
5. Undergo a preliminary calibration of the model extension by modifying hydraulic properties to reasonably replicate observed water levels;

The existing model (WHI, 2007) was refined and re-calibrated within this Integrated Water Budget study. The steps undertaken by AquaResource to enhance the model include the following:

1. Redesign the spatial finite element mesh to follow major river features and subwatershed boundaries, as necessary, to support more accurate water budget calculations. The node spacing along stream reaches in the refined model is approximately 300m;
2. Extend the finite element mesh to incorporate an area west of the Kettle Creek Conservation Authority. This area is outside the surface water boundary but was considered part of the groundwater flow system contributing to flows within this watershed;
3. Removal of deep bedrock layers which were not considered a part of the active, freshwater, groundwater flow system. The remaining model layers were not changed;
4. Re-assignment of hydraulic conductivities throughout the entire model to transform them from highly generalized zones to a more heterogeneous distribution that better reflects conditions recorded within the water well records for wells penetrating each model layer. Further, all bedrock layer hydraulic conductivities were adjusted to be consistent with values applied in the GRCA watershed model;
5. Re-assignment of boundary conditions and values applied around the perimeter of the model. Boundary conditions were limited to areas where water level mapping indicated a potential for cross-boundary flow, or where calibration suggested it was required, to avoid potentially misleading boundary flows (particularly important for the water budget); and
6. Re-assigned the recharge boundary condition values to be consistent with the refined surface water model.

The FEFLOW model was then calibrated to available water levels (see section 5.3).

1.5.4 Integrated Water Budget

In watersheds such as those found within the LPRCA/CCCA/KCCA areas, where surface and groundwater interactions are significant, a combined use of surface and groundwater models contribute to a greater understanding of the hydrologic system. For this reason, output from both the GAWSER and FEFLOW models are used to quantify the significant processes that drive the hydrologic cycle. The GAWSER model partitions precipitation into runoff, evapotranspiration and groundwater recharge, while the FEFLOW model simulates how the groundwater moves through the subsurface and interacts with the surface water system.

To compare output generated at a variety of spatial scales, using both models, all output data are aggregated to common subwatersheds. A summary of the water budget parameters presented at this scale is provided below:

- **Precipitation**. Hourly climate data (precipitation, temperature) is input into GAWSER for each Zone of Uniform Meteorology (ZUM). When formulating the input data for each catchment, the GAWSER input file refers to the climate station appropriate for that catchment. Precipitation data are reported in the output file prepared for each catchment.
- **Runoff**. GAWSER reports direct runoff at a variety of scales, from the individual geology/land cover combination that produces the hydrologic response from a precipitation event, to the direct runoff for an individual catchment, or the direct runoff for a subwatershed.
- **Groundwater Recharge**. As with runoff, GAWSER reports daily recharge and interflow rates for spatial scales ranging from the geology/land cover combination to the subwatershed scale. Recharge is defined at the amount of water that leaves the 2^{nd} soil layer within GAWSER. This value is effectively infiltration, net of evapotranspiration.
- **Evapotranspiration**. GAWSER computes evapotranspiration for every scale that runoff and recharge are available for. In addition to simulating evapotranspiration via a numerical model, evapotranspiration can be estimated by subtracting the long term stream outflow from a subwatershed, from the long term precipitation over that same subwatershed (assuming net groundwater flows are negligible). This is often useful for checking the appropriateness of evapotranspiration estimates.
- **Streamflow**. GAWSER computes total average streamflow, peak daily flow, and the baseflow component for each catchment, and reports these results for the catchment. The model also exports computed streamflow, observed streamflow, and upstream area precipitation at gauge locations, or at any junction point within the model.
- **FEFLOW Groundwater Discharge / Baseflow**. The three-dimensional groundwater flow model (FEFLOW) computes groundwater discharge rates at finite element nodes located along watercourses. This simulates the distribution of groundwater discharge that is often inferred at stream gauges to the estimated point locations of discharge.
- **External Groundwater Transfer.** FEFLOW is able to estimate the volume of groundwater that enters or exits through the model boundary. Because the current groundwater model domain is the topographic boundary of the LPRCA/CCCA/KCCA areas, FEFLOW identifies where groundwater is leaving or entering the boundaries of the three Conservation Authorities.

- **Inter-Basin Groundwater Transfer.** Similar to external groundwater transfers, FEFLOW is able to determine the quantity of groundwater that leaves one subwatershed within the model domain and enters an adjacent subwatershed.

2.0 Watershed Characterization

2.1 LAKE ERIE SOURCE PROTECTION REGION

The Lake Erie Source Protection Region is one of 19 Source Protection Regions in Ontario that aim to protect the sources of municipal drinking water to ensure a long-term, safe supply of clean drinking water now and into the future. The Lake Erie Region consists of four conservation authorities: the GRCA, LPRCA, CCCA and KCCA. These Conservation Authorities were brought together to develop individual drinking water source protection plans for each of the respective conservation authority jurisdictions. An Integrated Water Budget Report and Tier 2 Water Quantity Stress Assessment Report have been completed for the GRCA (AquaResource Inc., 2009b, 2009c). Therefore the GRCA area will not be discussed at length in this report; the focus will be on the remaining three Conservation Authorities within the Lake Erie Source Protection Region.

2.1.1 Long Point Region Conservation Authority

The land area included within the Long Point Region Conservation Authority's jurisdiction encompasses approximately 2,900 km^2 in southern Ontario. The watershed region is approximately 100 km wide at its widest point, and approximately 60 km from Lake Erie in the south to the headwaters of the region in the north. The LPRCA also contains approximately 225 km of Lake Erie shoreline, including the Long Point sand spit. Map 1.2a shows the many watercourses and watersheds that comprise the Long Point Region. The combined length of all rivers, streams and tributaries is over 3,700 km.

Major urban centres within the LPRCA include the communities of Delhi, Courtland, Waterford, Simcoe, Norwich, Otterville, Tillsonburg, Straffordville, Vienna, Port Burwell, Port Rowan, Port Dover, Jarvis, and Hagersville. The Conservation Authority encompasses most of Norfolk County and portions of Haldimand, Brant, Oxford and Elgin Counties.

All surface water features within the Study Area drain into Lake Erie. There are 4 larger scale watercourses, Big Otter Creek, Big Creek, Lynn River and Nanticoke Creek, as well as numerous small watercourses that drain directly into Lake Erie.

2.1.2 Catfish Creek Conservation Authority

The Catfish Creek Conservation Authority is located in southwestern Ontario (Map 1.2b) between the LPRCA to the east, and the KCCA to the west. Catfish Creek and its tributaries drain an area of approximately 490 km^2 in Elgin and Oxford Counties. The main branch of Catfish Creek flows southeast through the community of Aylmer, the watershed's largest community. The West and East Catfish Creek tributaries drain the northwestern portion of the watershed. The main branch of Catfish Creek joins the East and West Catfish Creeks just east of Aylmer, and then flows due south and enters into Lake Erie at Port Bruce.

In addition to the lands drained directly by Catfish Creek, there are also several Lake Erie tributaries within the Catfish Creek Conservation Authority. The most notable is Silver Creek, located in the southeast portion of the watershed, which drains a portion of the Norfolk Sand Plain.

2.1.3 Kettle Creek Conservation Authority

The Kettle Creek Conservation Authority is situated on the north shore of Lake Erie, west of the CCCA. As shown on Map 1.2c, the watershed is hourglass in shape and drains 520 km^2 of land including the south-central portion of Middlesex County and the City of London, as well as the central portion of Elgin County, including the City of St. Thomas. The tributaries to Kettle Creek within the Conservation Authority's jurisdiction are Dodd Creek, Upper Kettle Creek and Lower Kettle Creek.

The headwaters of Dodd Creek, a major tributary of Kettle Creek, lie in the northwest quadrant of the watershed with ground surface elevations ranging from 307 to 250 masl. This relatively flat clay plain has extensive cultivated farmland with small and isolated wooded areas and wetlands. As a result, baseflow is intermittent and little continuous flow is provided by Dodd Creek to the main branch of Kettle Creek in St. Thomas.

2.2 SUBWATERSHEDS

When reporting on water budget parameters, an appropriate spatial scale is required. In the case of this Study, a subwatershed approach was deemed appropriate. Thirty-one (31) subwatersheds were delineated for the LPRCA, CCCA and KCCA watersheds, and five factors were considered when delineating the subwatersheds that will be used for both this Integrated Water Budget and the companion Stress Assessment (AquaResource, 2009c).

1. Subwatersheds were delineated to fully encompass a particular municipal water supply system. This ensures the entire municipal demand associated with an urban area is reported in the same subwatershed that the urban centre is located in. The only exception to this is the Delhi system, where the Delhi surface water taking (Lehman Reservoir) is in a different subwatershed than are the municipal groundwater wells for Delhi. This was considered acceptable as surface water and groundwater municipal demands are calculated separately.

2. When quantifying water budget parameters for a subwatershed or subcatchment, it is preferable to have comparable or homogeneous geologic conditions. Therefore, Quaternary geology mapping across the region was considered when delineating the subwatersheds. Watercourses such as Big Creek, Nanticoke Creek and Big Otter Creek cross through clay plains, till plains, and the Norfolk Sand Plain. The subwatersheds were, therefore, split into additional subwatersheds to accommodate geologic contrasts.

3. Water takings were considered when delineating the subwatersheds to isolate areas with many takings. Subwatershed boundaries were defined where distinct breaks were observed in the density of permitted water takings. These boundaries closely followed the geologic boundaries discussed above.

4. The numerical models used in the assessment are regional in nature; therefore, the subwatersheds were sized appropriately and were large enough to provide an adequate assessment across the subwatershed.

5. Whenever possible, subwatersheds were created to have a stream gauge at the outlet of the subwatershed. In many cases, this was not possible; however, this was a factor in creating the subwatersheds across the Study Area.

The delineated subwatersheds are illustrated on Map 2.1, and listed in Tables 2.1-2.3. The location of no flow divides within the groundwater flow system may not correspond to the location of the surface-topography boundaries that define surface-flow subwatersheds. This is particularly true of deeper regional groundwater flow components (aquifers). It is thus expected that some groundwater may flow between subwatersheds as well as into and out of the overall Study Area. Numerical modelling tools are used to quantify groundwater transfers between subwatersheds, as well as between adjacent watersheds.

In addition to subwatersheds, Long Point Region Conservation Authority has been divided into five watersheds. These five watersheds correspond with the large watercourses present within the Long Point Region, and have been added for descriptive purposes only.

Table 2.1 - Long Point Conservation Authority Subwatersheds

Watersheds	***Subwatersheds***	***Drainage Area (km^2)***
Otter Creek	Otter Above Maple Dell Road	99
	Otter at Otterville	75
	Otter at Tillsonburg	153
	Spittler Creek	116
	Lower Otter	168
	Little Otter	118
	South Otter	120
	Clear Creek	87
Big Creek	Big Above Cement Road	89
	Big Above Kelvin Gauge	64
	Big Above Delhi	154
	North Creek	58
	Big Above Minnow Creek	72
	Big Above Walsingham Gauge	123
	Venison Creek	98
	Lower Big	96
	Dedrick Creek	138
Lynne River	Young/Hay Creek	120
	Lynne River	172
	Black Creek	134
Nanticoke Creek	Upper Nanticoke	114
	Lower Nanticoke	85
Eastern Tributaries	Sandusk Creek	182
	Stoney Creek	186

Table 2.2 - Catfish Creek Conservation Authority Subwatersheds

Subwatershed	*Drainage Area (km^2)*
West Catfish	147
Catfish Above Aylmer	143
Lower Catfish	103
Silver Creek	95

Table 2.3 - Kettle Creek Conservation Authority Subwatersheds

Subwatershed	*Drainage Area (km^2)*
Upper Kettle	199
Dodd Creek	131
Lower Kettle	148

2.3 GROUND SURFACE TOPOGRAPHY

The present day ground surface topography within the Study Area evolved from erosional and depositional processes that occurred during glacial and post-glacial times. The ground surface topography within the Study Area varies from approximately 330 masl to a low of 170 masl along the Lake Erie shoreline. Maps 2.2a-2.2c displays the topography across the area.

2.3.1 Long Point Region Conservation Authority

The ground surface elevation ranges from 330 masl in the northwest, to 170 masl in the southeastern limits of the Study Area along the Lake Erie shoreline (Map 2.2a). Areas mapped as hummocky topography are minimal through the LPRCA, and are illustrated on Map 2.3a. The Galt and Paris Moraines were not mapped as hummocky topography within Long Point Region.

2.3.2 Catfish Creek Conservation Authority

Map 2.2b shows the ground surface topography of the Catfish Creek Conservation Authority, which varies from 275 masl in the north to approximately 180 masl along the Lake Erie shoreline. The topographic highs within the watershed correspond to the St. Thomas Moraine and Sparta Moraines. The lowest elevations occur along the incised river valleys and along the Lake Erie shoreline. Hummocky topography is shown on Map 2.3b and is generally limited to the topographic divides.

2.3.3 Kettle Creek Conservation Authority

Map 2.2c illustrates the topography across the Kettle Creek Conservation Authority. Topography varies from 300 masl in the north to approximately 180 masl along the Lake Erie shoreline. Similar to the CCCA topography, the St. Thomas and Sparta Moraine are identifiable as topographic highs, as well as the Westminster Moraines. Topographic lows in the watershed also occur along the incised river valleys and the Lake Erie shoreline. As with the LPRCA and CCCA, hummocky topography is minimal within Kettle Creek, and is limited to areas immediately adjacent to the topographic divides. Hummocky topography for CCCA is shown in Map 2.3c.

2.4 PHYSIOGRAPHY

The physiographic features (as mapped by Chapman and Putnam, 1984) located within the Study Area are illustrated on Maps 2.4a to 2.4c. The physiographic regions within the Study Area are primarily the result of the Late Wisconsinan Glaciation (~10,000 to 25,000 years ago).

2.4.1 Long Point Region Conservation Authority

There are four distinct physiographic regions within the LPRCA (Map 2.4a): the Norfolk Sand Plain, the Haldimand Clay Plain, the Mount Elgin Ridges, and the Horseshoe Moraines (Chapman and Putnam, 1984). Each of these is discussed below.

2.4.1.1 Norfolk Sand Plain

The Norfolk Sand Plain is characterized as a low-relief, silty sand and gravel sand plain that extends through most of the western portion of the Long Point Region Conservation Authority jurisdiction. The sand plain ranges in thickness from less than a metre to over 25 m in isolated areas (Barnett, 1982).

2.4.1.2 Haldimand Clay Plain

The area east of the communities of Waterford and Simcoe is characterized by low-relief lacustrine clay plain (Chapman and Putnam, 1984), and is referred to as the Haldimand Clay Plain.

2.4.1.3 Horseshoe Moraines

The Horseshoe Moraines physiographic region is situated in the eastern portion of the Long Point Region Conservation Authority and it includes the Paris and Galt Moraines that provide low to moderate relief above the surrounding sand plain. The Paris and Galt Moraines are scarcely visible in the Long Point Region as they have been either eroded or buried by overlying glaciolacustrine or glaciofluvial sediments (Barnett, 1982). These two moraines were laid down by the Ontario sublobe and as such are oriented in a north-south direction, while several other moraines in the area trend in an east-west direction. While not identified as hummocky topography, the general locations of these moraines are shown in Map 2.3a.

2.4.1.4 Mount Elgin Ridges

The Mount Elgin Ridges physiographic region is situated in the northwestern portion of the Long Point Region Conservation Authority. It includes several end moraines that provide low to moderate relief above the surrounding sand plain and in some areas exhibit slightly hummocky topography. Several of these moraines were deposited at the front of the Lake Erie ice sublobe during the last glaciation (the Wisconsinan Glaciation; Chapman and Putnam, 1984). These moraines, which run east-west roughly paralleling the current Lake Erie shoreline, include (from north to south) the St. Thomas, Norwich, Tillsonburg, Courtland, and Mabee Moraines. These moraines are shown as hummocky topography in Map 2.3a

All of the moraines in the Long Point Region area reach kilometres in length and the surface expression of each is highly variable. Within the Long Point Region area, the St. Thomas Moraine is the oldest of the moraines and it has the greatest surficial expression (Chapman and Putnam, 1984). This end moraine is located in the most northwestern reaches of the Study Area extending beneath the towns of Mount Vernon and Mount Elgin (Barnett and Girard, 1982). In general, the surface expression of the moraines, west of the Paris Moraine, decreases in intensity southward towards Lake Erie. Those moraines located near the Lake Erie shoreline are smaller as they were subject to more erosion and/or burial following their deposition by elevated lake levels in the Lake Erie basin (Barnett, 1982; Chapman and Putnam, 1984).

There is a relationship between the surficial geology and the groundwater and surface water hydrology across the Study Area. In general, areas with fine-grained clays lying at surface (e.g. the Haldimand Clay Plain) tend to have more tributaries than those areas where coarse grained sediments dominate the surficial sediments. This is because of the low infiltration capacity of clay-rich soils. Precipitation falling on the clay plain commonly travels as overland flow to surface water features rather than infiltrating to the groundwater system. In contrast, areas with coarser sand and gravel at surface (e.g., the Norfolk Sand Plain and moraines) have fewer tributaries as a larger portion of precipitation percolates downward to recharge the groundwater system.

2.4.2 Catfish Creek Conservation Authority

The physiographic regions within the Catfish Creek Conservation Authority are presented in Map 2.4b. These landforms were shaped by glacial processes occurring during the Late Wisconsinan glaciation which occurred some 10,000 to 25,000 years ago when glaciers and glacial lobes extended into southern Ontario and as far south as Michigan, Indiana, Illinois and Ohio (Barnett, 1991).

The main physiographic regions within the Catfish Creek Conservation Authority are: the Mount Elgin Ridges, the Ekfrid Clay Plain, and the Norfolk Sand Plain.

2.4.2.1 Mount Elgin Ridges

The Mount Elgin Ridges physiographic region within the Catfish Creek Conservation Authority region includes several end moraines that provide low to moderate relief above the surrounding low-lying topography. These moraines were deposited at the front of the Lake Erie ice sublobe during the Wisconsinan Glaciation (Chapman and Putnam, 1984), and include the St. Thomas, Tillsonburg, and Sparta Moraines. (Refer to Map 2.3b)

The St. Thomas Moraine was built by a submerged ice front and is the largest moraine of the series, varying in width up to 5 km between London and Tillsonburg and is prominent as far as Wallacetown (Barnes, 1967). This moraine provides the surface water divide between Catfish and Kettle Creek northeast of St. Thomas. (Refer to Map 2.3b)

The Sparta Moraine divides the Catfish and Kettle Creek Conservation Authorities just north of Lake Erie. This subtle feature is capped by the clayey silt Port Stanley Till. The Tillsonburg Moraine is topographically subtle through the east-central portion of the watershed. This moraine is capped as well by the Port Stanley Till. The Norwich Moraine is another east-west trending moraine in the northern area of the Catfish Creek Conservation Authority. Like the Sparta and Tillsonburg Moraine, the Norwich Moraine is capped by the Port Stanley Till.

2.4.2.2 Ekfrid Clay Plain

The Ekfrid Clay Plain comprises a fairly large area in the Lake Erie region and is the dominant feature in the west-central portion of the Catfish Creek watershed. The flat lying area is characterized by clay and silt deposits providing little relief and poor drainage.

2.4.2.3 Norfolk Sand Plain

The Norfolk Sand Plain is extensive and dominates the southern portion of the Catfish Creek Conservation Authority, extending to the Lake Erie shoreline. It is wedge-shaped with a broad curved base along the shore of Lake Erie tapering northward to a point at Brantford on the Grand River. The sands and silts of this region were deposited as a delta in glacial Lakes Whittlesey and Warren. The great discharge of meltwater from the Grand River area entered the lake between the ice front and the moraines to the north-west, building the delta from west to east as the glacier withdrew. Thus it covered most of the area west of the Galt Moraine. From observations in exposed river valleys and along the very steep bluffs of Lake Erie there are records of sand beds up to 23 m deep but usually silt or clay strata or beds of boulder clay occur within 9 m of the surface (Barnett, 1976).

2.4.3 Kettle Creek Conservation Authority

The physiographic regions within the Kettle Creek Conservation Authority are presented in Map 2.4c. These regions were shaped by glacial processes during the Wisconsinan Glaciation which occurred some 10,000 to 25,000 years ago.

There are three distinct physiographic regions within the Kettle Creek watershed: the Mount Elgin Ridges, the Ekfrid Clay Plain, and the Norfolk Sand Plain.

2.4.3.1 Mount Elgin Ridges

Located between the Thames River Valley and the sand plains of Norfolk and Elgin counties, the Mount Elgin Ridges cover the majority of the northern third of the Kettle Creek watershed. This distinct physiographic region is made up of two prominent topographic features, the St. Thomas and Westminster Moraines. (Refer to Map 2.3c)

The St. Thomas Moraine was built by a submerged ice front. At St. Thomas a gap occurs in the ridge so the name for the moraine is not particularly suitable. However, it is the strongest moraine of the series, having a width of up to 5 km between London and Tillsonburg and is prominent as far as Wallacetown (Barnes, 1967). This moraine provides the surface water divide between Catfish and Kettle Creek northeast of St. Thomas.

The Westminster Moraine trends east to west and is approximately 5 km wide. It passes about 12 km south of the City of London's centre and is flanked on the north by the parallel Ingersoll Moraine. To the south, the Westminster Moraine is flanked by the parallel St. Thomas Moraine. The Westminster Moraine consists of heavy clay deposited over sand, gravel and boulder beds (Dewdney, 2000). The succession of ridges and valleys in the Mount Elgin Ridges is characterized by clay or silty clay ridges and valleys with alluvium of gravel, sand or silt.

The Sparta Moraine divides the Catfish and Kettle Creek Conservation Authorities just north of Lake Erie. This subtle feature is capped by the clayey silt Port Stanley Till.

2.4.3.2 Ekfrid Clay Plain

The Ekfrid Clay Plain is the dominant physiographic unit in the central and western portion of Kettle Creek. The flat lying area is characterized by clay and silt deposits providing little relief and poor drainage.

2.4.3.3 Norfolk Sand Plain

The Norfolk Sand Plain encompasses the southern third of the Kettle Creek Conservation Authority and extends to the Lake Erie shoreline. It is wedge-shaped with a broad curved base along the shore of Lake Erie tapering northward to a point at Brantford on the Grand River. The sands and silts of this region were deposited as a delta in glacial Lake Whittlesey and Warren. The great discharge of meltwater from the Grand River area entered the lake between the ice front and the moraines to the northwest, building the delta from west to east as the glacier withdrew. Thus it covered most of the area west of the Galt Moraine. From observations in exposed river valleys and along the very steep bluffs of Lake Erie there are records of sand beds up to 23 m deep but usually silt or clay strata or beds of boulder clay occur within 9 m of the surface (Barnett, 1976).

2.5 LAND USE

Land use planning plays a crucial role in management and protection of water. A strong understanding of the land use distribution across the watershed is required to identify where sources of existing and potential contamination can originate. An understanding of land use distribution also allows appropriate planning to take place to protect existing and future drinking water sources.

Land uses for Long Point, Catfish and Kettle Creek Conservation Authorities are very similar. They are characterized by small urban commercial, industrial and residential centres, surrounded by less-populated rural land used for intensive agricultural production. Maps 2.5a-2.5c show the distribution of land cover across the three conservation authorities.

2.6 BEDROCK TOPOGRAPHY

There was an extensive period of time between the final deposition of the Paleozoic sedimentary rocks (approximately 350 million years ago) and the earliest record of glacial deposition (in Ontario) during the Late Wisconsinan Glaciation approximately 115,000 years ago. During this period, it is believed that the bedrock surface was exposed and subject to glacial and fluvial erosion and weathering that shaped the underlying bedrock surface. Much of the irregular topography on the bedrock surface is attributed to fluvial erosion whereby paleo-drainage was focused along the bedrock for extensive periods of time, leading to the erosion of river valleys in the bedrock, that in some places were subsequently infilled with sediment. Generally, bedrock topography slopes from the north towards the south. Maps 2.6a-2.6c illustrate bedrock topography for each Conservation Authority. To generate these surfaces, high quality MOE well logs which penetrated bedrock were used.

2.7 BEDROCK GEOLOGY

The Study Area is underlain by a series of gently dipping Paleozoic sedimentary rocks consisting of deep-water shales interbedded with shallow water carbonate rocks (dolostone and limestone) and sandstone. These rocks are overlain by overburden sediments of variable thickness that were laid down after the last glaciation (~135,000 years ago; Eyles, 2002). Paleozoic rocks outcrop in the Study Area in only a few areas in the east near Hagersville; however, in the remainder of the Study Area these rocks are buried beneath a thick veneer of Quaternary-aged (2 million years to present) sediments. Dolostone and limestone of the Salina, Dundee, Lucas, Amherstburg, Onondaga, Bois Blanc and Bertie Formations underlie the Study Area, with shales of the Marcellus Formation subcropping areas along the north shore of Lake Erie. The bedrock geology of the Study Area was assembled by the Ontario Geological Survey (OGS) in 2001, and is presented on Maps 2.7a-2.7c.

2.7.1 Long Point Region Conservation Authority

The Long Point Region Conservation Authority is underlain by various bedrock units, whereas the Catfish Creek and Kettle Creek Conservation Authorities are underlain by the Dundee and Marcellus Formations exclusively. Note: portions of the following discussion were provided by GRCA from the LPRCA Watershed Characterization Report, which were referenced to be taken from the Long Point Region Groundwater Resource Inventory Project (WHI, 2003).

2.7.1.1 Salina Formation

The oldest Paleozoic bedrock subcropping beneath the Study Area is the Salina Formation deposited during the Upper Silurian roughly 420 million years ago (Johnson et al., 1992). This formation consists of interbedded shale, mudstone, dolostone, and evaporites (including gypsum and salt; Johnson et al., 1992). The Formation is subdivided into eight members designated by the letters A1, A2, B, C, D, E, F, and G (Hewitt, 1972; Johnson et al., 1992). Units A1, A2, B and D are mainly evaporite deposits of salt and anhydrite and are well developed in the subsurface in many areas of southern Ontario (Hewitt, 1972). Within the Long Point Region Conservation Authority, the Salina subcrops in the far northern reaches near Hagersville (Johnson et al., 1992), and outside the village of Springvale. In this area, gypsum is mined to produce wall-board and other related construction products (Johnson et al., 1992).

Groundwater associated with the Salina Formation is generally poor as the evaporite deposits (anhydrite, gypsum and salt) often cause undesirable sulphurous qualities including sulphate and/or hydrogen sulphide gas. Although water wells intersecting this formation may be high yielding, water from the Salina is primarily used for irrigation, and due to the poor and sulphurous water quality is seldom used for domestic water supply (Johnson et al., 1992).

The contact between the Salina Formation and the overlying Bertie/ Bass Islands Formation is conformable (i.e. parallel without interruption).

2.7.1.2 Bertie/ Bass Islands Formation

Subcropping south of the Salina Formation is the younger (Late Silurian) Bertie/ Bass Islands Formation. The Bertie Formation was deposited in the Michigan Basin, while the Bass Islands Formation was deposited at the same time in the Appalachian Basin. The interpretation of the lateral transition between these two basins is marked as a contact between the two formations; however, the transition is rather gradational (Johnson et al., 1992). As these two formations were deposited under very similar environments, they will be discussed as one. The Bertie/ Bass Island Formations form a narrow, 1-3 km wide band of oolitic and microsucrosic brown dolostone with minor thin beds of shaley dolostone along the northern edges of the LPRCA (Hewitt, 1972; Barnett, 1982; Johnson et al., 1992).

2.7.1.3 Oriskany Formation

The Oriskany Formation is a very small and localized (approximately 10 km east of Hagersville) pocket of coarse-grained, calcareous quartz sandstone with a thin conglomerate at the base (Johnson et al., 1992). The outcrop for this bedrock formation is located just outside the LPRCA, and for this reason, is not shown on Map 2.7a. This formation is restricted in outcrop and subcrop to a small (approximately 6 km^2) erosional depression that pinches out laterally between the underlying Bertie and the overlying Bois Blanc Formation (Johnson et al., 1992). It is estimated to have a maximum thickness of less than 6 m (Johnson et al., 1992).

2.7.1.4 Bois Blanc Formation

Resting stratigraphically above the Oriskany, or the Bertie/ Bass Islands Formations, is the Early Devonian Bois Blanc Formation. This formation consists of cherty brownish grey, fossiliferous limestone and is estimated to be roughly 3 to 15 m thick in the Study Area (Johnson et al., 1992). This unit is well exposed east of the Study Area where it forms the caprock of the Niagara Peninsula's Onondaga Escarpment (Johnson et al., 1992).

The Devonian-aged Bois Blanc Formation and the overlying Silurian-aged Bass Islands are separated by a major regional unconformity (Hewitt, 1972; Johnson et al., 1992). This feature may be significant from a hydrogeologic perspective as the upper surface of the Bois Blanc is interpreted to be weathered, highly fractured and therefore, able to transmit greater volumes of water than the more competent rock at depth.

2.7.1.5 Detroit River Group

The Detroit River Group stratigraphically overlies the Bois Blanc Formation and extends through Norwich, and Otterville, beneath Waterford eastward to Lake Erie. Within the LPRCA, this Middle Devonian formation consists of the Lucas Formation, a microcrystalline limestone, and resting conformably below the Lucas is the Amherstburg Formation, a crinoidal limestone and dolostone (Johnson et al., 1992). The Lucas Formation pinches out near the town of Port Dover, and in this area the Amherstburg Formation is unconformably overlain by the Dundee Formation (Johnson et al., 1992).

2.7.1.6 Dundee Formation

The Dundee Formation is a grey to brown fossiliferous limestone that lies stratigraphically beneath the Detroit River Group. This formation extends across the Long Point Region, Catfish Creek and Kettle Creek Conservation Authority regions, and beyond. In the Dunnville area, the Dundee Formation is described as brown, medium-bedded, fine-grained, weakly cherty, and poorly fossiliferous (Barnett, 1978). In the Tillsonburg area, the Dundee was described as consisting of an upper medium brown microcrystalline limestone above a crinoidal limestone with quartz sand grains and chert (Barnett, 1982). The Dundee Formation is the subcrop strata across much of the central portion of the Study Area and is buried beneath Quaternary sediments throughout the majority of the Study Area; however, it outcrops along Black Creek, Nanticoke Creek, a small area just north of the town of Nanticoke, as well as the Lake Erie shoreline between Port Dover and Nanticoke.

Within the Study Area, several karst features were mapped in association with the Dundee Formation (Barnett, 1978). Karst is a distinctive type of topography or terrain, formed primarily by the dissolution of carbonate rocks, such as limestone or dolostone, by groundwater. In areas near Port Dover, the mildly acidic groundwater reacts with carbon dioxide in the atmosphere and soil, and enlarges the openings in the Dundee Formation limestone, creating a subsurface drainage system. As more and more surface drainage is diverted underground, streams may disappear and become replaced by closed basins called sinkholes. Barnett (1982) mapped several sinkholes in the field, up to 15 m in diameter and 8 m deep. From a hydrogeological standpoint, bedrock aquifers in these karstic areas are highly susceptible to groundwater contamination as the aquifers receive recharge from the surface through the soil, as well as concentrated recharge from surface streams and drains that flow directly into the aquifer at sinks and sinkhole drains.

2.7.1.7 Marcellus Formation

The youngest Paleozoic bedrock formation to subcrop beneath the Study Area is the Marcellus Formation. This formation is restricted to the southwestern portions of the Study Area on the north shores of Lake Erie where it conformably overlies the Dundee Formation. The Marcellus Formation is described as a black, organic-rich shale, with a few minor, thin, impure carbonate interbeds (Barnett, 1982; Johnson et al., 1992). The Marcellus Formation marks a sharp change in the bedrock from older carbonate-dominated bedrock to shale-dominated strata (Johnson et al., 1992). North of the Lake Erie shorelines, the Marcellus Formation varies in thickness between 3 and 15 m along a narrow (approximately 20 km wide) belt (Barnett, 1993).

2.7.2 Catfish Creek and Kettle Creek Conservation Authority

The bedrock geology beneath the Catfish Creek and Kettle Creek Conservation Authorities consists of Middle Devonian Michigan Basin (Dundee Formation) and Appalachian Basin (Marcellus Formation) sedimentary rocks, and the Hamilton Group subcrops in a small portion of the Kettle Creek Conservation Authority. Bedrock does not outcrop within either watershed as a thick layer of Quaternary sediments (30 m to 140 m) covers the bedrock. Bedrock geology across the Watersheds is shown on Maps 2.7b-2.7c.

2.7.2.1 Dundee Formation

The Dundee Formation is the oldest bedrock unit in the watershed, and it subcrops throughout most of the northern portions of the two watersheds. The Dundee Formation is characterized as a fossiliferous limestone with bituminous partings and chert nodules (Johnson et al., 1992). The rocks are interpreted to have formed in depositional environments ranging from lagoonal to open shelf and deep water (Johnson et al., 1992). In Ontario, the average thickness of the Dundee Formation ranges from 35 to 45 m. Both Singer et al. (1997) and MacRitchie et al. (1994) identified the Dundee Formation as a major hydrogeologic unit stretching across Ontario. As a regional aquifer, well yields depend on secondary permeability, created through enhanced porosity resulting from fracturing, dissolution, dolomitization, etc. Relatively high well yields observed in the top 1.5 m of the Dundee Formation suggest that flow is confined to joint and fracture zones developed as a result of differential glacial stresses (Schwartz, 1974).

2.7.2.2 Marcellus Formation

The Marcellus Formation, which conformably overlays the Dundee Formation, subcrops throughout the southern portion of the watershed between the town of Aylmer and the Lake Erie shoreline. The Marcellus Formation within southwestern Ontario has been characterized as a black, organic-rich shale with grey shale interbeds and sparse fossils. The Formation was deposited in a marine environment with a stratified water column and can range up to 12 m in thickness (Dillon, Golder, 2004; Johnson et al., 1992).

2.7.2.3 Hamilton Group

The Dundee Formation is overlain by the Hamilton Group along the western edge of the Kettle Creek Conservation Authority boundary. There is a sharp, erosional contact between the Hamilton Group and the Dundee Formation. The Marcellus Formation conformably overlays the

Dundee Formation along the southern boundary of the watershed, between St. Thomas and Lake Erie.

The Hamilton Group comprises six distinct units which primarily consist of mudstone and shale with thin, impure, lateral carbonate horizons (Johnson et al., 1992). The overall thickness of the Hamilton Group can reach up to 80 m (Dillon and Golder, 2004).

2.8 QUATERNARY GEOLOGY

Quaternary-aged overburden sediments within the Study Area provide a detailed record of glacial and interglacial events that took place throughout the most recent glaciation (Wisconsinan Glaciation). During the Late Wisconsinan stage, glacial ice advanced into the lower Great Lakes region (stades; the Nissouri, Port Bruce, and Port Huron Stades). These stades were separated by two periods of temporary ice retreat (interstades; the Erie and Mackinaw Interstades).

Table 2.4 presents a list of the Quaternary sediments identified in the Study Area, their distribution, and the general time period in which the deposits were laid down. Maps 2.8a-2.8c, show the spatial distribution of these units at surface across the watersheds.

Table 2.4 - Quaternary Deposits Located Within the LPCRA Study Area

*Age (y.b.p)**	*Glacial Stage*	*Substage*	*Glacial Stade/ Interstade*	*Associated Deposits*
5000-11,500	Wisconsinan	Late Wisconsinan	Holocene/ Recent	Modern alluvium, organic deposits, Long Point spit, Eolian sand dunes
11,500-12,000			Twocreekean Interstade	Shoreline Formation Glaciolacustrine Deposition
12,000-13,200			Port Huron Stade	Wentworth Till, Norfolk Sand Plain, Haldimand Clay Plain
13,200-14,000			Mackinaw Interstade	Paris/ Galt Moraines
14,000-15,500			Port Bruce Stade	Port Stanley Till, Glaciolacustrine Deposits
15,500-18,000			Erie Interstade	Glaciolacustrine Deposits
18,000-25,000			Nissouri Stade	Catfish Creek Till
25,000-53,000	**Middle Wisconsinan**		Undifferentiated tills and deposits	

* y.b.p. represents number of years before present

During the Wisconsinan glacial period (115 to 7 ka before present), a continental-scale glacier termed the Laurentide Ice Sheet repeatedly advanced and retreated through Ontario, extending southward into Ohio and Indiana in the United States (Barnett, 1992). The ice front advanced forward during cold periods (glacial stades) and retreated when the climate temporarily warmed (glacial interstades) leaving behind a complex subsurface sedimentological record. As the Laurentide advanced over southern Ontario, it scoured the Paleozoic bedrock surface and reworked the vast majority of pre-existing glacial and interglacial sediments. Within the Study Area, advance of ice during the Late Wisconsinan essentially erased over 250,000 years of climatic history (period of time between the deposition of the Paleozoic rocks (350 ka) and the deposition of pre-Wisconsinan overburden sediments (100 ka b.p.). Within the LPRCA Study Area, the glacial events of the Late Wisconsinan and their resulting deposits are the most common and extensive. These deposits are summarized in Table 2.4, are illustrated on Maps 2.8a-2.8c, and are discussed in detail below.

The Late Wisconsinan lasted from 23,000 years ago (23 ka) to 10,000 years ago (10 ka; Dreimanis and Goldthwait, 1973). This period is divided into several different stades and interstades, and it was during this period that the Laurentide Ice Sheet reached its most southerly extent, advancing through Ontario extending into the United States. It was also during the Late Wisconsinan that the Laurentide thinned and formed a series of sublobes, each moving independently of one another at different rates, and in different directions. Each of these sublobes deposited a series of distinct subglacial tills and associated landforms within the Study Area. Overburden within the Study Area was predominately deposited by the Erie sublobe, or at times by the Ontario-Erie sublobe, when the two sublobes temporarily amalgamated.

The discussion of Quaternary deposits found within the Study Area progresses chronologically from oldest to youngest deposits, with a summary timeline including the glacial substages, stades/ interstades and deposits illustrated in Table 2.4.

2.8.1 The Nissouri Stade and Sedimentary Deposits

The Nissouri Stade (25 to 18 ka) represents the initial stage of advance of the Laurentide Ice Sheet during the Late Wisconsinan (Barnett, 1982; 1992). It was during this time period that the Laurentide Ice Sheet last moved as one thick cohesive ice sheet, depositing the most extensive subglacial till sheet in southern Ontario; the Catfish Creek Till (deVries and Dreimanis, 1960; Barnett, 1978; 1992; 1993). The Catfish Creek Till has been mapped in areas across southern Ontario including the nearby areas of Port Talbot (Dreimanis, 1958), St. Thomas (Dreimanis, 1964), Brantford (Cowan, 1972), London (Fenton and Dreimanis, 1976), and Tillsonburg (Barnett, 1982). The till is composed of stacked layers of subglacial lodgement till as well as stratified glaciofluvial and glaciolacustrine sediments and supraglacial till layers and lenses (Dreimanis, 1982; Barnett, 1992). The till is described as a gritty sandy silt till, highly calcareous (approximately 80% carbonate clasts; Barnett, 1982), and it is often described as hardpan in water well drillers' records because of its stoniness and hardness (Barnett, 1978; 1982; 1992). The maximum observed thickness in an outcrop exposure was 2.5 m; however tills of similar description in borehole logs record thicknesses of up to 23 m (Barnett, 1982).

The till occurs primarily as a buried till plain across the Long Point Region, Catfish and Kettle Creek Conservation Authority jurisdictions; however, in the Long Point Region it outcrops along the Tillsonburg Moraine and on selected drumlins in the northeastern portion of the Study Area near Hagersville (Barnett, 1978; 1982).

Within the Catfish Creek Conservation Authority, the Catfish Creek Till outcrops near the community of Sparta and within the Lake Erie bluffs near Port Talbot. The till comprises several layers of subglacial till, stratified sediments of glaciofluvial and glaciolacustrine origin, and supraglacial till layers and lenses (Barnett, 1992). Within the vicinity of the Catfish Creek Conservation Authority, Catfish Creek Till has a reported thickness of 15 to 61 m (Schwartz, 1974). The interlobate Sparta Moraine, located along the central watershed divide between Catfish Creek and Kettle Creek Conservation Authorities, may have been formed in part during the initial advance of the glacial ice lobes during the beginning of the Nissouri Stade (Barnett, 1992).

Within the Kettle Creek Conservation Authority, Catfish Creek Till outcrops near the community of Sparta and occurs as buried till beneath much of the remainder of the Conservation Authority. Within the Kettle Creek Conservation Authority, Schwartz (1974) estimates the Catfish Creek Till to have a thickness of 15 to 61 m.

2.8.2 The Erie Interstade and Sedimentary Deposits

Following the Nissouri Stade, the climate warmed and this triggered the onset of the Erie Interstade (16.5 ka and 15.5 ka; Dreimanis and Goldthwait, 1973). It was during this period that the ice margin of the Erie-Ontario lobe retreated eastward to the Niagara Escarpment (Dreimanis and Goldthwait, 1973) leading to the formation of a series of large ice contact lakes at the southern ends of Lakes Michigan, Erie and Huron (Barnett, 1992).

Within the Study Area, elevated lake levels in the Lake Erie basin caused portions of the Study Area to be inundated, and a blanket of fine-grained silts and clays was deposited on top of the Catfish Creek Till mentioned above (Barnett, 1982; 1992). Although subsequent ice advances may have removed substantial portions of the Erie Interstade sediment record, the fine-grained nature of the overlying tills (e.g., Port Stanley Till) suggests the ice lobes were overpassing and reworking previously deposited glaciolacustrine mud (Barnett, 1993).

Within the Catfish Creek and Kettle Creek Conservation Authorities, the Catfish Creek Till and the overlying Port Stanley Till are separated by a discontinuous layer of glaciolacustrine sediments that are up to 4 m thick and texturally vary from well-sorted sand to clay (Schwartz, 1974). These sediments are interpreted to have been laid down during the Erie Interstadial.

2.8.3 Port Bruce Stade and Sedimentary Deposits

The Port Bruce Stade (approximately 14-15.5 ka) records the second advance of the Laurentide Ice Sheet into the United States during the Late Wisconsin. In the early stages of the Port Bruce Stade, the southward advancing Laurentide Ice Sheet blocked the drainage outlet for the Lake Erie basin leading to the formation of a large glacial lake (Lake Leverett) in the Erie basin. This led to the deposition of glaciolacustrine silts and clays in some portions of the Study Area including the town of Bayham (Barnett, 1982). As the ice continued to advance southward, the Ontario and Erie ice sublobes coalesced and overrode (and incorporated) fine-grained glaciolacustrine sediments deposited during the Erie Interstade. This led to the subglacial deposition of the Port Stanley Till as the ice sheet moved radially outward from the centre of the Lake Erie basin across the Study Area (Barnett, 1982; 1992).

The Port Stanley Till is described as a silt to clayey silt till with few clasts (Barnett, 1982). Within the Study Area, the `till complex' consists of up to 5 layers of subglacial till separated by glaciolacustrine sediments resulting from lake level fluctuations within the Lake Erie basin (Barnett, 1982; 1992). Further inland, the Port Stanley Till consists of only one layer of subglacial till with associated glaciofluvial sediments (Barnett, 1992).

The Port Stanley Till is buried beneath younger glaciolacustrine sediments across most of the Long Point Region; however it outcrops north of Tillsonburg (Barnett and Girard, 1982). The Till also makes up the vast majority of the end moraines within the Long Point Region including (from oldest to youngest) the St. Thomas, Norwich, Tillsonburg, Courtland and Mabee Moraines (Barnett, 1993). These moraines were formed as the Erie-Ontario ice lobe advanced from southeast to northwest towards the Ingersoll Moraine (northwest of the Study Area; Barnett, 1982; 1993). Fluctuations and minor standstills in the ice advance led to the formation of each of the moraines at different times throughout the Port Bruce Stade. Also at this time glacial meltwater became ponded between the front of the glacier and the recently constructed end moraines. This led to the deposition of the fine-grained glaciolacustrine sediments on top of the Port Stanley Till in the northwest portions of the Study Area (Barnett, 1982).

The recession of the Erie lobe toward the southeast into the Lake Erie and Ontario basins also formed the end moraines present in the Catfish Creek and Kettle Creek Conservation Authorities including the Ingersoll, Westminster, St. Thomas, Norwich and Tillsonburg Moraines. These moraines mark either positions of standstill or minor re-advances of the ice margin.

Within the northern portions of the Catfish Creek Conservation Authority the Port Stanley Till is the dominant surficial unit. The older, basal portion of the Port Stanley Till was deposited during the initial advances of the Erie Lobe. Previously deposited glaciofluvial sand and gravel and bedrock clasts were incorporated into the till. The younger overlying till units were deposited during retreat cycles of the Erie ice lobe. This generated a depositional environment of subaquatic flow in glaciolacustrine conditions and produced lacustrine silt and sand interbeds within the Port Stanley Till (Dillon and Golder, 2004).

2.8.4 The Mackinaw Interstade and Sedimentary Deposits

The Mackinaw Interstade took place from approximately 13.5 ka to 14 ka and the onset of this Interstade was characterized by the rapid retreat of ice out of southern Ontario. The Ontario Erie lobe retreated into the Ontario basin east of Toronto (Dreimanis and Goldthwait, 1973) blocking the drainage outlet for Lake Erie and Ontario. This led to the formation of a large lake within the Lake Erie basin with lake levels significantly higher than those seen today. The first lake was termed Glacial Lake Maumee, and it was followed by Glacial Lake Arkona (Barnett, 1992). There are very few sediments associated with Glacial Lake Maumee and none on record within the Study Area for Glacial Lake Arkona, likely due to their reworking by overlying glaciolacustrine sediments (Barnett, 1982). One shoreline bluff associated with Lake Maumee was reported to lie on top of eroded Port Stanley Till along the top of the Tillsonburg Moraine (Barnett, 1982) in the Long Point Region.

2.8.5 The Port Huron Stade and Sedimentary Deposits

The Port Huron Stade took place from approximately 13.5 ka to 13 ka, when the Laurentide Ice Sheet advanced for the last time through southern Ontario depositing the Wentworth Till and the Paris and Galt moraines. The Wentworth Till is the youngest till located in the Study Area, and is commonly buried beneath glaciolacustrine sediments (Barnett, 1982); however, it outcrops in some areas northeast of Delhi along the Paris Moraine, in areas approximately 3 km north of Port Rowan, and in drumlins north of Hagersville (Barnett, 1978). The Paris Moraine marks the maximum southwestern extent of the Port Huron ice (and the Wentworth Till), and therefore this till is restricted to areas east of the Paris Moraine. Within the Study Area, the Wentworth Till is described as a stony, silt till that coarsens inland, as the ice lobe overrode and incorporated fine-grained glaciolacustrine sediments of the Lake Erie basin before advancing westward into the Study Area (Barnett, 1992; 1993). As mentioned earlier, the Paris and Galt moraines are not well exposed in the Study Area as younger glaciolacustrine sediments have largely buried these two features.

As the ice sheet began to withdraw from the Study Area, large glacial lakes were formed in the Lake Erie basin, with water levels much higher than the present day elevation of Lake Erie. Glacial Lake Whittlesey was formed, followed by Glacial Lake Warren, each flooding a large portion of the Study Area throughout the Port Huron Stade (Barnett, 1992). It was at the base of these lakes that the Haldimand Clay Plain was deposited in the Long Point Region and the extensive Norfolk Sand Plain was deposited across the three watershed regions (Barnett, 1982).

In the Long Point Region, the Haldimand Clay Plain was deposited in the east as fine-grained silts and clays settled to the bottom of the deep lake basin. In the Catfish and Kettle Creek Conservation Authorities, the Ekfrid Clay Plain was laid down under calm conditions where the fine-grained suspended sediment settled out onto the lake floor.

The sandy Norfolk Sand Plain lies across the watershed regions and forms an extensive surficial feature deposited when the sediment laden Grand River (historic alignment) emptied into the deep glacial lake. The Grand River deposited a deltaic sequence of sands and silts throughout the western portion of the region at the front of the eastward retreating ice front (Chapman and Putnam, 1984). Sands of the Norfolk Sand Plain are described as fine to medium-grained, ranging in thickness from less than 1 m, to roughly 27 m (although this estimate may include deeper, and older sands; Barnett, 1982). As the levels in Lake Whittlesey were much higher than the present day, the moraines evident in the (north)western portions of the Study Area acted as 'islands' in an otherwise flooded terrain. The extent of Lake Whittlesey can essentially be mapped by the presence or absence of surficial sand deposits. Where sand exists, the land was inundated by water, and where sand does not exist (such as the crests of the local end moraines) these areas remained above water. It was also during the retreat of the Port Huron ice that the drumlin field located north of Hagersville was deposited (Dreimanis and Goldthwait, 1973).

Within the Catfish and Kettle Creek Conservation Authorities, the Norfolk Sand Plain is located across the southern portions of the region and it continues northward along the eastern boundary of the Catfish Creek watershed. The Norfolk Sand Plain forms an important aquifer across the area and is extensively used for private groundwater supply.

As the water elevation in the Lake Erie basin dropped from the level of Lake Warren, new glacial lakes formed in the basin each with a different shoreline and associated deposits (Barnett, 1992). Although the high waters of several of the glacial lakes are believed to have covered up to half of the Study Area, post- Whittlesey and Warren shoreline features are rare (Barnett, 1982).

2.8.6 Twocreekean Interstade and the Greatlakean Stade and Sedimentary Deposits

The Twocreekean Interstade represents a period of continued ice retreat out of southern Ontario, which began approximately 12,500 years ago (Barnett, 1992). Ice marginal lakes began to drain as the retreating ice uncovered drainage outlets. Separate lakes formed in the Lake Ontario (Lake Iroquois) and Lake Erie (Early Lake Erie) basins, and Lake Huron and Lake Michigan merged to form one large lake, Lake Algonquin. Minor oscillations of the ice front during the Greatlakean Stade led to the deposition of localized tills in northern Ontario, but by this time, the ice front had fully retreated from the Study Area.

2.8.7 Holocene Deglaciation and Sedimentary Deposits

The Holocene began roughly 10,000 years ago and at this time, Ontario was still undergoing massive deglaciation throughout much of the north. Lake Superior was still covered with ice, as were the areas now home to the cities of North Bay and Timmins (Barnett, 1992). Isostatic depression of the North Bay area allowed the upper Great Lakes to drain through the Ottawa River, resulting in lower water levels in the Great Lakes than those seen today. From this point in time to the present day, the lake basins have rebounded and the lake levels returned to those found in the Great Lakes today.

Postglacial and erosional processes during the Holocene continued to work to shape the landscape within the Long Point Region. The 40 km long Long Point sand spit began to form in Lake Erie roughly 7,600 years ago when coarse grained sediments were carried by long shore currents from the west, and this process has continued ever since (Stenson, 1993; Davidson-Arnott and Van Heyningen, 2003). Most sand spits or peninsulas become eroded or separated from the mainland during storms or high water events (Davidson-Arnott, 1988) and the distance between the Long Point sand spit and the mainland will continue to fluctuate with time as deposition and erosion rates fluctuate with the climate.

In the Tillsonburg area of the Long Point Region, portions of the Norfolk Sand Plain have been modified to varying extents throughout the Holocene by the wind as it forms large dunes, some reaching 6 m high (Barnett, 1982). In addition, modern alluvial deposits are scattered throughout the Study Area and are associated with Big Creek, Big Otter Creek and the Grand River (Barnett, 1993).

2.9 OVERBURDEN THICKNESS

Overburden thickness is important to review as it provides an indication on the relative protection of deeply buried overburden and bedrock aquifers. Overburden thickness and grain size distribution of those sediments control the infiltration rate of precipitation, as well as the rate of movement of surface contamination into these aquifers.

Overburden thickness was derived by subtracting the bedrock topographic surface (see Section 2.6 above) from the ground surface digital elevation model (DEM). Maps 2.9a-2.9c show the distribution of overburden throughout the Study Area, and the maps illustrate the presence of moraines, incised river valleys and possible buried bedrock valleys.

Overburden thickness ranges from zero along some river valleys, to over 115 m in areas where the end moraines overlie thick till deposits. The thickest overburden materials are found in the vicinity of Straffordville, Vienna, Port Burwell and Port Rowan, all located in the southern regions of the Study Area along the Lake Erie shoreline. In addition, the thicknesses of the St. Thomas, Sparta, Norwich, Tillsonburg and Paris Moraines located are also readily identifiable on this map.

2.10 HYDROGEOLOGY

To a large extent, the regional groundwater flow system in the Study Area is a reflection of the ground surface topography. Groundwater moves from areas of high hydraulic head to areas of low hydraulic head, generally following topographic relief, unless it is impeded by geologic conditions, or local changes in relief such as stream valleys that intersect the water table. In areas where rivers, streams or wetlands intersect the water table, groundwater discharges into the stream or river and contributes baseflow to the surface water feature.

A portion of the water arriving at the surface as precipitation or runoff from upslope infiltrates into the soil and is either stored, as soilwater storage in the root zone, or percolates downward until it reaches the water table. Areas where water moves downward from the water table are known as recharge areas. These areas are generally in areas of topographically high relief. The rate and scale of recharge and discharge are variable. Water can discharge to local surface water features or travel great distances from its source of recharge.

Understanding the movement of groundwater through the subsurface, and interactions with surface water features, requires an understanding of the three-dimensional geometry of aquifers (water bearing units) and aquitards (confining units) as well as key recharge areas.

2.10.1 Conceptual Hydrostratigraphy

Conceptual hydrostratigraphic cross-sections and models provide a technical basis for the development of numerical groundwater flow models. The conceptual hydrostratigraphy is based primarily on the geology reported in borehole logs, the majority of which are from MOE water well records. Hydrogeologic characterization involves understanding the lateral and vertical extent, and subsequent interconnection of the aquifer and aquitard units along with their representative hydrogeologic characteristics. The extent and interconnection, or lack thereof, of the aquifer units can be a significant factor in determining the availability of groundwater for anthropogenic (i.e.

human) use and potential impacts from withdrawal. Within the Long Point Region Study Area, the Quaternary overburden sediments are highly complex and multiple conceptual hydrostratigraphic models exist. One such model was presented by Barnett (1982), and a conceptual cross-section through the Tillsonburg area is presented in Figure 2.1 below.

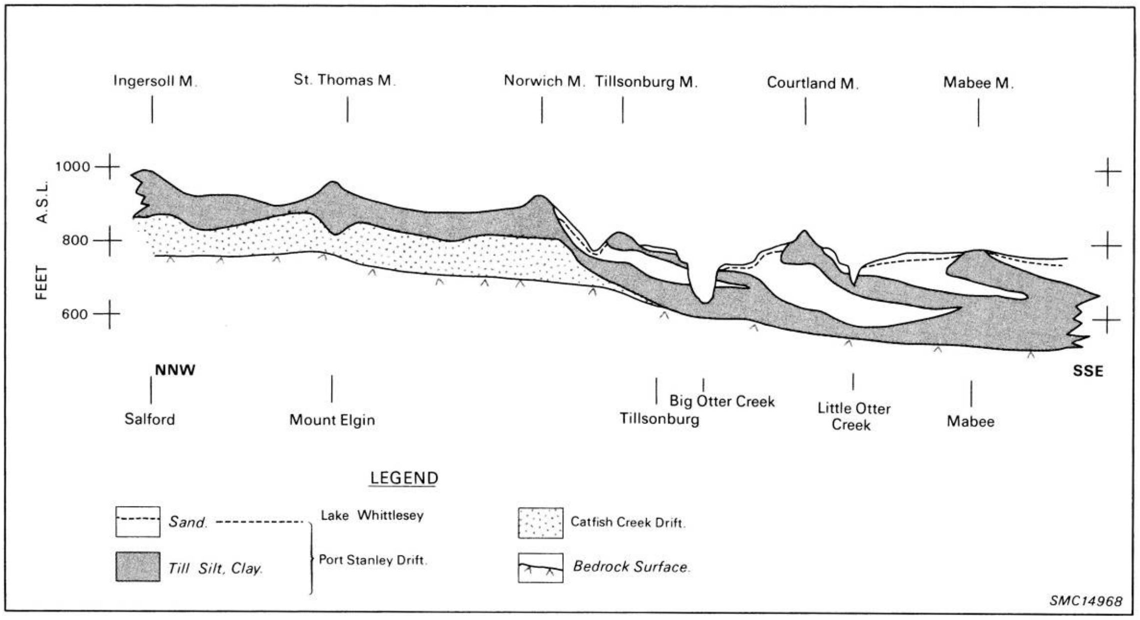
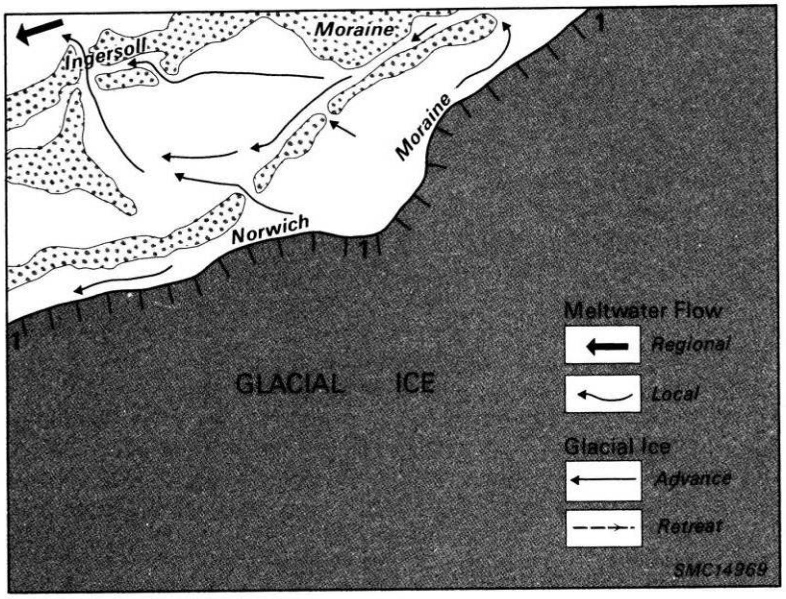
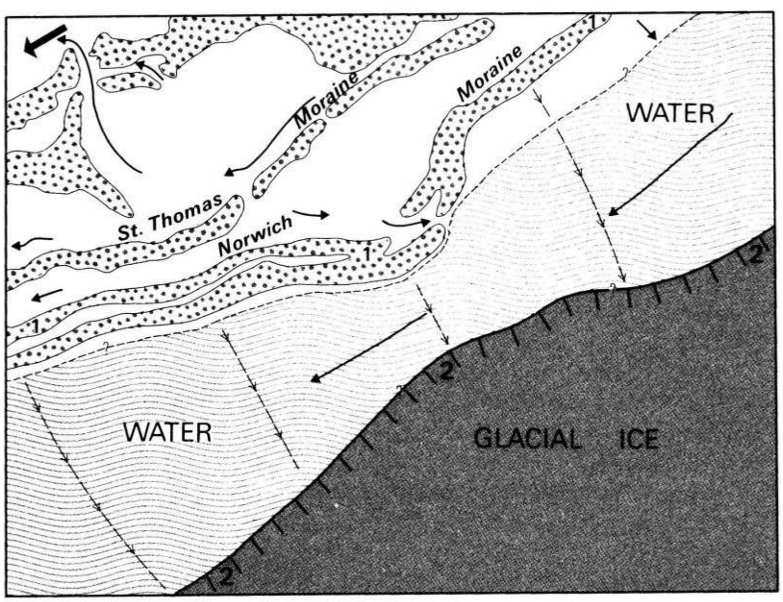


Figure 2.1 - Conceptual Stratigraphic Cross-Section for the Tillsonburg Area (Barnett, 1982)

The cross-section presented in Figure 2.1 extends from the Ingersoll Moraine north-northwest of Tillsonburg to the Mabee Moraine to the south-southeast. The cross-section was constructed utilizing water well records. Barnett (1982) hypothesized that the two moraines were formed during advances of a fluctuating ice margin, fronted by a glacial lake (Port Huron Stade – see section 2.8.5). The cross-section illustrates the wedge-shaped bodies of the deltaic and glaciolacustrine sands with the upper Lake Whittlesey sand unit representing the surficial Norfolk Sand Plain. Barnett (1982) presents the glacial chronology as it relates to the individual moraines, ice front locations and glacial water in Figures 2.2-2.3. These figures illustrate the location and direction of meltwater flow from the front of the glacier, and parallel to the end moraines which formed during successive glacial advances and retreats. This process is hypothesized to have created the stratigraphic layer structure illustrated in Figure 2.1.

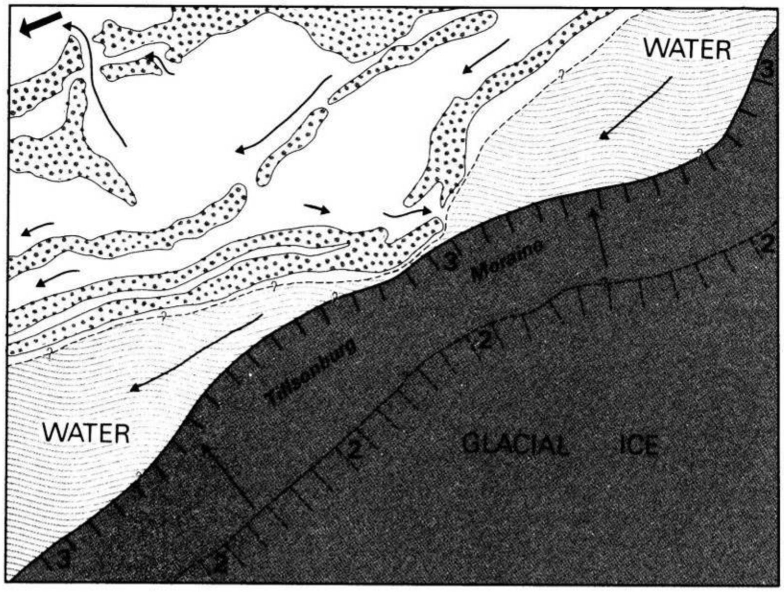


Meltwater drained northward during the retreat of the ice front from the Ingersoll Moraine to the Norwich Moraine positions.

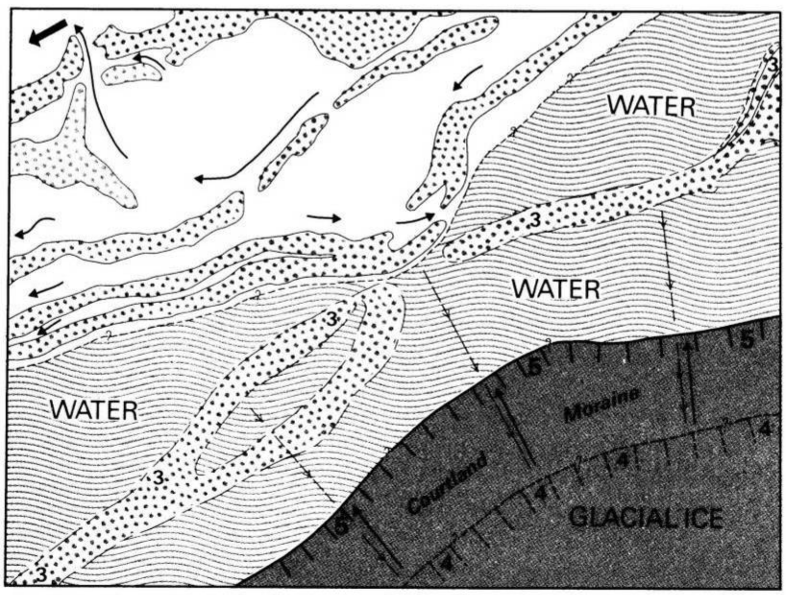


Once the ice front retreated from the Norwich Moraine, drainage in the area south of the St. Thomas Moraine was to the south into a glacial lake in front of the ice.

Figure 2.2 - Glacial Chronology (Barnett, 1982)



A minor readvance of the glacier from position 2 to position 3, overrode deltaic sands deposited in the proglacial lake and formed the Tillsonburg Moraine.



The ice front retreated to approximately position 4 and the lake level probably lowered. The ice readvanced to position 5 to form the Courtland Moraine, again overriding the deltaic sand. Submerged portions of the Tillsonburg Moraine are delineated by dashed boundaries.

Figure 2.3 - Glacial Chronology (Barnett, 1982)

The schematic section generalizes the location of the Catfish Creek and Port Stanley Till units and the sand unit. The wide variety of glacial processes which formed these units have been discussed previously (Barnett, 1982; Barnett, 1992), and are outlined in Section 2.8. These processes give rise to hydrostratigraphic deposits that are variable both laterally and vertically, particularly within the ice contact environment. Within the Long Point area several glacial and interglacial environments were present leading to the deposition of subglacial, glaciofluvial, and glaciolacustrine deposits.

Glaciofluvial sedimentation at the ice contact environment is subject to extreme spatial and temporal variability arising from the high variability in the amount and velocity of glacial meltwater discharge at the front of the glacier. Morphological structures can include ice-marginal deltas, subaqueous fans, eskers, kames, crevasse fillings and kame terraces for example. These structures can be highly variable and in some cases produce well sorted deposits, but will generally be limited spatially. Outwash deposits are commonly laid down beyond the ice margin, and on a larger scale can be quite variable due to; (1) varying sediment loads dependent on the amount of meltwater being generated, (2) the channels continually shifting across an alluvial plain and (3) and gradation of coarse grained to fine grained deposits as one moves away from the ice margin into the ice distal environment. Grain size variations in outwash deposits are generally more latterly consistent that in ice contact deposits.

There are two types of glaciolacustrine environments; ice proximal (glacial ice in contact with the lake) and distal (ice is further away from the lake, and meltwater carries sediment into the glacial lake). Sediments laid down in a proximal ice environment are generally coarser-grained and more poorly sorted than those laid down in the distal environment. In both instances, the deposition of sediments is affected by the characteristics of the meltwater, such as the discharge variations, temperature and density of the waters, and the sediment loads.

Meltwater streams entering glacial lakes can produce deltaic structures with the coarsest material lying at the mouth of the delta, and the finer material deposited further from the meltwater source. Rhythmites are the most common deposit in glacier fed lakes (Barnett, 1992). Rhythmites consist of a sand silt base layer that is overlain by a silt clay layer. The grain size that dominates the rhythmite and the varying thicknesses for the layers depends on various factors including whether or not the lake is stratified by temperature or density, the bathymetry of the lake, and the sediment input. Barnett, 1998 presented sediment correlations along the Lake Erie bluffs distinguishing sand, silt and clay dominated rhythmites among other units. Lateral correlation of various units was on the order of kilometres in some cases.

Glaciolacustrine deposits at the ice-contact environment include subaqueous fans, flowtills and debris flows. Ice margin calving produces icebergs which can scour and disturb lake bottom sediments, and glacial debris (dropstones) are commonly dropped from the ice bergs into the sediments below.

The preceding discussion was presented to outline the glacial processes that may have been at work within the Study Area, and it demonstrates the potential for spatial variability in layer thickness, lateral extent and grain size predominance. The deposits described above could exist in the Study Area in their initial state or they may have been overridden by the ice front during glacial re-advancement. The re-advancement could redistribute portions of the of the glaciolacustrine and glaciofluvial units or incorporate these material within overlying subglacial deposits.

Where we may correlate larger more extensive layers of either fine grained till, silt or clay (aquitards) or coarser grained sand and gravel units (aquifers) the detailed smaller scale variations in the stratigraphy play a more dominant role in the hydrostratigraphy. Within the generalized Tillsonburg cross-section the fine grained Port Stanley drift may not be continuous in places and there are likely connections between upper and lower sand units (Barnett, Bajc, pers.com.). The same will hold true for the more permeable wedge shaped sand units in that there are existing fine grained silt and clay layers within this unit that don't make the entire unit hydraulically connected but as Barnett (1982) points out there is more of a potential for aquifer(s) within these units and there is higher potential for hydraulic interconnectivity (Barnett, pers.com.).

The Tillsonburg conceptual stratigraphy and the glacial history which formed it are likely the most complex in the overall Study Area. For example to the east, on the Haldimand Clay Plain, the overburden is dominated by clays and silts. Throughout a majority of the Catfish and Kettle Creek Conservation Authorities the Catfish Creek and the Port Stanley Till (Drift) are the dominant fine grained layers, similar to the hydrostratigraphic setting in the north-northwest part of the Tillsonburg cross-section. In the south-east half of the Catfish Creek Conservation Authority and the southeast corner of the Kettle Creek Conservation Authority the hydrostratigraphy bears more resemblance to that of the south-southeast portion of the Tillsonburg cross-section. The incorporation of the more permeable sand and gravel within the Port Stanley Till is noticeable within the Catfish and Kettle Creek watersheds. Throughout the entire Study Area west of the Haldimand Clay Plain there is a good probability of discrete sand and gravel layers directly overlying the bedrock below the Catfish Creek, Port Stanley or Wentworth Till. The Wentworth Till is the more dominant Till east of the Paris Moraine (extending south to Lake Erie west of Long Point) but it is noted that this till unit may also be a combination to varying degrees of Catfish Creek and Port Stanley Till (Bajc, pers.com.).

From a hydrogeologic standpoint, there are large variations in horizontal and vertical hydraulic conductivities within outwash, glaciolacustrine and ice contact glaciofluvial deposits due to the extreme variation in the environment under which the sediments are laid down. This variability means that hydraulic testing or properties completed on one portion of a deposit are unlikely to be representative of the conductivity across the entire deposit. Heterogeneities are known to exist within the Study Area; however, modelling such units requires a simplification of the system with bulk hydraulic conductivity values, as well as an understanding of the limitations of the characterization in such complex environments.

During the course of this study existing cross-sections were re-examined to correlate larger scale aquifer and aquitard features with the general glacial history and previous conceptualization in mind. Although some cross-sections demonstrated some of the general features illustrated in the conceptual section (Figure 2.1) it was evident that variability in the borehole logs did not consistently support large scale (5-10's of km) laterally continuous aquifer units (e.g. continuous sand unit at the Jacksonburg Delta along the Lake Erie shoreline east of Long Point as described in Barnett, 1998). There are likely a large number of discontinuous, smaller-scale (1-2 km), more permeable, hydrostratigraphic units. The vertical extent of these units range from metres to tens of metres. These units are likely hydraulically interconnected to varying degrees both in a deeper system and connected to ground surface. Given this discussion, the regional hydrostratigraphic model utilized for the westward expansion of the Norfolk County groundwater model (WHI, 2007), which does not represent this conceptualization, may not be entirely appropriate. It is expected that uncertainty in the conceptual model would impact the ability to predict local groundwater flow conditions. However, it is expected that the regional trends in groundwater flow, both for recharge and for deep groundwater flow, are reasonably represented within the current hydrostratigraphic interpretation.

2.10.2 Aquifer Units

The following sections outline the various aquifer units within each of the three Conservation Authority jurisdictions. The mapping and portions of the discussion were previously completed within the Ontario Geological Survey Groundwater Resources Inventory Project – LPRCA Pilot

Project (WHI, 2004) and The Groundwater Resources of the Catfish Creek Conservation Authority and Kettle Creek Conservation Authority (Strynatka et. al. 2006).

The location and spatial distribution of these aquifers has largely been based upon geologic and hydrogeologic information held within the MOE's Water Well Information System (WWIS), in combination with the knowledge of the glacial history of the area. High quality, geophysical logs have not been collected as part of this study. Cross-sections through the subsurface have been drawn across much of the Study Area for various water supply or groundwater related studies, and the discussion below touches on some of the information gained in these subwatershed and watershed scale studies.

2.10.2.1 Long Point Region Conservation Authority

Groundwater resources are found within both overburden and bedrock aquifers. Two overburden aquifers are located in the western portion of Long Point Region and one bedrock aquifer is utilized in the eastern portion of the region. In the eastern portion, an upper unconfined overburden aquifer consists of sand and gravel while the lower overburden aquifer is confined by lower permeability layers of silt and clay till. In the eastern extents of the region, in the vicinity of the Haldimand Clay Plain, the Dundee Formation is utilized as a productive aquifer as the clay-rich overburden sediments are not able to yield significant quantities of groundwater, even for domestic water supplies.

2.10.2.1.1 OVERBURDEN AQUIFERS

Overburden thickness and the geology of the overburden units within the Long Point Region are highly variable. Significant overburden aquifers are found in the western half of the Long Point Region, in the glaciolacustrine sands of the Norfolk Sand Plain where sand and gravel deposits can be over 10 m thick (WHI. and others, 2003). Two significant overburden aquifers are located in the vicinity of the Norfolk Sand Plain, one located within shallow sediments and one within deeper sediments. These two aquifers are typically separated by a layer of low permeability material; however, these low permeability sediments may be absent in some areas. The upper, shallow aquifer is unconfined and consists of sand and gravel deposits associated with the Norfolk Sand Plain. The water table surface for LPRCA is included in Map 2.10a.

Thick sequences of unconfined sand and gravel, associated with glaciofluvial deposits were identified west of Waterford (below water table gravel extraction and Waterford municipal water supply well(s)) and in the northeast corner of the Big Creek Watershed (Burford Area and south to include much of the subwatershed area designated as “Big Creek Above Kelvin Gauge”). These features in both of these areas are expected to be high recharge areas due to coarse sediments and are located astride or near (sub)watershed boundaries.

The Waterford area deposits contain several active and closed below water table gravel extraction pits. The deposits are estimated to be over 5 m deep, and the water table is estimated to be within 1.5 m of ground surface. Consequently, these ponds are expected to be hydraulically connected to the aquifer, which Waterford’s municipal supply wells draw upon.

The lower aquifer in this area is interpreted to grade from medium sand to fine sand, and pinches out east of the communities of Simcoe and Waterford where the Haldimand Clay Plain becomes the dominant overburden geologic formation (WHI. and others, 2003). In the Haldimand Clay Plain area, there is no evidence of an underlying sand layer (WHI. and others, 2003).

In the Big Creek Basin Study (Gamsby and Mannerow Ltd. et al., 2002), a conceptual model of three overburden aquifers (the lower one connected to bedrock) and two upper aquifers was developed. Based on updated understanding presented in Section 2.10.1, refinement of the conceptual model may be warranted in the Norfolk Sand Plain area and the Big Creek Watershed to reflect this refined understanding of the geologic setting.

Upper Unconfined Aquifer: The upper unconfined aquifer in the Big Creek drainage area is found throughout the watershed and generally extends beyond it over much of the Norfolk Sand Plain. Throughout much of the area it ranges from 2.5 to 10 m thick. At several locations it ranges from more than 10 to 20 m thick to more than 30 m thick. These areas include near Burford extending southerly to Four Ponds Corners (in Big Creek Above Kelvin subwatershed identified in Map 2.1), east of Delhi (source of Municipal water), in parts of the Venison Creek subwatershed and the reach of Big Creek from Walsingham to east of Delhi (see Map 2.1). Throughout much of the Big Creek drainage area, the fine-grained nature of the unconfined soils and/or the limited thickness of the upper unconfined aquifer results, with few exceptions, in low yield wells from this formation. The primary areas of exception in the Big Creek drainage area are east of Delhi and south of Burford and in a few small isolated locations as well as east of Waterford.

The upper aquifer occurs as an unconfined unit over much of the north and west portions of the region. The aquifer supports municipal wells for a number of communities. Thicknesses of the upper aquifer appear to range from <3 m to about 30 m. At the municipal wells in Otterville, the upper aquifer thickness is approximately 10 m and the aquifer essentially occurs at surface.

The upper aquifer is complicated and can be difficult to interpret near the contact between the surficial sand deposits associated with the Norfolk Sand Plain and the till deposits associated with the moraine located in the northwest part of the watershed region. An example of this is the Tillsonburg area where thicknesses of the surficial sand/gravel/silt (both saturated and unsaturated portions seem to range from almost zero to about 24 m. In some cross-sections, it appears that the till may overlie the upper aquifer, potentially leading to some confusion as to whether the aquifer should be included as part of the upper aquifer or part of an intermediate or middle aquifer.

Upper Aquitard: The upper aquitard consists of sandy silt and clay (glaciolacustrine deposits) (K= $10x10^{-7}$ to 1×10^{-9} m/s, WHI, 2003), ranges in thickness from 0 to 30 m thick and underlies the upper unconfined aquifer in the morainal areas of the Big Creek drainage area and in much of the area south of Delhi. It is absent in the same areas where the upper aquifer is more than 20 m thick so that the upper and intermediate aquifer are not separated in these areas. Where there is no underlying aquifer, the upper aquitard is underlain by bedrock.

Middle Aquifer: The middle aquifer is distributed discontinuously in the watershed and in places is not separated from the upper unconfined aquifer, where the total thickness of saturated aquifer is greater than about 20 m. The middle aquifer consists of medium sand under the western portion of the Big Creek drainage area, grading to fine sand or silty sand under the central portions of the watershed. Further to the east, the middle aquifer thins and grades into clayey sediments. The middle aquifer is absent at a number of locations, both where the upper aquitard is absent and where it is thick. It is most predominant in the southwestern and southeastern parts of the Big Creek drainage area. Potentially high yield wells (>200 L/min) are identified east of Delhi (municipal wells). From south of Kelvin, there is generally an upward gradient from the middle aquifer to the upper aquifer.

Lower Aquitard: The lower aquitard consists of similar soils as the other aquitards. It has limited extent, being primarily found south-west of Delhi and in the lower part of the Big Creek drainage area.

Lower Aquifer: The lower aquifer consists of medium sand and gravel at a number of isolated locations (primary locations: east of Burgessville, south of Burford, in central part of Venison Creek Subwatershed). It is often connected to upper bedrock. There is generally an upward gradient from the lower aquifer /bedrock complex into the overlying overburden units.

A regional water table elevation map, as produced from WHI, (2003) is shown Map 2.10a. This map is based on the static water levels in wells completed in overburden at depths less than 15 m and assumes unconfined conditions (WHI., 2003). The map was also augmented with the elevation of surface water streams and rivers to constrain the water table map. In general, the elevation of the shallow groundwater table is a subdued reflection of the ground surface topography. Water table elevations range from 330 masl in the north-western portion of Long Point Region, to 166 masl adjacent to Lake Erie. The groundwater gradient is also consistent throughout the area, except for steeper gradients in the areas of the deep river valleys of Big Otter and Big Creek river courses. Regionally, the direction of groundwater flow is southerly to southeasterly towards Lake Erie. Groundwater flow divides also generally follow surface water boundaries. Water table maps of the middle and lower aquifer were not generated by WHI (2003).

2.10.2.1.2 BEDROCK AQUIFERS

The occurrence and movement of groundwater in bedrock formations are governed by the rock type, structure and, in some cases, by the thickness and type of the overlying overburden. In sedimentary rocks such as those in Long Point Region, groundwater movement commonly occurs in weathered rock and fractures, and less commonly in crevices, vugs, and other pore spaces characteristic of carbonaceous (dolostone/limestone) rocks. The movement of groundwater through these features may improve permeability with time due to dissolution of minerals along bedding features and fractures; these solution features can be similar to karst-type processes.

Domestic bedrock wells within Long Point Region are typically completed into the upper 10 to 30 m of the Dundee Formation (Waterloo Hydrogeologic Inc. and others, 2003) especially in the eastern reaches of the watershed where the overburden comprises fine-grained Haldimand Clay Plain sediments. In other areas, including the Norwich municipal wells the bedrock wells are interpreted as being completed in the Detroit River Group.

The bedrock potentiometric surface, created using the reported static water levels of all the bedrock wells in the region, is illustrated on Map 2.12a. This map shows higher elevations (314 masl) are located in the northwestern portion of the Region, sloping towards lows (144 masl) adjacent to the Lake Erie shoreline. Groundwater flow direction in the bedrock is from north to south towards Lake Erie (Waterloo Hydrogeologic Inc. and others, 2003).

Under the Norfolk Sand Plain area, there is generally an upward gradient from the lower aquifer / bedrock into the overlying overburden units.

2.10.2.2 Catfish Creek Conservation Authority

The Catfish Creek watershed contains three aquifer units; shallow overburden, deep overburden and bedrock. Shallow overburden aquifers in this area are unconfined to semi-confined aquifers tapped by water wells that are completed less than 20 m below ground surface, whereas deep overburden aquifers are defined as wells completed over 20 m below ground surface. The development of these aquifer categories was developed from work completed by Dillon (2004) and Waterloo Hydrogeologic Inc. (2003).

An assessment of water well records within the Catfish Creek Conservation Authority indicates that approximately 90% of the water wells are completed in the shallow or deep overburden aquifers. This is expected as the overburden within the watershed is thick and reaches up to 135 m along the Sparta Moraine. Overburden thins along Catfish Creek to approximately 35 m in thickness.

The primary aquifer within the Catfish Creek Conservation Authority is a broad shallow unconfined sand and gravel aquifer located between Aylmer and Lake Erie. The deeper (greater than 20 m) confined overburden aquifers, are located in the central portions of the watershed within the basal portions of the Port Stanley Till where discontinuous sand and gravel lenses exist. A local aquifer is located near the community of Brownsville. These aquifer units were defined through work completed by Strynatka et al. (2006), Dillon (2004) and Waterloo Hydrogeologic Inc. (2003).

Within the Catfish Creek Conservation Authority, the most commonly used bedrock aquifer is the Dundee Formation. This carbonate aquifer is largely untapped as there are sufficient overburden groundwater resources in this watershed.

2.10.2.2.1 SHALLOW OVERBURDEN AQUIFER

The water table elevation surface represents groundwater conditions within the shallow aquifer under unconfined conditions. The water table surface can be used to identify shallow groundwater divides and the general flow direction of groundwater within the shallow overburden. Within the Catfish Creek Conservation Authority, the water table was generated from the static water level elevations of overburden wells that were completed less than 20 m below ground surface (Map 2.10b).

Map 2.10b indicates that shallow wells are generally associated with the surficial sand deposits located throughout the Catfish Creek Conservation Authority, primarily between Aylmer and Lake Erie. Shallow wells are clustered in these areas and sand and gravel deposits with a cumulative thickness greater than 2 m are common in these areas. There are very few shallow overburden wells in the central portion of the watershed and along the western boundary with the Kettle Creek Conservation Authority as the upper aquifer is absent in this area. The upper 20 to 30 m of overburden is interpreted to be Port Stanley Till and similar fine-grained sediments. Due to the lack of data across the watershed boundaries between Catfish Creek and Kettle Creek, it is not possible to determine if a shallow groundwater divide exists between the two watersheds.

Map 2.10b indicates that water table elevations vary from approximately 290 masl across the northern portions of the watershed to 170 masl along Catfish Creek and the Lake Erie shoreline. Shallow groundwater flow is predominantly from north to south towards Lake Erie, with local shallow flow influenced by Catfish Creek.

2.10.2.2.2 DEEPER OVERBURDEN AQUIFER

Static groundwater elevations within the deep overburden sediments were used to generate a potentiometric surface for the deep aquifer unit. General groundwater flow directions and groundwater divides within the deep overburden can be inferred using the interpreted surface. The deep overburden potentiometric surface was generated by interpolating a surface of all static water levels in overburden wells completed more than 20 m below ground surface. Map 2.11a illustrates the deeper overburden potentiometric surface. The deep overburden unit is considered to be semi-confined to confined yet the general groundwater flow directions are very similar to the water table surface whereby the dominant groundwater flow direction is from north to south towards Lake Erie. Flow directions within the southern half of the watershed are also locally influenced by Catfish Creek. There is also evidence of a groundwater divide located along the surface water divide between the Catfish Creek and the Kettle Creek Conservation Authorities. This groundwater divide is located west of the surface water divide in the southern portion of the Catfish Creek watershed (south of Aylmer). As shown on Map 2.11a, overburden potentiometric surface elevations vary from approximately 290 masl across the north of the watershed to 150 masl along Catfish Creek and the Lake Erie shoreline.

The deeper overburden hydrostratigraphic unit includes spatially discontinuous sand and gravel deposits related to lenses within the Port Stanley Till and the underlying Catfish Creek Till. Sand and gravel units that lie at depths greater than 20 m are generally less than 5 m thick.

2.10.2.2.3 BEDROCK AQUIFER

Static groundwater elevations measured within the bedrock water wells were used to develop the bedrock potentiometric surface. This surface was used to determine groundwater flow directions in the bedrock. Within the Catfish Creek Conservation Authority, the bedrock potentiometric surface, shown on Map 2.12b was generated using the static water levels for all water wells completed in the bedrock. The bedrock potentiometric surface is similar, but more subdued when compared to the overburden potentiometric surface. Groundwater flows from the north- northeast to the south towards the Lake Erie shoreline. Surface water features do not appear to have any impact on bedrock groundwater flow directions. Bedrock groundwater elevations are similar to the deep overburden potentiometric surface, and range from 270 masl in the northeast of the watershed, to 170 to 190 masl along the Lake Erie shoreline.

2.10.2.3 Kettle Creek Conservation Authority

Approximately 90% of the water wells within the Kettle Creek Conservation Authority are completed in overburden sediments. This is expected as the overburden cover within the watershed is quite thick, and reaches up to 120 m near the community of Sparta. Overburden thickness tends to thin along Kettle Creek to approximately 40 m.

Aquifers within the Kettle Creek Conservation Authority can be characterized as three aquifer units. The primary aquifer complex is comprised of broad unconfined shallow sand and gravel units located between St. Thomas and Lake Erie. Smaller sand and gravel aquifers occur in the City of London in the northeastern extents of the watershed. Deeper confined overburden aquifers, generally located at depths of greater than 20 m, are found within the central parts of the watershed as discontinuous sand and gravel lenses within the Port Stanley Till. The Dundee Formation forms the bedrock aquifer in the watershed; however, it is largely untapped as a result of adequate groundwater resources within the overburden. These hydrostratigraphic units were defined through work completed by Strynatka et al. (2006), Dillon and Golder (2004) and Waterloo Hydrogeologic Inc and others (2003).

2.10.2.3.1 SHALLOW OVERBURDEN AQUIFER

A water table surface represents groundwater conditions within the shallow aquifer under unconfined conditions. The water table surface can be used to identify shallow groundwater divides and the general flow direction of groundwater within the shallow overburden. Within the Kettle Creek Conservation Authority, the water table was generated using the static water level elevations of overburden wells completed less than 20 m below ground surface. Map 2.10c shows the location of the water table, derived from the reported static water levels within those wells.

Map 2.10c indicates that shallow wells are generally associated with the surficial sand deposits located throughout the Kettle Creek Conservation Authority, particularly between St. Thomas and Lake Erie. There are few shallow wells in the central portion of the watershed and along the boundary with the Catfish Creek Conservation Authority to the east as the upper primary aquifer is absent.

Water table elevations vary from approximately 280 masl across the north of the watershed to 180 masl along Kettle Creek and the Lake Erie shoreline. Shallow groundwater flow is predominantly from the north, flowing south towards Lake Erie. Flow is influenced by Kettle Creek with local shallow groundwater flow directed towards the main branch of the creek.

2.10.2.3.2 DEEPER OVERBURDEN AQUIFER

Static groundwater elevations within the deep overburden sediments were used to generate a potentiometric surface for the deep overburden aquifer unit. The deep overburden potentiometric surface was generated by kriging all static water levels in overburden wells completed more than 20 m below ground surface. Map 2.11b illustrates the position of the deeper overburden potentiometric surface. The deep overburden unit is semi-confined to confined and consists of thin (less than 5 m) discontinuous sand and gravel lenses within the Port Stanley and underlying Catfish Creek Tills. Groundwater flow directions in this deep unit are similar to the water table surface with groundwater flow occurring primarily from the north to the south towards Lake Erie. Groundwater flow within the southern portions of the watershed is locally influenced by Kettle Creek. The overburden potentiometric surface varies from 290 masl across the north of the watershed to 150 masl along Kettle Creek and the Lake Erie shoreline (Map 2.11b).

2.10.2.3.3 BEDROCK AQUIFER

Static groundwater elevations measured within the bedrock water wells were used to develop the bedrock potentiometric surface. Within the Kettle Creek watershed, the bedrock potentiometric surface was generated using the static water levels for all water wells terminating in bedrock (Map 2.12c). The bedrock potentiometric surface is similar to the overburden potentiometric surfaces, and groundwater flow is from the northeast towards the Lake Erie shoreline in the south. Surface water features do not appear to have a significant impact on the bedrock groundwater flow directions. Bedrock groundwater elevations range from approximately 270 masl in the northeast to 170 to 190 masl along the Lake Erie shoreline.

2.10.3 Surface and Groundwater Interactions

Interactions between the surface and groundwater systems are critical to support wetland communities, as well as to provide habitat to coldwater species. Groundwater, entering the stream channel through areas of groundwater discharge, sustains streamflow during low flow periods, providing a reliable volume of water for water taking or assimilative capacity purposes.

2.10.3.1 Long Point Region Conservation Authority

Groundwater and surface water interaction occurs predominantly in the central/western portion of the watershed, where a shallow groundwater system is located within the sandy, coarse-grained deposits of the Norfolk Sand Plain. Temperature mapping of the water courses in this area are typically classified as cool water with sustained baseflows indicating groundwater discharge into the creeks and streams. Ground and surface water pumping in the summer months when flows are reduced has the potential to affect the groundwater-surface water interactions. Years where precipitation and recharge are decreased can lead to increased water use for various uses, and this can place stress on both the surface water and groundwater systems, and the ecological systems dependent on sustained baseflows.

In the eastern portion of the watershed region, the low permeability Haldimand Clay Plain limits the interaction between the groundwater and surface water features. The watercourses in this area are runoff-driven and there is little baseflow provided by groundwater discharge.

In the central, northern and western portions of the region, Big Creek, Big Otter Creek and Little Otter Creek and their associated tributary creeks (e.g., Spittler Creek) are supported by significant groundwater discharge.

2.10.3.2 Catfish Creek

Thick deposits of low permeability till located in the northern and eastern parts of the watershed inhibit the interaction between the groundwater and surface water systems. There are low baseflows during dry periods in the upper branches of Catfish Creek, which lie within the till plain.

In the southern part of the watershed, surficial sands of the Norfolk Sand Plain are the dominant surficial sediments and stronger interactions between surface and groundwater are reported. The Catfish Creek has eroded a deep valley into the overburden and it intersects the water table allowing for discharge from groundwater to supply baseflows to the creek. Similarly, Silver Creek, located in the southeastern part of the watershed in the Norfolk Sand Plain, has flows supported by groundwater discharge. Most water courses in the southern part of the watershed are classified as coolwater with sustained baseflows indicating discharge from groundwater.

2.10.3.3 Kettle Creek

The thick fine-grained overburden with low permeability inhibits a large degree of interaction between the groundwater and surface water systems in the Kettle Creek Conservation Authority. Groundwater influences the surface water system in the headwaters of Kettle Creek by feeding Lake Whittaker which in turn produces baseflows for the creek. Beaver Creek in the south travels through sandy deposits and groundwater discharge supports a cool water fishery in this creek.

2.10.4 Monitoring

Groundwater levels within the LPRCA, CCCA and KCCA areas are primarily monitored by the Provincial Groundwater Monitoring Network (PGMN), a network of wells distributed throughout the province that provides insight on long-term ambient groundwater level and water quality trends and conditions. The monitors are typically sited so that they are reflective of broad hydrogeologic conditions, away from areas where pumping or contamination may impact the data collected. Water levels in the wells are monitored manually and electronically (data loggers) in some wells. Where electronic dataloggers are in place, water levels are recorded hourly and manual measurements are made in all wells every 3 months. This network is relatively recent, with most wells having been instrumented in the early 2000’s. Water well observations, from dedicated observation wells associated with municipal supply systems, were not collected as part of this study.

2.10.4.1 LPRCA Groundwater Monitoring

There are currently 11 PGMN wells at 9 locations in Long Point Region Conservation Authority’s jurisdiction. The wells are located throughout the central portion of the region (Map 2.13a). Ten of the 11 wells are completed in overburden and one well is completed in bedrock.

Included in Figure 2.4 are the groundwater elevation hydrographs for an overburden well nest located in LPRCA, which contains the PGMN monitors, W013 and W014. These monitors are located near the watershed divide of Big and Nanticoke Creeks, just west of Waterford. This area has a particularly high density of agricultural water takings. The shallow monitor, W013, is screened at a depth of 6.3 m below ground surface and displays seasonal fluctuations of approximately 1 m. The deep monitor, W014, is screened at a depth of 36.6 m below ground surface, and displays fluctuations similar to those observed by the shallow monitor. Interestingly, the deep monitor seems to be impacted to a higher degree from pumping in the July-October period than the shallow monitor.

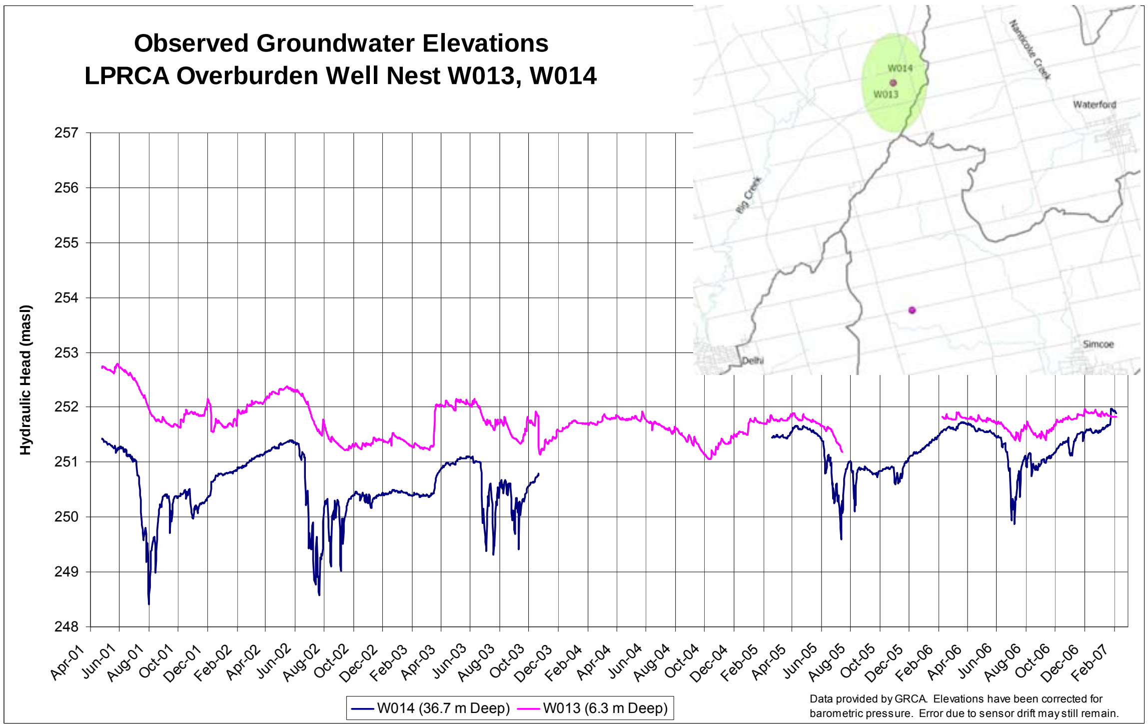


Figure 2.4 - PGMN Hydrographs for LPRCA

This data set represents the best available transient data for analysis of long-term trends in groundwater levels. No long-term trends are evident in this data set; however, the time-period is relatively short and so long-term trends cannot be supported or refuted with this data.

2.10.4.2 Catfish Creek Groundwater Monitoring

There are currently 5 PGMN wells at 2 locations within the Catfish Creek Conservation Authority. All 5 of the wells are located in the eastern extents of the watershed (Map 2.14b) and are completed in the overburden. The fact that all the PGMN monitors are located on the eastern boundary of the Catfish Creek Conservation Authority may be considered a data gap.

Included in Figure 2.5 is a plot of groundwater elevations for the PGMN monitor W353-1, which is located within CCCA. W353-1 is an overburden monitor that is screened approximately 55 m below surface. There are a total of 3 monitors associated with this well nest, however the remaining two monitors only have approximately 10 days of data available, and were therefore not included in Figure 2.5. The well nest is located just to the east of Aylmer, near the watershed divide between Catfish and Big Otter Creeks. The monitor displays a small seasonal fluctuation of approximately 0.2 m, with highs being reached during the month of May, then falling to lows in July-October. For the years monitored, elevations rapidly rose during the fall months.

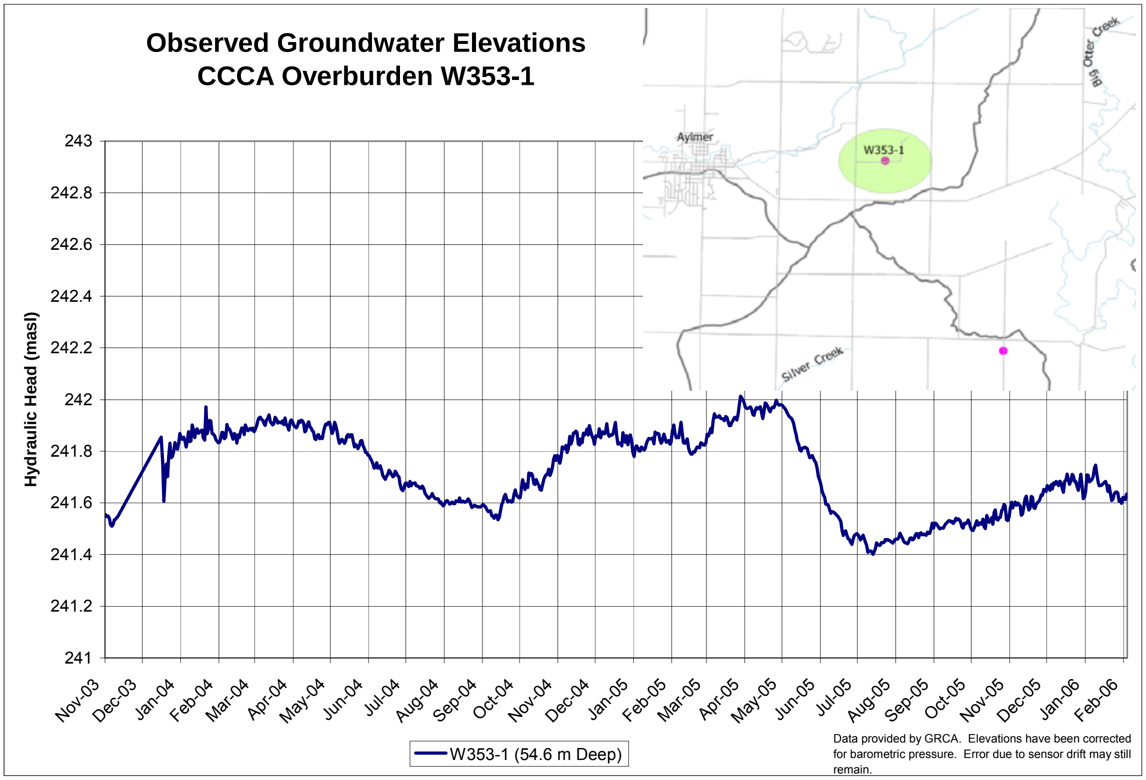


Figure 2.5 - PGMN Hydrograph for CCCA

This data set represents the best available transient data for analysis of long-term trends in groundwater levels. No long-term trends are evident in this data set, however the time-period is relatively short and so long-term trends cannot be supported or refuted with this data.

2.10.4.3 Kettle Creek Groundwater Monitoring

There are currently seven PGMN wells at seven locations within the Kettle Creek watershed. The wells are generally located in close proximity to Kettle Creek or one of its tributaries (Map 2.13c) and all of the wells are completed in the overburden.

Shown in Figure 2.6 are the hydrographs from two PGMN monitors, W372-1 and W410-1, which are in close proximity to one another. Monitor W410-1 is the shallower of the two monitors, and is screened at approximately 18 m below ground surface. Monitor W372-1 is screened approximately 41 m below ground surface. The monitors are located in the upper reaches of the Kettle Creek, to the east of Belmont. Both monitors display small seasonal fluctuations that closely mirror one another, with the shallower monitor (W410-1) showing slightly more variation. The deeper monitor, W372-1, seems to be impacted by a water taking, as evidenced by the sharp fluctuations during the months of May-September.

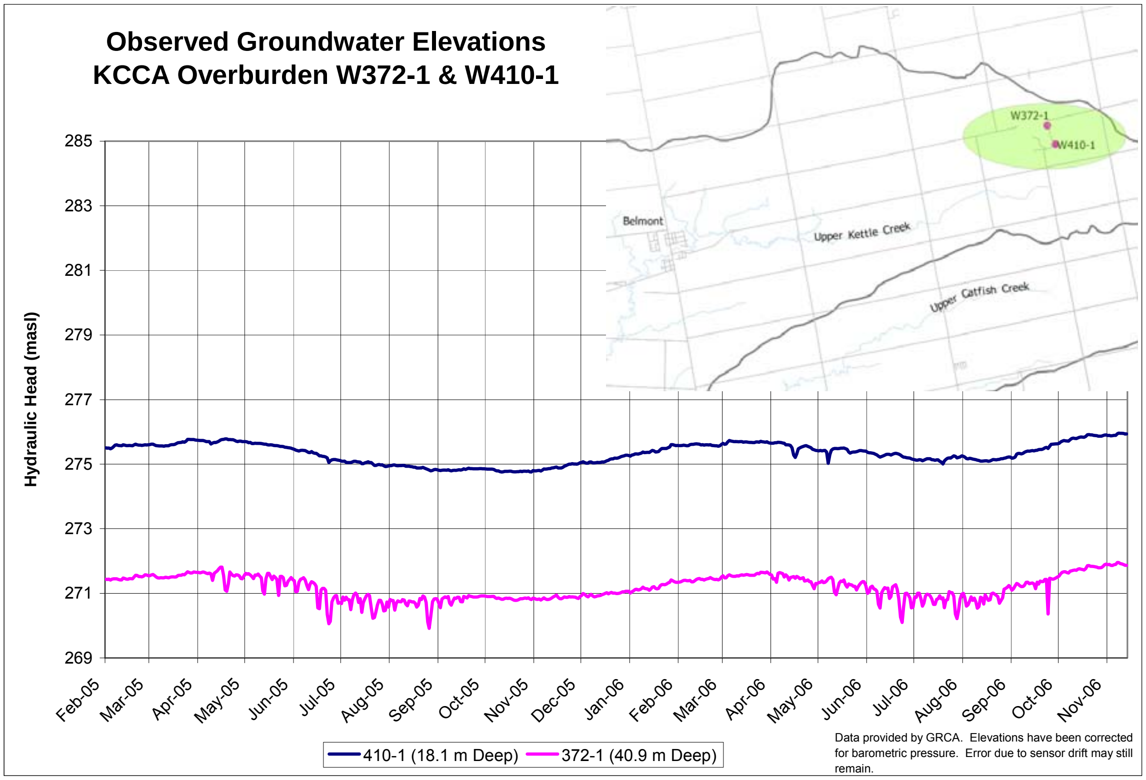


Figure 2.6 - PGMN Hydrographs for KCCA

This data set represents the best available transient data for analysis of long-term trends in groundwater levels. No long-term trends are evident in this data set; however, the time-period is relatively short and so long-term trends cannot be supported or refuted with this data.

2.11 HYDROLOGY

2.11.1 Climate

2.11.1.1 Long Point Region Conservation Authority

The Long Point Region, which has low latitude and elevation compared to other parts of southern Ontario, has a moderate temperate climate with moderate, even precipitation throughout the year and temperatures ranging from warm to hot and humid in summers to below freezing in winter. Winters are mild compared to the rest of Ontario due to its southerly location. The proximity to Lake Erie also creates a moderating effect. With Lake Erie to the south, winds coming across the lake are warmer in winter and cooler in summer than the land, thereby moderating air temperatures over the watershed.

Climate in southern Ontario is quite varied throughout the year and although there are forecasted normals and averages, the daily and seasonal weather patterns can be quite different and unpredictable. This region is affected by jet streams, lake effects from the Great Lakes, high and low pressure cells and clashing weather coming from the cold Arctic and the warm, moist Gulf of Mexico. It is thus easier to discuss the normal climate patterns of the year than to predict the daily weather patterns in such a complicated climatic zone.

General weather patterns in this region consist of four seasons, including winters that see some precipitation in the form of snow, and summers that are hot and humid. Figure 2.7 shows the daily average temperatures for the region based on the Delhi CDA station, for each month of the year. Winter is generally considered to have temperatures lower than 0 ^{o}C, beginning in December and lasting until late February or early March. Spring usually lasts two months, followed by four months (June to September) of summer and two months of autumn. The average annual temperature is about 7.5 to 8 ^{o}C, see Table 2.5.

The climate network within Long Point Region is comprised of stations operated by Environment Canada, LPRCA, as well as privately operated stations, and is shown in Map 2.15a. Annual average precipitation over the watershed is generally between 950 to 1,075 mm, as seen in Map 2.14a. There is no rainy season in this region; precipitation is fairly evenly distributed throughout the year. In winter most of the precipitation is rain. Even in January, the coldest month, more than half the precipitation is rain. The total snowfall across the LPRCA is between 100 and 150 cm between November and April (see Table 2.6).

The seasonal thaw of spring often brings long, low intensity rainfall and when coupled with the melting snow can make the spring season appear to be constantly wet and overcast. In summer many of the rainfall events are intense with short durations (e.g. thunderstorms). The duration of events, coupled with the high evapotranspiration rates between events, leaves an impression of less rain than in other seasons in terms of frequency of rain-created runoff and recharge. As seen in Figure 2.7, precipitation amounts are in actuality slightly higher in the summer and fall months than winter/spring, despite the perception of wetter winters and drier summers in this region.

In addition to the Environment Canada stations discussed, the LPRCA is developing programs and models for the use of radar data, in combination with an increased number of precipitation gauge sites to determine climatic patterns and precipitation variation [see Map 2.15a for locations of precipitation monitoring stations in the Long Point Region watersheds].

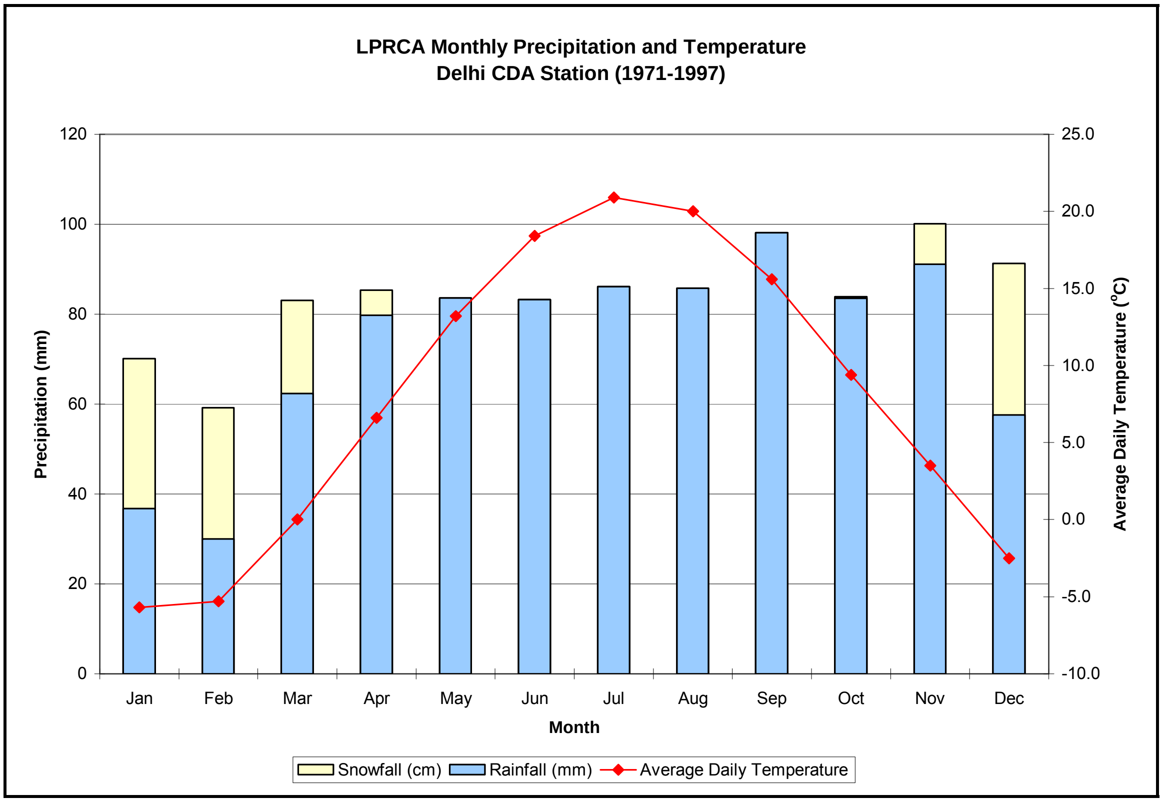


Figure 2.7 - LPRCA Average Monthly Temperature and Precipitation, 1971-2000

Table 2.5 - LPRCA Normal Daily Temperatures, 1971-2000

Station	Daily Temperature (°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Culloden Easey	Average	-6.3	-5.2	-0.1	6.5	13.5	18.4	20.8	19.8	15.4	9.1	3.1	-3.0	7.7
	Maximum	-2.9	-1.6	3.9	11.2	19.0	23.9	26.4	25.2	20.5	13.5	6.4	0.1	---
	Minimum	-9.8	-8.9	-4.1	1.8	8.0	12.9	15.2	14.3	10.3	4.6	-0.2	-6.1	---
Delhi CDA	Average	-5.7	-5.3	0.0	6.6	13.2	18.4	20.9	20.0	15.6	9.4	3.5	-2.5	7.8
	Maximum	-2.1	-1.3	4.4	11.9	19.3	24.4	27.0	25.7	20.9	14.2	7.2	1.0	12.7
	Minimum	-9.4	-9.4	-4.3	1.2	7.1	12.3	14.8	14.2	10.2	4.5	-0.2	-5.9	2.9
Dunnville Pumping Stn	Average	-4.8	-4.6	0.0	5.7	11.9	17.0	20.4	20.1	16.2	10.0	4.6	-1.2	7.9
	Maximum	-1.3	-0.8	4.0	10.1	16.5	21.2	24.6	24.3	20.4	14.1	8.2	2.2	---
	Minimum	-8.3	-8.3	-4.0	1.3	7.2	12.7	16.2	15.9	12.0	5.8	1.1	-4.6	---
Foldens	Average	-6.3	-5.4	-0.3	6.5	13.3	18.3	20.7	19.9	15.7	9.4	3.0	-3.1	7.6
	Maximum	-2.9	-1.8	3.6	11.2	18.7	23.6	25.9	25.0	20.6	13.7	6.3	0.0	12.0
	Minimum	-9.7	-9.0	-4.3	1.7	7.9	12.9	15.4	14.8	10.8	4.9	-0.3	-6.2	3.3
Hagersville	Average	-4.4	-4.1	0.7	7.0	13.7	18.8	21.3	20.1	15.9	9.8	3.7	-2.1	8.4
	Maximum	-0.7	-0.2	5.1	12.1	19.4	24.5	26.9	25.5	21.1	14.4	7.2	1.2	13.1
	Minimum	-8.0	-8.0	-3.8	1.8	7.9	13.0	15.7	14.6	10.6	5.0	0.1	-5.3	3.6
Woodstock	Average	-6.3	-5.4	-0.3	6.4	13.2	18.2	20.4	19.6	15.4	9.1	3.1	-3.0	7.5
	Maximum	-2.3	-1.1	4.2	11.6	19.2	24.1	26.4	25.3	20.9	14.1	6.8	0.5	12.5
	Minimum	-10.2	-9.6	-4.8	1.1	7.1	12.2	14.5	13.7	9.8	4.1	-0.7	-6.5	2.6

Table 2.6 - LPRCA Average Precipitation, 1971-2000

Station	Precipitation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Aylmer Ont Hydro	Rainfall (mm)	49	38	54	78	80	86	81	87	89	83	88	59	873
	Snowfall (cm)	37	28	19	4	0	0	0	0	0	0	7	21	116
	Precipitation (mm)	86	66	73	82	80	86	81	87	89	83	95	80	989
Culloden Easey	Rainfall (mm)	37	31	59	85	84	95	95	91	102	86	93	56	913
	Snowfall (cm)	44	29	23	5	0	0	0	0	0	1	14	39	154
	Precipitation (mm)	81	60	82	90	84	95	95	91	102	87	106	95	1068
Delhi CDA	Rainfall (mm)	37	30	62	80	84	83	86	86	98	84	91	58	878
	Snowfall (cm)	33	30	21	6	0	0	0	0	0	1	9	34	133
	Precipitation (mm)	70	59	83	85	84	83	86	86	98	84	100	91	1010
Dunnville Pumping Stn	Rainfall (mm)	24	32	59	66	79	89	76	80	97	85	81	65	832
	Snowfall (cm)	28	22	15	3	0	0	0	0	0	0	7	26	101
	Precipitation (mm)	52	54	73	68	80	89	76	80	97	85	88	90	932
Foldens	Rainfall (mm)	33	28	57	74	77	87	99	93	92	76	77	47	840
	Snowfall (cm)	33	23	17	6	0	0	0	0	0	1	11	29	120
	Precipitation (mm)	66	51	74	79	78	87	99	93	92	77	88	76	959
Hagersville	Rainfall (mm)	35	28	60	77	77	85	88	86	94	83	80	50	842
	Snowfall (cm)	27	20	16	4	0	0	0	0	0	0	7	24	98
	Precipitation (mm)	62	48	76	81	77	85	88	86	94	83	87	74	940
Nanticoke Esso	Rainfall (mm)	31	37	66	81	74	84	95	90	111	86	84	67	905
	Snowfall (cm)	33	31	13	3	0	0	0	0	0	0	4	33	118
	Precipitation (mm)	64	68	80	84	74	84	95	90	111	86	88	100	1023
Tillsonburg	Rainfall (mm)	40	36	67	78	82	87	87	83	94	83	86	61	882
	Snowfall (cm)	36	27	18	5	0	0	0	0	0	0	11	32	128
	Precipitation (mm)	76	62	84	82	82	87	87	83	94	83	96	93	1010
Waterford	Rainfall (mm)	31	28	55	70	73	87	89	81	98	76	74	51	813
	Snowfall (cm)	37	27	18	5	0	0	0	0	0	1	8	33	129
	Precipitation (mm)	68	55	72	75	73	87	89	81	98	77	82	84	943
Woodstock	Rainfall (mm)	32	32	53	75	80	84	96	92	94	73	76	50	837
	Snowfall (cm)	32	22	19	5	0	0	0	0	0	1	10	29	117
	Precipitation (mm)	64	54	72	80	81	84	96	92	94	74	86	79	954

2.11.1.2 Catfish Creek

The Catfish Creek Conservation Authority, situated on the northern shore of Lake Erie, has a geographic location that provides a more temperate climate compared to other parts of Southern Ontario. The temperate climate denotes moderate, even precipitation throughout the year, summers that are warm to hot and humid, and freezing temperatures in winter. Winters are mild compared to the rest of Ontario due to the watershed's southerly location and the moderating effect of Lake Erie. Map 2.15b shows the location of precipitation monitoring stations in the watershed.

General weather patterns in this region consist of four seasons. Winter is generally considered to have temperatures lower than 0 ^{o}C, beginning in December and lasting until late February or early March. Spring lasts approximately two months, followed by four months (June to September) of summer and two months of autumn (Sanderson, 1998). The average annual temperature is about 7.5 ^{o}C to 8.5 ^{o}C (see Table 2.7).

Lake Erie moderates the climate in this region by absorbing solar radiation and heat energy during the summer months and releasing heat slowly throughout the winter months. Winds blowing across the lake bring air warmer than the land in winter and cooler in summer, thereby moderating the air temperature over the Catfish Creek watershed, adding to a longer frost-free growing season in the lowland plains.

Annual average precipitation in the watershed is generally between 950 mm to 1,075 mm, as seen in Map 2.14b. A majority of winter precipitation falls as rain.

Precipitation is quite evenly distributed throughout the year, although the intensity, duration and frequency of precipitation are quite different among the seasons. The accumulation of snow in the winter months prolongs the effects of precipitation, as infiltration is delayed until a thaw. Spring thaw often brings long, low intensity rainfall and when coupled with the melting snow can make the spring season appear to be constantly wet and overcast. In summer many of the rainfall events are intense with short durations. The duration of events, coupled with the high evapotranspiration rates between events, leaves an impression of less rain than in other seasons in terms of frequency of rain-created runoff and recharge. As seen in Figure 2.8 and Table 2.8, precipitation amounts are quite evenly distributed. Rain gauges operated by CCCA are shown in Map 2.15b.

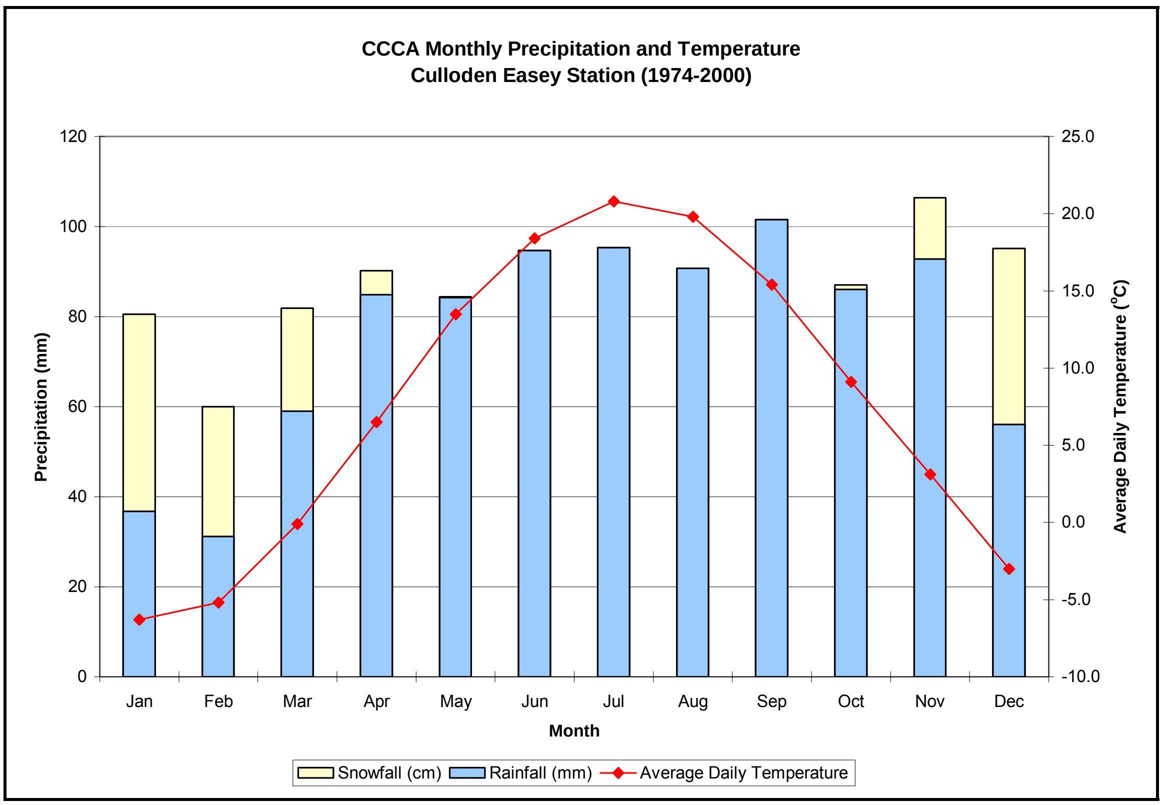


Figure 2.8 - CCCA Average Monthly Precipitation and Temperature, 1971-2000

Table 2.7 - CCCA Normal Daily Temperatures, 1971-2000

Station	Daily Temperature (°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Culloden Easey	Average	-6.3	-5.2	-0.1	6.5	13.5	18.4	20.8	19.8	15.4	9.1	3.1	-3.0	7.7
	Maximum	-2.9	-1.6	3.9	11.2	19.0	23.9	26.4	25.2	20.5	13.5	6.4	0.1	---
	Minimum	-9.8	-8.9	-4.1	1.8	8.0	12.9	15.2	14.3	10.3	4.6	-0.2	-6.1	---
Port Stanley	Average	-5.5	-5.2	0.0	6.1	12.4	17.2	20.0	19.4	15.6	9.4	4.1	-2.0	7.6
	Maximum	-1.7	-0.9	4.1	10.6	17.6	22.2	25.2	24.6	20.8	14.2	7.7	1.5	12.2
	Minimum	-9.4	-9.5	-4.0	1.6	7.2	12.2	14.7	14.1	10.4	4.5	0.4	-5.4	3.1
St Thomas	Average	-4.8	-3.7	1.0	7.4	13.8	18.6	21.0	20.2	16.1	10.0	4.1	-1.8	8.5
	Maximum	-0.9	0.6	5.6	12.9	19.9	24.5	26.8	25.8	21.5	15.1	7.8	1.7	13.4
	Minimum	-8.6	-7.9	-3.7	2.0	7.8	12.6	15.2	14.6	10.7	4.9	0.3	-5.3	3.5
Westminster	Average	-6.3	-5.7	-0.1	6.7	13.2	18.0	20.7	19.7	15.5	9.2	3.3	-2.8	7.6
	Maximum	-2.7	-1.8	4.0	11.8	19.1	23.8	26.5	25.4	20.8	14.0	7.0	0.6	12.4
	Minimum	-9.9	-9.7	-4.2	1.6	7.3	12.1	14.7	14.0	10.1	4.4	-0.3	-6.1	2.8
London Airport	Average	-6.3	-5.5	-0.3	6.3	13.0	18.0	20.5	19.5	15.3	9.0	3.1	-3.0	7.5
	Maximum	-2.4	-1.4	4.2	11.6	19.0	23.8	26.3	25.2	20.9	14.0	6.9	0.6	12.4
	Minimum	-10.1	-9.7	-4.7	1.0	7.0	12.1	14.6	13.7	9.6	4.0	-0.7	-6.5	2.5

Table 2.8 - CCCA Average Precipitation, 1971-2000

Station	Precipitation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Aylmer	Rainfall (mm)	49	38	54	78	80	86	81	87	89	83	88	59	873
	Snowfall (cm)	37	28	19	4	0	0	0	0	0	0	7	21	116
	Precipitation (mm)	86	66	73	82	80	86	81	87	89	83	95	80	989
Culloden Easey	Rainfall (mm)	37	31	59	85	84	95	95	91	102	86	93	56	913
	Snowfall (cm)	44	29	23	5	0	0	0	0	0	1	14	39	154
	Precipitation (mm)	81	60	82	90	84	95	95	91	102	87	106	95	1068
Port Stanley	Rainfall (mm)	32	35	72	82	80	88	87	109	99	78	100	74	937
	Snowfall (cm)	32	22	15	3	0	0	0	0	0	1	6	25	104
	Precipitation (mm)	64	57	87	84	80	88	87	109	99	79	106	99	1040
St Thomas	Rainfall (mm)	37	37	52	81	83	102	86	88	97	83	89	61	897
	Snowfall (cm)	38	27	17	4	0	0	0	0	0	0	7	27	120
	Precipitation (mm)	75	64	68	85	83	102	86	88	97	84	96	89	1017
Westminster	Rainfall (mm)	26	30	57	71	77	85	85	101	93	74	87	52	836
	Snowfall (cm)	46	34	19	5	0	0	0	0	0	1	10	38	153
	Precipitation (mm)	72	63	75	76	77	85	85	101	93	75	97	90	989
London Airport	Rainfall (mm)	31	29	54	74	83	87	82	85	98	75	74	47	818
	Snowfall (cm)	53	38	29	9	0	0	0	0	0	3	20	51	202
	Precipitation (mm)	74	60	78	82	83	87	82	85	98	78	91	89	987

2.11.1.3 Kettle Creek

The Kettle Creek watershed enjoys a temperate climate compared to other parts of southern Ontario. Lake Erie moderates the climate by absorbing heat from the sun during the summer months and releasing it slowly throughout the winter months. Winds coming across the lake are warmer in winter and cooler in summer than the land. This results in a temperate climate with a longer frost-free growing season.

General weather patterns in this region consist of four distinct seasons. Winter is generally considered to have temperatures lower than 0 °C, beginning in December and lasting until late February or early March. Spring is generally only two months, followed by four months (June to September) of summer and two months of autumn (Sanderson, 1998). The average annual temperature is about 7.5 to 8.5 °C (see Table 2.9).

Annual average precipitation over the watershed is generally between 950 to 1,075 mm, as seen in Map 2.14c. A majority of precipitation in the winter falls as rain. Even in January, generally the coldest month of the winter, more than half the precipitation falls as rain. Snowfall across the watershed is between 115 to 150 mm combined over the months of November to April. Precipitation is monitored at three locations in the watershed, as shown in Map 2.15c.

Precipitation is fairly evenly distributed throughout the year, although the intensity, duration and frequency of precipitation events are quite different among the seasons (see Table 2.10). The accumulation of snow in the winter months makes the effects of the precipitation longer, as infiltration is delayed until a thaw. The spring thaw often brings long, low intensity rainfall and when coupled with the melting snow can make the spring season appear to be constantly wet and overcast.

In summer many of the rainfall events are intense with short durations. The duration of events, coupled with the high evapotranspiration rates between events, leaves an impression of less rain than in other seasons in terms of frequency of rain-created runoff and recharge. As seen in Figure 2.9, precipitation amounts are in actuality quite evenly distributed throughout the year despite the perception of wetter and drier seasons in this region.

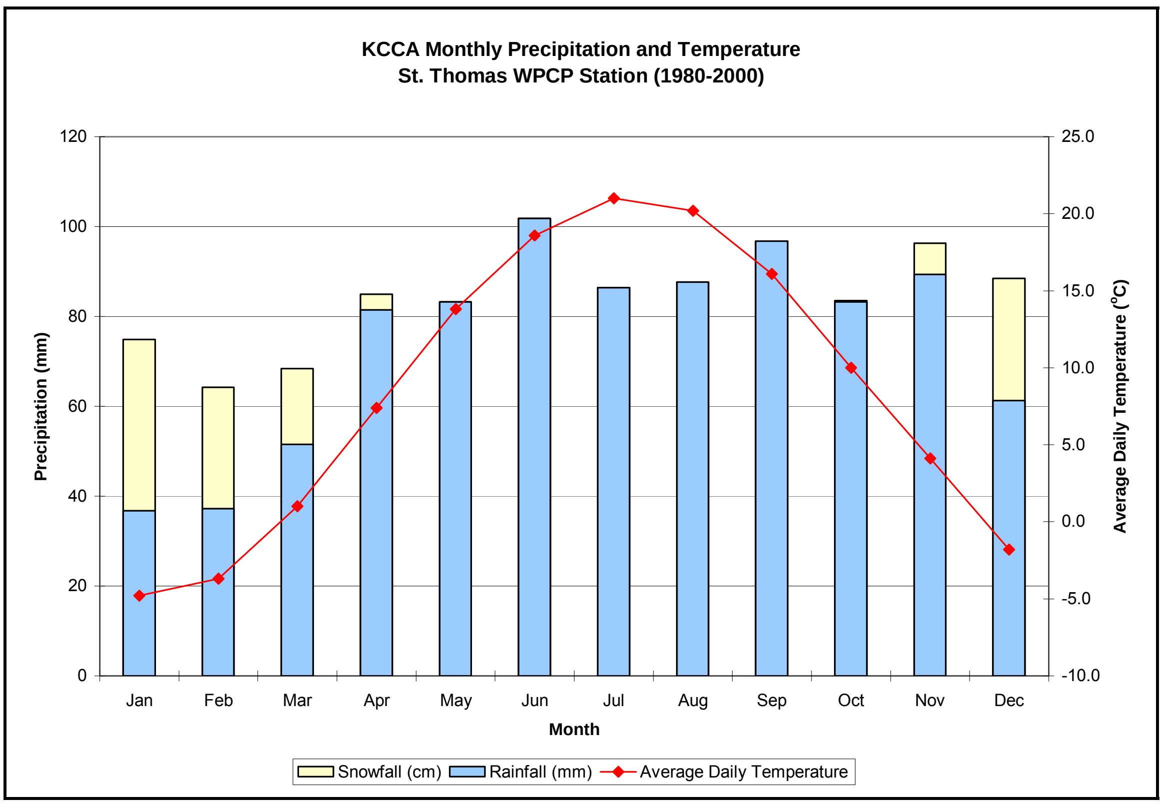


Figure 2.9 - KCCA Average Monthly Precipitation and Temperature, 1971-2000

Table 2.9 - KCCA Normal Daily Temperatures, 1971-2000.

Station	Daily Temperature (^{o}C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Culloden Easey	Average	-6.3	-5.2	-0.1	6.5	13.5	18.4	20.8	19.8	15.4	9.1	3.1	-3.0	7.7
	Maximum	-2.9	-1.6	3.9	11.2	19.0	23.9	26.4	25.2	20.5	13.5	6.4	0.1	---
	Minimum	-9.8	-8.9	-4.1	1.8	8.0	12.9	15.2	14.3	10.3	4.6	-0.2	-6.1	---
Port Stanley	Average	-5.5	-5.2	0.0	6.1	12.4	17.2	20.0	19.4	15.6	9.4	4.1	-2.0	7.6
	Maximum	-1.7	-0.9	4.1	10.6	17.6	22.2	25.2	24.6	20.8	14.2	7.7	1.5	12.2
	Minimum	-9.4	-9.5	-4.0	1.6	7.2	12.2	14.7	14.1	10.4	4.5	0.4	-5.4	3.1
St Thomas WPCP	Average	-4.8	-3.7	1.0	7.4	13.8	18.6	21.0	20.2	16.1	10.0	4.1	-1.8	8.5
	Maximum	-0.9	0.6	5.6	12.9	19.9	24.5	26.8	25.8	21.5	15.1	7.8	1.7	13.4
	Minimum	-8.6	-7.9	-3.7	2.0	7.8	12.6	15.2	14.6	10.7	4.9	0.3	-5.3	3.5
Westminster TWC WPCP	Average	-6.3	-5.7	-0.1	6.7	13.2	18.0	20.7	19.7	15.5	9.2	3.3	-2.8	7.6
	Maximum	-2.7	-1.8	4.0	11.8	19.1	23.8	26.5	25.4	20.8	14.0	7.0	0.6	12.4
	Minimum	-9.9	-9.7	-4.2	1.6	7.3	12.1	14.7	14.0	10.1	4.4	-0.3	-6.1	2.8
London Airport	Average	-6.3	-5.5	-0.3	6.3	13.0	18.0	20.5	19.5	15.3	9.0	3.1	-3.0	7.5
	Maximum	-2.4	-1.4	4.2	11.6	19.0	23.8	26.3	25.2	20.9	14.0	6.9	0.6	12.4
	Minimum	-10.1	-9.7	-4.7	1.0	7.0	12.1	14.6	13.7	9.6	4.0	-0.7	-6.5	2.5

Table 2.10 - KCCA Average Precipitation, 1971-2000

Station	Precipitation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Culloden Easey	Rainfall (mm)	37	31	59	85	84	95	95	91	102	86	93	56	913
	Snowfall (cm)	44	29	23	5	0	0	0	0	0	1	14	39	154
	Precipitation (mm)	81	60	82	90	84	95	95	91	102	87	106	95	1068
Port Stanley	Rainfall (mm)	32	35	72	82	80	88	87	109	99	78	100	74	937
	Snowfall (cm)	32	22	15	3	0	0	0	0	0	1	6	25	104
	Precipitation (mm)	64	57	87	84	80	88	87	109	99	79	106	99	1040
St Thomas WPCP	Rainfall (mm)	37	37	52	81	83	102	86	88	97	83	89	61	897
	Snowfall (cm)	38	27	17	4	0	0	0	0	0	0	7	27	120
	Precipitation (mm)	75	64	68	85	83	102	86	88	97	84	96	89	1017
Westminster TWC WPCP	Rainfall (mm)	26	30	57	71	77	85	85	101	93	74	87	52	836
	Snowfall (cm)	46	34	19	5	0	0	0	0	0	1	10	38	153
	Precipitation (mm)	72	63	75	76	77	85	85	101	93	75	97	90	989
London Airport	Rainfall (mm)	31	29	54	74	83	87	82	85	98	75	74	47	818
	Snowfall (cm)	53	38	29	9	0	0	0	0	0	3	20	51	202
	Precipitation (mm)	74	60	78	82	83	87	82	85	98	78	91	89	987

2.11.2 Climate Data Gaps

Climate trends for precipitation and temperature are limited by the sparse coverage of weather stations. There are fewer than 550 stations currently collecting data in the entire Province of Ontario and these stations do not all collect the same information. It is difficult to accurately assess the climate of an area that is lacking a weather station as weather can be highly localized. The precipitation monitoring networks for LPRCA, CCCA and KCCA are illustrated on Maps 2.15a, b and c, respectively.

Precipitation data is especially difficult to map, as it can vary drastically across a small area and it is often not uniformly distributed. Unless there are several precipitation gauges directly underneath a storm cell, it will not accurately capture the storm's variability and area of influence. For example, weather fronts and convection storms create distinct boundaries of precipitation so interpolating results between weather stations will not yield accurate results.

Temperature is far less variable across an area and generally is more accurate to estimate between weather stations that are spatially far apart.

There is a need to have provincial maps for both precipitation and temperature for seasonal and longer term trends. Standardizing the methods used to create isolines of either precipitation or temperature for the province could provide some consistency to estimates between climate stations. Restoring some of the many weather stations that were previously in use (there were more than 1,100 weather stations in the province between 1960 and 1980) would provide better coverage. In particular, additional gauges near the Lake Erie shore are needed to verify an apparent increase in rain amounts near Lake Erie compared to more inland locations.

2.11.3 Evapotranspiration

Evapotranspiration is a term used to describe the amount, or rate of transfer of liquid or solid water into atmospheric water vapour at the watershed surface. Evapotranspiration is the sum of sublimation of snow or ice, evaporation of liquid water in surface depressions (streams, ponds or lakes), evaporation of liquid water in leaf stomata (transpiration), evaporation of liquid water in soil water pores exposed to the atmosphere, and evaporation from groundwater in locations where the water table is exposed to the atmosphere. In summer, and for vegetated surfaces, the main contribution to evapotranspiration is transpired water.

Evapotranspiration is a critical parameter in understanding the Water Budget across an area as it is usually the largest component. Unfortunately, it is often poorly understood as it cannot be accurately measured with conventional monitoring techniques. Instead, conditions are extrapolated from non-ideal measurement devices, which are sparsely distributed throughout Ontario.

Provincial estimates of mean annual evapotranspiration have been documented within the Water Quantity Resources of Ontario (MNR, 1984), by subtracting mean annual streamflow from mean annual precipitation. Over the long term, the difference between annual streamflow and precipitation equals annual evapotranspiration (assuming negligible net groundwater outflow/inflow from the watershed). For the area that comprises LPRCA, CCCA and KCCA, evapotranspiration is shown to be approximately 550-600 mm per year.

It is important to consider that in southern Ontario, evapotranspiration totals for a particular year are dependent on the amount of water that is available to be evaporated. Areas with an unlimited supply of water will evaporate at the potential evapotranspiration rate. Areas that have a limited supply of water, and rely on precipitation events to replenish the soil water supply will evaporate water at an actual evapotranspiration rate that is less than the potential rate for that type of surface when fully wetted. The difference can be very significant in years of drought, where very little soil water is replenished due to the reduced precipitation. This can result in observations that seem counter-intuitive to some, where in a drought, actual evapotranspiration can be drastically reduced.

2.11.4 Wetlands

Wetlands play an important role in many of the watersheds' hydrological and ecological processes. The hydrologic function of wetlands vary with some wetlands being groundwater discharge areas that provide baseflow during low flow periods, while other wetlands provide recharge to the underlying aquifer system during dry periods of the year. Wetlands are also critical as they retain surface runoff and reduce downstream flood flows. They also act as water filters and capture sediment, dissolved nutrients and other contaminants, improving the surface water quality. Wetlands are also typically highly productive ecological habitats, with great biodiversity, and often home to a large number of species.

Wetlands throughout the Study Area have been extensively drained although some significant wetland complexes remain. The following tables summarize selected wetlands within each of the three conservation authorities. Maps 2.16a-2.16c illustrates the wetlands listed in Table 2.11-2.13, below.

Table 2.11 - Selected Long Point Region Wetlands

Official Wetland Complex Name (MNR, 2005)	*Primary Sub-Watershed*	*Other Subwatersheds*	*Area (ha)*
Hatchley Swamp	Otter Above Maple Dell Road	Big Creek Above Cement Road	877
Long Point Wetland	Dedrick Creek		595
Windham Centre Sandy Swampland (NC1)	Upper Nanticoke Creek	Lynne River	346
DYC3 (2)	Lower Big Creek	Dedrick Creek	310
Dereham Wetland	Spittler Creek	Otter at Tillsonburg	264
Courtland Swamp Complex BOC1	Little Otter		262
NC2 (1)	Upper Nanticoke Creek		255
Kent Creek Complex Wetland (LR1)	Lynne River		211
SOC5	Clear Creek		205

Table 2.12 - Selected Catfish Creek Wetlands

Official Wetland Complex Name (MNR, 2005)	*Sub-Watershed*	*Area (ha)*
Calton Swamp	Silver Creek	50
Springwater Conservation Area	Lower Catfish Creek	39
EM11/EM18	Catfish Above Aylmer	30
EY6	Lower Catfish Creek	20

Table 2.13 - Selected Kettle Creek Wetlands

Official Wetland Complex Name (MNR, 2005)	*Sub-Watershed*	*Area (ha)*
Lake Whittaker Wetlands (KC23)	Upper Kettle Creek	60
Glanworth Wetland Complex (KC13)	Upper Kettle Creek	45
Regina Mundi Kirk Cousins Wetland (UT-6)	Upper Kettle Creek	28
Kettle Creek Woods	Upper Kettle Creek	27

2.11.5 Water Control Structures

2.11.5.1 Long Point

Several hundred small dams have been constructed on virtually every tributary of Big Creek and Big Otter Creek and other small watercourses in the watershed, to store water as a source for irrigation. They were constructed mainly in the last half of the 20th century. There are also several old mill dams that were constructed in the 1800's and replaced or maintained in various states since. The majority of dams operated by LPRCA are for recreational uses, but also include structures for flood control, low flow augmentation, drinking water supply, irrigation and wildlife habitat. Selected dams and reservoirs in the Long Point Region are shown on Map 2.17a.

2.11.5.2 Catfish Creek

There are two main water control structures within CCCA. The first, and most significant structure, is Springwater Reservoir, which is a structure of approximately 3 m of available head. Two spillways are available for outflows, and are controlled by stoplogs and a sluicegate. No low-flow valve exists to allow drawdown below the spillway crest. The surface area of the reservoir is approximately 10 ha, and the upstream drainage area is approximately 22 km^2. While no detailed operation rule has been imposed for the reservoir, it is generally drawn down over a 2 week period starting in late October, and filled in mid-March. Elevations remain at their maximum throughout the summer. The location of Springwater Reservoir is included in Map 2.17b.

The second water control structure is located just downstream of Springwater Reservoir in Bradley's Creek, and is relatively insignificant in terms of watershed hydrology. It is an uncontrolled spillway structure with 3 m of available head.

2.11.5.3 Kettle Creek

By 1977, KCCA had acquired four reservoirs and floodplain properties to partially meet the goals of headwater source protection and baseflow augmentation. These four reservoirs include Dalewood Reservoir, Union Pond, and Lake Whittaker (Map 2.17c).

The Dalewood Reservoir was originally owned by the City of St. Thomas and was known as St. Thomas Waterworks Reservoir. The main purpose of the reservoir was to supply the City's drinking water supply. However, insufficient surface water flows in Kettle Creek prompted St. Thomas to be connected to the Elgin Area Primary Water Supply system.

The Dalewood Dam, which is a stop-log structure, was constructed in 1928, and has been subject to extensive maintenance and rehabilitation. It is still used today to augment stream flows and control flood events.

The Union Dam was built prior to 1900 and consists of an earthen embankment with a concrete spillway. The dam backs up water in a series of online ponds along Beaver Creek in the village of Union. The primary use of this reservoir is flood control, and baseflow augmentation. Until the 1940's the Union Dam was used for gristmill operation. KCCA acquired the dam and pond in 1972. In 2003, the dam was upgraded to meet provincial maintenance and operations standards. The reservoir itself is approximately 13 ha in area with a holding capacity of approximately 8,000 m^3 (Riggs, 2002). The reservoir is gradually infilling with silt especially in the upstream ponds. The reservoir is lowered in response to expected heavy rain events, and allowed to rise in the interim.

Lake Whittaker is an 11 ha kettle lake that forms the headwaters for Kettle Creek. It is located at the uppermost height of land in the watershed. Various parcels of property around the lake were purchased by the Authority from 1972 to 1995. A small, one metre concrete weir serves to maintain static water levels in the lake while permitting continual outflows. The lake waters are sourced primarily from groundwater surfacing in adjacent wetlands and within the lake itself.

As outlined within the 2004 Inventory of Watershed Dams, a large number of privately-owned reservoirs and ponds supplement baseflow in the Kettle Creek Conservation Authority. Those located in headwater reaches are of highest value, including: Lake Margaret, Mill Creek Pond, Corners Pond, and Sandam Pond. Approximately 27 other dams and associated reservoirs can be found throughout the watershed that were constructed to collect and retain surface water flows. All of these reservoirs have a more localized low flow augmentation benefit and are serving as sediment catches.

2.11.6 Surface Water Monitoring

Streamflow monitoring within the Long Point Region, Catfish Creek and Kettle Creek is predominantly carried out by the Water Survey of Canada (WSC). Rating curves and gauge infrastructure are frequently maintained, with observed data undergoing extensive quality assurance and quality controls. As such, streamflow data from WSC stations is considered to be the highest quality streamflow data available. The following sections describe the surface water monitoring network in each of the CAs.

2.11.6.1 Long Point

The flow monitoring network in the Long Point Region has been expanded in recent years with the re-opening of a number of historic gauges. There are 10 active WSC gauges in the Long Point Region as shown on Map 2.18a. The gauge network is denser in the western part of the region and is focused on the larger watercourses. There are three gauges in the Big Otter Creek Watershed that cover most of the watershed area. Stream flow data is available beginning in 1948 with the longest continuous data set from 1960 to present. There are 4 active stream gauges in the Big Creek Watershed with 2 gauges in continuous operation since 1955 and 2 recently re-opened gauges.

The other 3 stream gauges are on Young Creek, Nanticoke Creek and the Lynn River. The gauge on Young Creek has been operated for various periods since 1963. The Lynn River gauge has a continuous data set beginning in 1957. The Nanticoke Creek gauge is the only gauge in the eastern part of the region and has been in operation since 1969. There is also flow data available from abandoned stations for North Creek, Little Otter Creek, South Otter Creek, Dedrick Creek, Patterson Creek, Fishers Creek and Hemlock Creek in the western part, and Sandusk Creek in the eastern part of the region.

2.11.6.2 Catfish Creek

Flow monitoring in the Catfish Creek Conservation Authority consists of three Water Survey of Canada (WSC) stream gauges, as shown in Map 2.18b. The first gauge is located within the Town of Aylmer on the main branch of Catfish Creek. It was originally opened in 1987 and operated for 11 years until 1998. The gauge was reopened in 2002. The other gauge on Catfish Creek is located near Sparta. It has been in continuous operation since 1964. This gauge captures 290 km^2 of the watershed or approximately 74% of the area drained by Catfish Creek. Flow data from both gauges on Catfish Creek is available in real time. The last stream gauge in the watershed is located on Silver Creek near Grovesend. This gauge is a recent addition to the network in 2005. It replaces a historic stream gauge that was located upstream of the current gauge, that was in operation from 1970 to 1978. Data from the new Silver Creek gauge are not available yet.

2.11.6.3 Kettle Creek

The flow monitoring network in the Kettle Creek Conservation Authority consists of three Water Survey of Canada (WSC) stream gauges, as shown on Map 2.18c. The first gauge is on Dodd Creek below Payne's Mill and covers a drainage area of approximately 95 km^2. It has been in continuous operation since 1987. The other two gauges are on Kettle Creek, one above St. Thomas and the other at St. Thomas. The stream gauge above St. Thomas captures a drainage area of 135 km^2 and has been in operation since 1985. The stream gauge at St. Thomas is the oldest in the watershed. It is located past the confluence of Dodd and Kettle Creeks and captures a drainage area of 330 km^2 or 75% of the watershed. This gauge has been in operation since 1945. Real-time stream flow information is available from all three gauges.

2.11.7 Surface Water Characterization

This section summarizes the main elements of the watersheds and subwatersheds within the Long Point/Catfish/Kettle Creek Conservation Authorities as they might affect the overall water budget. Each of the watersheds referenced in Tables 2.1-2.3 and on Map 2.1 are characterized with respect to their general surficial geology and land cover. The general effects of these parameters on the surface water hydrology are discussed, with reference to summaries of stream gauge data where appropriate.

Throughout the following section, the response for each streamgauge will be characterized in terms of the median (most often observed streamflow), the 90th percentile flow (flow met or exceeded 90% of the time), and the 10th percentile flow (flow met or exceeded 10% of the time). These streamflow statistics will be presented for each month of the year, allowing the reader to visualize the variability in streamflow throughout the year, as well as the variability within a particular month. Included in Figure 2.10 is an example ranked duration plot for the month of May, with the median, 90th percentile and 10th percentile flow indicated. A large difference between the 10th and 90th percentile flows would indicate that streamflow is quite variable throughout the particular month, a characteristic of a runoff-driven system. Alternatively, a gauge with similar 10th and 90th percentile flows would have steady flows throughout the month, a characteristic of a baseflow-driven system.

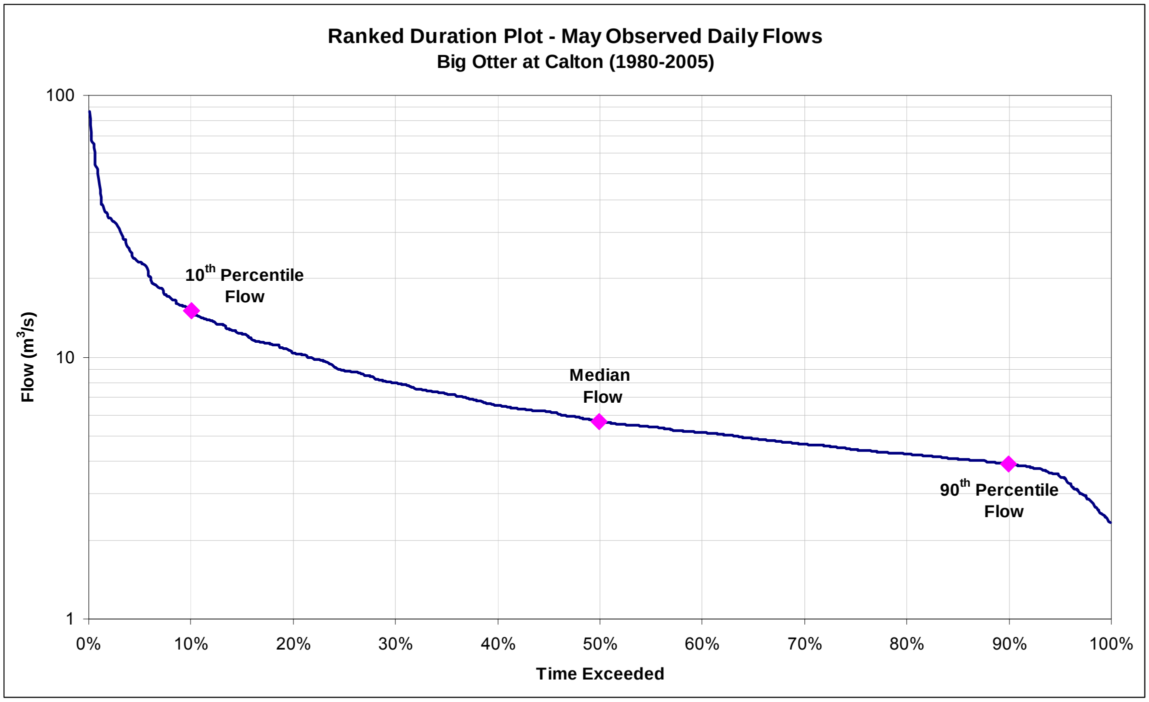


Figure 2.10 - Ranked Duration Plot Example

In addition to calculating flow statistics, long term streamflow datasets were investigated to determine if any apparent decline in streamflow was apparent. While no station displayed a long term decline in summer flows, consideration should be given to the start date of the stations. All stations analyzed began collecting data in the late 1950's or early 1960's, a time of extreme drought, and when irrigation was already well established. Having the period of record start during a low period would significantly affect any trend analysis. Additionally, the effect of increased wastewater treatment plant discharges and certainty regarding historical streamflow estimates, should also be kept in mind.

2.11.7.1 Long Point Region Conservation Authority

Table 2.14 summarizes the simplified surficial geology and physiography of each of the Long Point subwatersheds. This summary was calculated from hydrologic response unit mapping produced by Grand River Conservation Authority staff.. Any of the land areas can be further classified as hummocky, which may indicate closed drainage areas resulting in higher recharge rates and reduced runoff.

Table 2.14 - Long Point Region Subwatershed Characteristics

	Area (km^2)	Impervious	Wetland	Urban	Clayey Tills	Silty Tills	Sandy Till	Sand & Gravel	Hummocky
Big Otter Creek	**935**	**1%**	**1%**	**1%**	**9%**	**32%**	**0%**	**56%**	**6%**
Otter Above Maple Dell Road	99	1%	2%	1%	7%	42%	1%	46%	4%
Otter at Otterville	75	1%	1%	0%	27%	32%	0%	39%	6%

	Area (km^2)	Impervious	Wetland	Urban	Clayey Tills	Silty Tills	Sandy Till	Sand & Gravel	Hummocky
Otter at Tillsonburg	153	1%	1%	4%	6%	38%	0%	51%	16%
Spittler Creek	116	1%	1%	0%	14%	70%	0%	14%	12%
Lower Otter	168	1%	1%	0%	15%	37%	0%	46%	3%
Little Otter	118	1%	1%	0%	3%	14%	0%	82%	3%
South Otter	120	1%	0%	0%	3%	6%	0%	89%	0%
Clear Creek	87	1%	0%	0%	3%	9%	0%	87%	0%
Big Creek	**1013**	**1%**	**3%**	**0%**	**9%**	**14%**	**1%**	**72%**	**2%**
Big Above Cement Road	89	1%	1%	0%	7%	49%	0%	43%	0%
Big Above Kelvin Gauge	64	1%	2%	0%	4%	15%	1%	78%	3%
Big Above Delhi	154	1%	1%	0%	3%	13%	7%	75%	7%
North Creek	58	1%	0%	0%	2%	2%	0%	95%	1%
Big Above Minnow Creek	72	1%	1%	0%	4%	1%	4%	90%	0%
Big Above Walsingham Gauge	123	1%	1%	0%	7%	12%	0%	80%	0%
Venison Creek	98	1%	0%	0%	3%	7%	0%	89%	3%
Lower Big	96	2%	12%	0%	22%	20%	0%	44%	0%
Dedrick Creek	138	4%	7%	0%	12%	15%	0%	63%	0%
Lynne River	**425**	**1%**	**0%**	**1%**	**36%**	**1%**	**0%**	**60%**	**0%**
Young/Hay Creek	120	1%	1%	0%	18%	4%	0%	77%	0%
Lynne River	172	1%	0%	3%	11%	0%	1%	84%	0%
Black Creek	134	1%	0%	0%	86%	0%	0%	13%	0%
Nanticoke Creek	**199**	**3%**	**0%**	**2%**	**54%**	**0%**	**4%**	**37%**	**0%**
Upper Nanticoke	114	2%	1%	0%	27%	0%	6%	64%	0%
Lower Nanticoke	85	4%	0%	5%	89%	0%	0%	2%	0%
Eastern Tributaries	**367**	**5%**	**0%**	**0%**	**95%**	**0%**	**0%**	**0%**	**0%**
Sandusk Creek	182	4%	0%	0%	95%	0%	0%	0%	0%
Stoney Creek	186	5%	0%	0%	95%	0%	0%	0%	0%

The following sections describe hydrologic conditions throughout the major Long Point Region Watersheds, and make reference to a series of charts summarizing monthly flow distributions at selected gauges. These charts show median monthly flow, the 10th percentile monthly flow, and the 90th percentile monthly flow. The median monthly flow can be considered to represent typical streamflow conditions. The 90th percentile monthly flow can be considered to represent low flows, and the 10th percentile monthly flow can be considered to represent high flows.

2.11.7.1.1 BIG OTTER CREEK

Big Otter Creek is the second largest watershed in the region, draining an area of approximately 712 km^2. The upper part of the watershed in the northwestern corner of the region lies in till plain. The creek flows southward in the Norfolk Sand Plain through the communities of Norwich, Otterville, and Tillsonburg before draining to Lake Erie at Port Burwell. The Big Otter Watershed is characterized by moderate runoff, soil infiltration, and baseflows. The largest tributary, Little

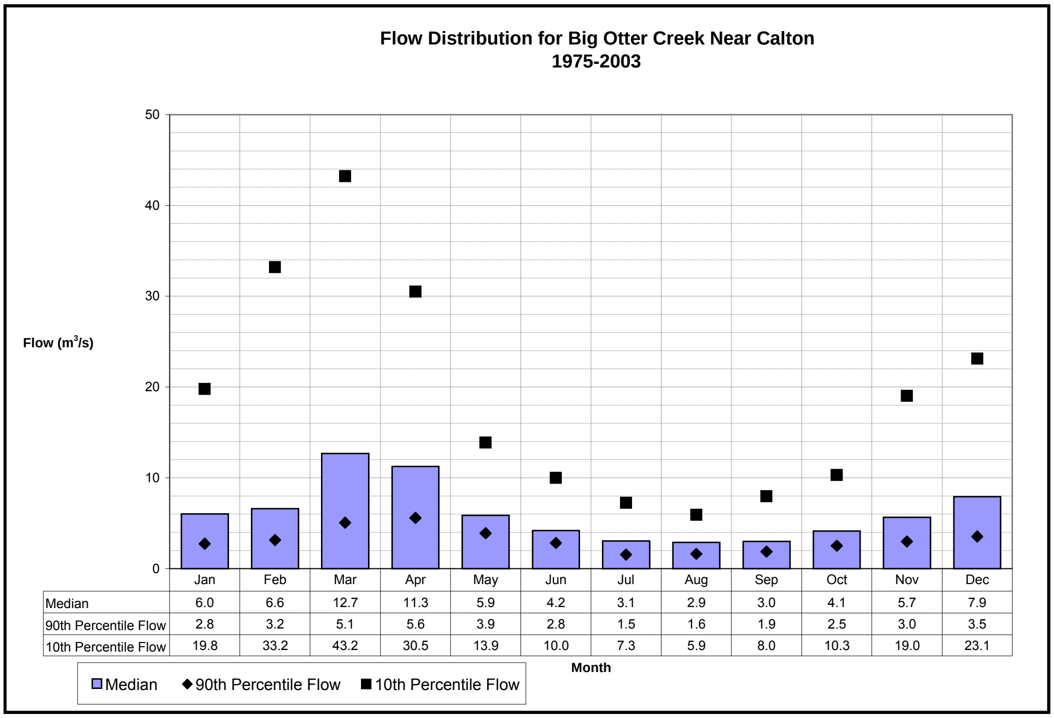
Otter Creek, joins Big Otter Creek past Straffordville. Little Otter is classified as a cold water stream and drains approximately 117 km^2.

There are three active gauges in the Big Otter Creek Watershed. The first one is located in the upper part of the watershed above Otterville, and it was installed in 1964. The second gauge is located at the Town of Tillsonburg. This gauge is the oldest active gauge in the watershed and has been in operation since 1960, except for a brief period from 1998-2002 where flow levels were not taken; however, water levels were continuously recorded during this time. The third gauge is located near the community of Calton, and it has been in operation since 1975 and captures approximately 95% of the drainage area including Little Otter Creek. Prior to 1975 the gauge was located downstream near the community of Vienna where it had been in operation since 1948. The flow distribution at the Calton gauge is illustrated in Figure 2.11.

The distribution in Figure 2.11 shows both a runoff component with high 10^{th} percentile flows in the spring and a strong groundwater fed baseflow component with steady median and 90^{th} percentile low flows throughout the summer months.

There are two reservoirs on Big Otter Creek; the Norwich Dam in Norwich, and the Otterville Dam in Otterville. The Norwich Dam is operated by LPRCA and its functions include supporting recreational activities, water supply, flood control and flow augmentation; the flow through the dam is controlled by a control valve. The Otterville Dam is passively operated by the municipality. There are also numerous small, private control structures within the watershed that are used to store water for irrigation in the summer months.

Also grouped with the Big Otter Watershed are the Lake Erie tributaries, South Otter and Clear Creeks. South Otter Creek drains an area of approximately 111 km^2 adjacent to the lower portion of Big Otter Creek along the Lake Erie shoreline. Clear Creek is similar in size and drains an area of approximately 106 km^2 to the east of South Otter Creek. Both creeks are within the Norfolk Sand Plain and are characterized by low runoff, high infiltration, and groundwater fed baseflows. There are no active gauges in this watershed grouping, but there was an historic gauge located on South Otter Creek near its outlet to Lake Erie at Port Burwell. The gauge operated from 1964 to 1978.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	6.0	6.6	12.7	11.3	5.9	4.2	3.1	2.9	3.0	4.1	5.7	7.9
90th Percentile Flow	2.8	3.2	5.1	5.6	3.9	2.8	1.5	1.6	1.9	2.5	3.0	3.5
10th Percentile Flow	19.8	33.2	43.2	30.5	13.9	10.0	7.3	5.9	8.0	10.3	19.0	23.1

Figure 2.11 - Flow Distribution for Big Otter Creek near Calton Gauge

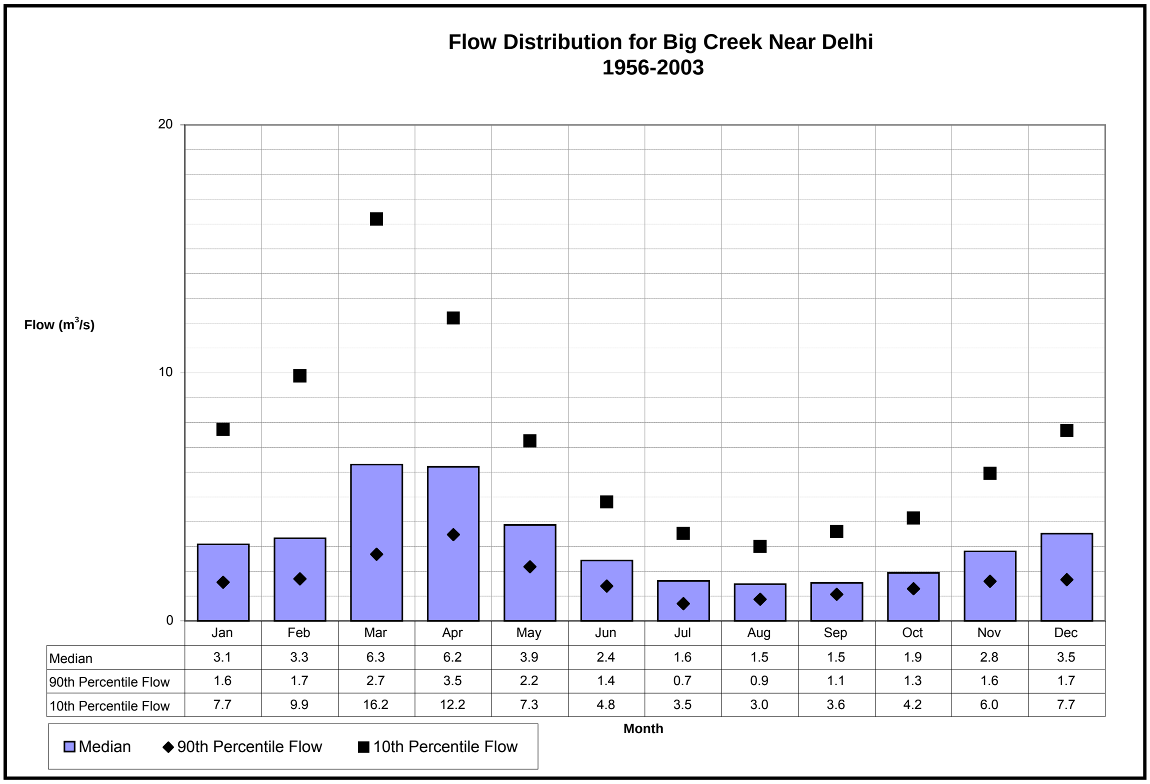
2.11.7.1.2 BIG CREEK

Big Creek is the largest watercourse in the Long Point Region with a total drainage area of 750 km^2. Big Creek headwaters are at the most northerly part of the region. The creek flows predominately southward through the community of Delhi, where it joins with North Creek through Lehman's Reservoir. From Delhi, stream flow continues southward picking up Venison Creek downstream of Walsingham and finally draining into Lake Erie near Port Rowan.

Big Creek contains portions of the Norfolk Sand Plain, and is characterized by very low runoff and high baseflow. Water use within the drainage area is significant with over 1,000 permits to take water or approximately one and a half permits per square kilometre. Irrigation is the primary water use within the watershed and unmonitored water takings have the potential to reduce summer flows in the creek.

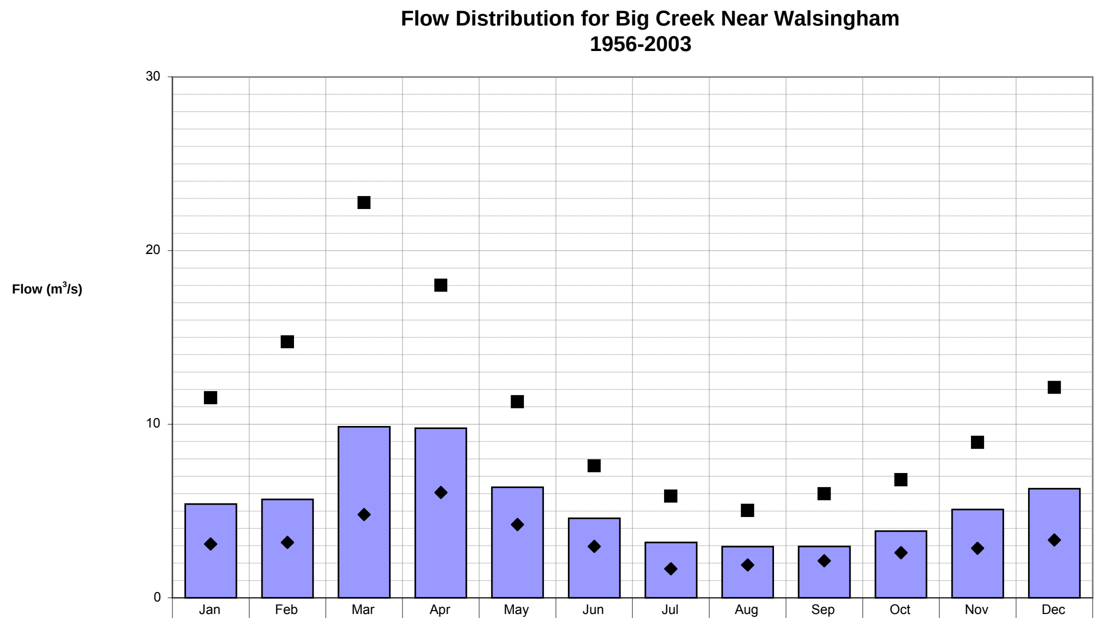
There are three reservoirs in the Big Creek Watershed; Teeterville, Lehman and Deer Creek Reservoirs. The Teeterville Reservoir is located in the upper portion of the watershed on Big Creek, and it is used for recreation, flood control, and low flow augmentation. Lehman's Reservoir is located in the community of Delhi on North Creek and it is used for recreation (shore fishing) and to supplement the community of Delhi's drinking water supply. The final reservoir is located on Deer Creek, a tributary of Big Creek. Most of the Big Creek tributaries have small private dams and reservoirs used for irrigation.

Flow distribution plots for two gauges on Big Creek, Big Creek Near Delhi, and Big Creek at Walsingham are included in Figures 2.12 and 2.13, respectively. The narrow range of median, 10^{th} and 90^{th} percentile flows in Figures 2.12 and 2.13 show the moderating effects of large annual recharge amounts, significant groundwater storage volumes, and reservoir operations upstream of the gauge. There is a very high baseflow component throughout the year with fairly steady median and 90th percentile flows.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	3.1	3.3	6.3	6.2	3.9	2.4	1.6	1.5	1.5	1.9	2.8	3.5
90th Percentile Flow	1.6	1.7	2.7	3.5	2.2	1.4	0.7	0.9	1.1	1.3	1.6	1.7
10th Percentile Flow	7.7	9.9	16.2	12.2	7.3	4.8	3.5	3.0	3.6	4.2	6.0	7.7

Figure 2.12 - Flow Distribution for Big Creek near Delhi Gauge



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	5.4	5.7	9.9	9.8	6.4	4.6	3.2	3.0	3.0	3.9	5.1	6.3
90th Percentile Flow	3.1	3.2	4.8	6.1	4.2	3.0	1.7	1.9	2.1	2.6	2.9	3.3
10th Percentile Flow	11.5	14.8	22.8	18.0	11.3	7.6	5.9	5.0	6.0	6.8	9.0	12.1

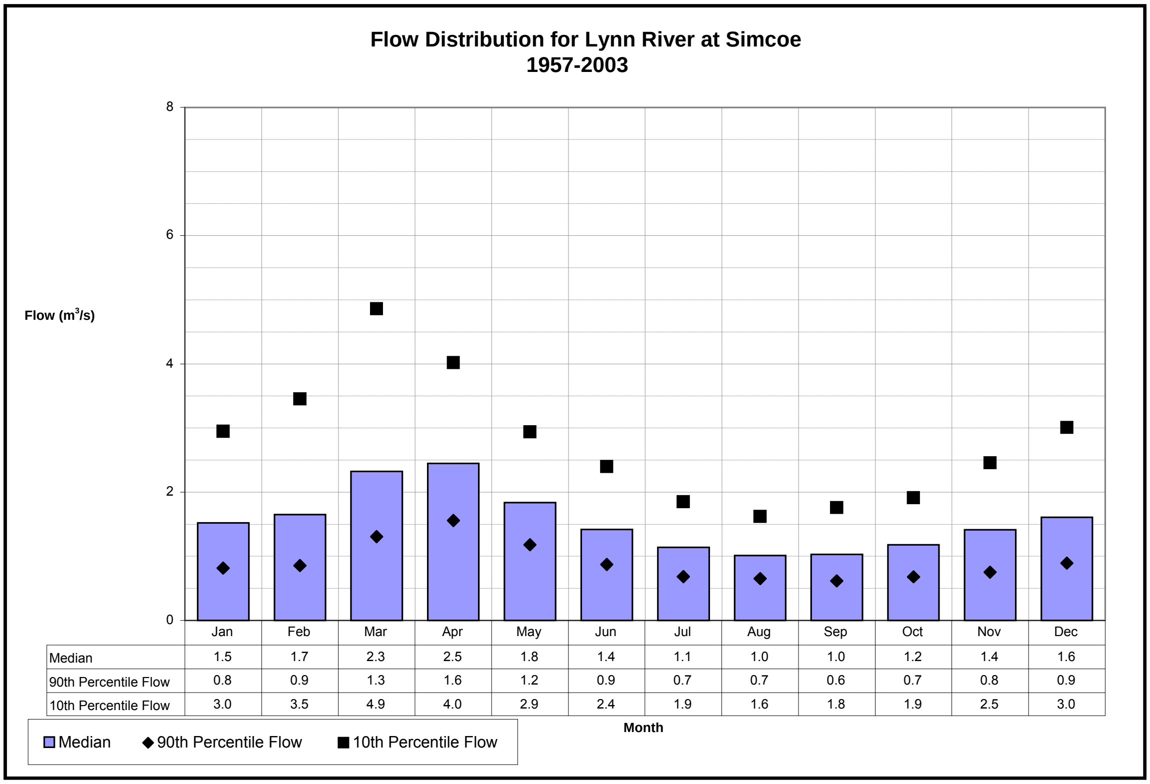
Figure 2.13 - Flow Distribution for Big Creek near Walsingham Gauge

Also included in the Big Creek Watershed is the Dedrick Creek subwatershed, and numerous tributaries that drain directly into Lake Erie. The subwatershed lies mainly within the Norfolk Sand Plain. With groundwater fed creeks and streams, the area contains several coldwater fisheries. While there are no active stream gauges within Dedrick Creek or the smaller tributaries, there is a historical (1963 to 1984) gauge on Dedrick Creek near Port Rowan.

2.11.7.1.3 LYNN RIVER

The Lynn River flows from north of the community of Simcoe to the southeast to Lake Erie at Port Dover. It is joined by Black Creek in Port Dover just prior to draining into Lake Erie. The combined drainage area of this watershed group is approximately 285 km^2.

The watershed drains two different portions of the region; the first is a portion of the Norfolk Sand Plain where there is low surface runoff, high recharge amounts, and sustained baseflows. And the second is the Haldimand Clay Plain drained by Black Creek. This watershed is characterized by high runoff, low baseflows, and predominantly warmwater fish communities.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	1.5	1.7	2.3	2.5	1.8	1.4	1.1	1.0	1.0	1.2	1.4	1.6
90th Percentile Flow	0.8	0.9	1.3	1.6	1.2	0.9	0.7	0.7	0.6	0.7	0.8	0.9
10th Percentile Flow	3.0	3.5	4.9	4.0	2.9	2.4	1.9	1.6	1.8	1.9	2.5	3.0

Figure 2.14 - Flow Distribution for Lynn River at Simcoe Gauge

There is one active stream gauge on the Lynn River and it is located in the Village of Simcoe. It has been in continuous operation since 1957, and the flow regime for this gauge is illustrated on Figure 2.14. There are also two controlled reservoirs on the Lynn River, Crystal Lake (Quance Dam) in Simcoe and Silver Lake (Misner Dam) in Port Dover. There are no stream gauges on Black Creek.

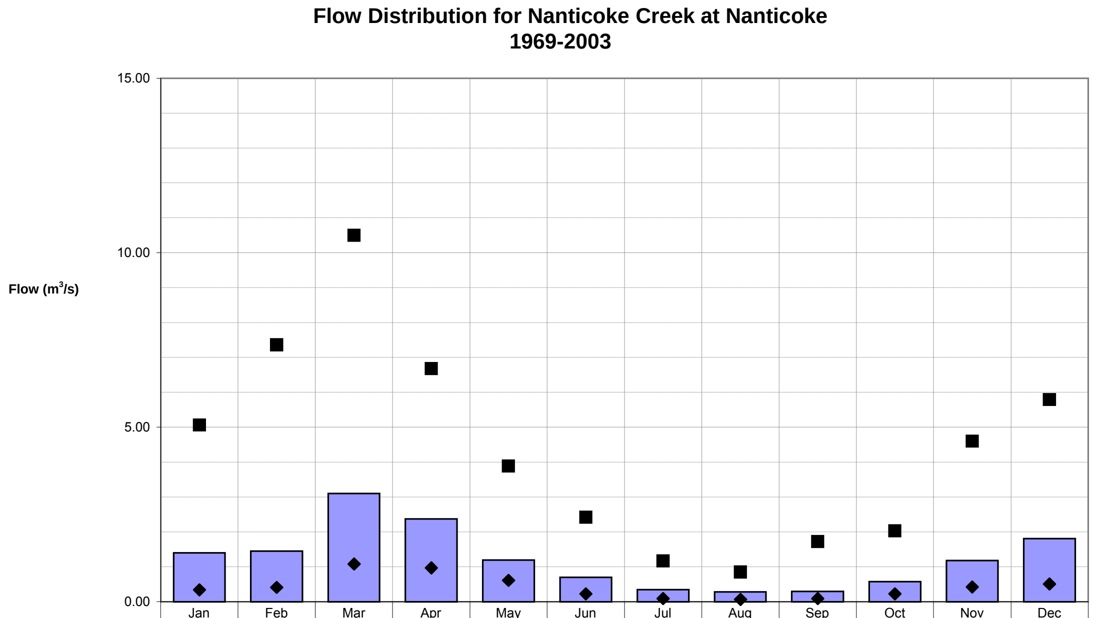
The narrow monthly flow distribution and high baseflows show the moderating influence of the Norfolk Sand Plain and the small drainage area upstream of the gauge.

Young and Hay Creeks are also included in this watershed group. These Lake Erie tributaries drain a portion of the Norfolk Sand Plain, just to the west of the Lynn River. There are two reservoirs, both used for recreation, the Hay Creek Dam on Hay Creek and Vittoria Pond on Young Creek.

There is one reactivated stream gauge on Young Creek downstream of the Vittoria Pond Reservoir which has been in operation for various periods since 1963.

2.11.7.1.4 NANTICOKE CREEK

The headwaters of Nanticoke Creek contain cool water fisheries, as these headwaters sit within the Norfolk Sand Plain where groundwater discharge is strong. The Creek migrates through the Waterford Ponds, a series of lakes, ponds, and wetlands in the community of Waterford. Nanticoke Creek fisheries mapping suggests the fish communities contain warmwater species where the creek passes into the Haldimand Clay Plain outside Waterford. There is one stream gauge on Nanticoke Creek near Nanticoke which captures most of the Watershed. The gauge has been in operation since 1969 and its flow distribution is given in Figure 2.15.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	1.40	1.46	3.10	2.38	1.20	0.70	0.35	0.28	0.30	0.58	1.18	1.81
90th Percentile Flow	0.34	0.41	1.08	0.97	0.61	0.23	0.09	0.06	0.09	0.23	0.42	0.51
10th Percentile Flow	5.06	7.36	10.50	6.68	3.89	2.42	1.17	0.85	1.72	2.03	4.60	5.79

Figure 2.15 - Flow Distribution for Nanticoke Creek at Nanticoke Gauge

Low flows, shown by 90th percentile flow, are very low throughout the year. Median flows are also low during the summer months. The wide monthly distribution shows a large runoff component to the flow regime as is expected from the influence of the Haldimand Clay Plain.

2.11.7.1.5 EASTERN TRIBUTARIES

The watershed grouping that makes up the Eastern Tributaries includes such watercourses as Sandusk, Stoney, Evans, Hickory and Fories-Stelco Creeks. These small watercourses drain directly into Lake Erie and their drainage areas are entirely contained within the Haldimand Clay Plain. They have high runoff and very little baseflow. There are no active stream gauges within this Watershed; however there are two historical gauges on Sandusk Creek, which operated for a short time in the 1990's.

2.11.7.2 Catfish Creek Conservation Authority

Table 2.15 summarizes the simplified surficial geology and physiography of each of the Catfish Creek subwatersheds. This summary was calculated from hydrologic response unit mapping produced by the GRCA. The land areas may be classed further as hummocky or non-hummocky, which may indicate closed drainage areas resulting in higher recharge rates and reduced runoff.

Table 2.15 - Catfish Creek Subwatershed Characteristics

	Area (km^2)	Impervious	Wetland	Urban	Clayey Tills	Silty Tills	Sandy Till	Sand & Gravel	Hummocky
Catfish Creek	392	1%	0%	1%	14%	62%	1%	21%	10%
West Catfish	147	1%	0%	0%	16%	80%	1%	3%	19%
Catfish Above Aylmer	143	1%	0%	1%	16%	59%	0%	22%	7%
Lower Catfish	103	1%	0%	1%	10%	40%	1%	46%	2%
Silver Creek	95	2%	0%	0%	3%	40%	0%	55%	1%

Catfish Creek and its Lake Erie tributaries drain approximately 490 km^2. The surficial materials of the Watershed dominate the surface hydrology. Upper and western portions of the Watershed are largely comprised of Ekfrid Clay Plain with high surface runoff and little soil infiltration. The lower and eastern portions of the Watershed contain areas of Norfolk Sand Plain with little runoff and high groundwater recharge, but also high irrigation water use. The Watershed can be broken down into three subwatersheds: Upper Catfish Creek, Lower Catfish Creek, and the Lake Erie tributaries.

The Catfish Creek watershed is predominantly influenced by two hydrologic processes: surface runoff and shallow groundwater-surface water interactions. In the north-western portion of the watershed, the surficial geology is predominantly Port Stanley Till, a fine-grained clay till with a low permeability. This surficial geology acts as an aquitard, inhibiting water flow through the upper overburden layers and creating an effective barrier between the surface water and groundwater systems. Subsequently the surface water hydrology of this area is almost entirely driven by runoff.

Lower in the watershed groundwater has a larger influence in the surface water flow regime. The southeastern portion of the watershed contains deposits of coarse-grained sands and gravels, part of the Norfolk Sand Plain. This highly permeable surficial geology allows water to flow through it fairly easily with points of recharge and discharge throughout the area. Watercourses in this area have higher and more stable baseflows as a result of the addition of discharge from groundwater to runoff flow.

The following sections describe hydrologic conditions throughout the watersheds, and make reference to a series of charts summarizing monthly flow distributions at selected gauges. These charts show median monthly flow, the 10^{th} percentile monthly flow, and the 90^{th} percentile monthly flow. The median monthly flow can be considered to represent typical streamflow conditions. The 90^{th} percentile monthly flow can be considered to represent low flows, and the 10^{th} percentile monthly flow can be considered to represent high flows.

2.11.7.2.1 UPPER CATFISH CREEK

Much of the subwatershed is comprised of Ekfrid Clay Plain. This relatively flat terrain with little soil infiltration has caused the need for extensive drainage networks for agriculture. As a result much of the area has been tiled and many watercourses re-channelized changing the natural drainage characteristics of the subwatershed.

There are three branches in the Upper Catfish Creek Subwatershed: West Catfish Creek, East Catfish Creek, and Catfish Creek. The West and East branches of Catfish Creek drain approximately 103 km^2 of Ekfrid Clay Plain in the western and central portions of the subwatershed. These branches are characterized by high runoff and low recharge. Flow can be quite low during the summer months. There are no stream gauges located on the West and East branches of Catfish Creek.

The main branch of Catfish Creek originates in the northeastern portion of the watershed and flows in a southwesterly direction to the Town of Aylmer. It then joins with the East and West branches of Catfish Creek west of the Town of Aylmer. The upper branch of Catfish Creek drains approximately 143 km^2 of mostly Ekfrid Clay Plain, but the main channel of the creek runs through Norfolk Sand Plain. This allows for higher baseflows than in the West and East Catfish branches. It also leads to higher water use for irrigation. There is one stream gauge located within the Town of Aylmer on the main branch of Catfish Creek that has been in operation periodically since 1987.

2.11.7.2.2 LOWER CATFISH CREEK

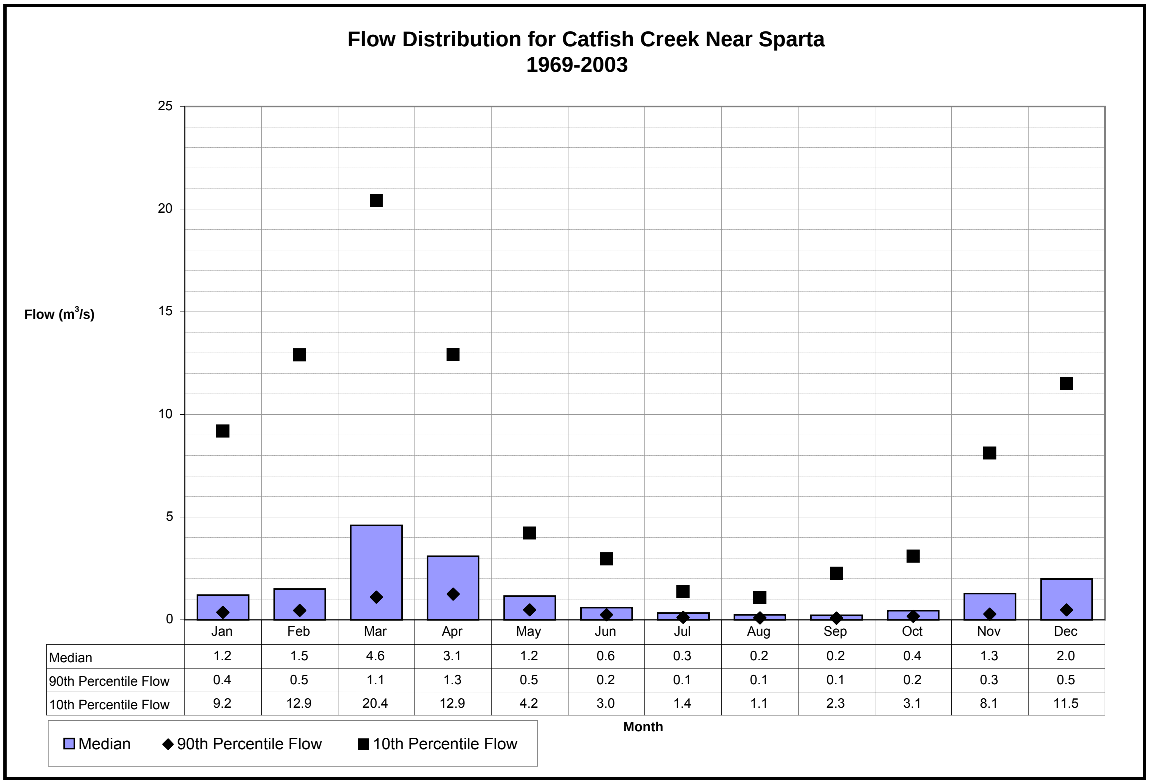
Catfish Creek has two major tributaries, Nineteen Creek and Bradley's Creek, as well as numerous minor tributaries that join with the main branch of Catfish Creek between the confluence of the upper branches of Catfish Creek to the outlet at Lake Erie.

Nineteen Creek drains an area of approximately 41 km^2 in the most western part of the Watershed. Although most of the drainage area consists of agricultural land uses, part of the urban area of City of St. Thomas is also in the Subwatershed. Flows in the creek are variable because of the high runoff and low groundwater recharge in the till plain drainage area. There is no stream gauge on Nineteen Creek.

Nineteen Creek joins Catfish Creek upstream of the Catfish Creek near Sparta stream gauge. This is the last gauge on Catfish Creek before it discharges into Lake Erie, and has been in operation since 1964. The gauge captures 290 km^2 of the watershed or approximately 74% of the area drained by Catfish Creek, and the flow regime for the Catfish Creek at Sparta gauge is shown in Figure 2.16.

High flows are flashy as shown by the difference between median and 10th percentile flows. Baseflows, as shown with 90th percentile flows, are low and variable throughout the year. This distribution is typical of a runoff dominated system with drainage characteristics of the till plain.

Bradley's Creek joins Catfish Creek less than one kilometre downstream of the Catfish Creek near Sparta gauge. The watershed of Bradley's Creek has a drainage area of approximately 28 km^2 and contains the only controlled reservoir within the Catfish Creek watershed. Springwater Reservoir is used primarily for recreation and has two spillways with stop logs and a sluice gate as a control structure. Bradley's Creek subwatershed lies mainly within the Norfolk Sand Plain. This area is characterized by higher recharge rates than runoff rates. There are a number of significant wetland features within this watershed as well. There is no stream gauge on Bradley's Creek.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	1.2	1.5	4.6	3.1	1.2	0.6	0.3	0.2	0.2	0.4	1.3	2.0
90th Percentile Flow	0.4	0.5	1.1	1.3	0.5	0.2	0.1	0.1	0.1	0.2	0.3	0.5
10th Percentile Flow	9.2	12.9	20.4	12.9	4.2	3.0	1.4	1.1	2.3	3.1	8.1	11.5

Figure 2.16 - Flow Distribution for Catfish Creek near Sparta Gauge

The lower portions of Catfish Creek run through a steep sloped valley with a well defined floodplain. The creek widens significantly as it approaches the outlet to Lake Erie at Port Bruce. Catfish Creek drains a total area of approximately 392 km^2.

2.11.7.2.3 SILVER CREEK

Along the Lake Erie shoreline on the east side of Catfish Creek are a number of small watersheds that drain directly into Lake Erie. The largest is Silver Creek with a drainage area of approximately 41 km^2. Much of the drainage area of Silver Creek is sand plain with high rates of groundwater recharge and low runoff. Flows in the creek can be greatly affected by water taking for irrigation purposes. There was an historic stream gauge located on Silver Creek near Copenhagen that was in operation from 1970 to 1978.

The remaining small watercourses along the shoreline are within the sand plain or sand plain that is interspersed with silt till, and they drain a total area of approximately 55 km^2.

2.11.7.3 Kettle Creek Conservation Authority

Table 2.16 summarizes the simplified surficial geology and physiography of each of the Kettle Creek subwatersheds. This summary was calculated from hydrologic response unit mapping produced by the GRCA. The land areas can be further classified as hummocky, which may indicate closed drainage areas resulting in higher recharge rates and reduced runoff.

Table 2.16 - Kettle Creek Subwatershed Characteristics

	Area (km^2)	Impervious	Wetland	Urban	Clayey Tills	Silty Tills	Sandy Till	Sand & Gravel	Hummocky
Kettle Creek	479	1%	0%	2%	10%	72%	0%	13%	20%
Upper Kettle	199	1%	0%	2%	10%	80%	0%	7%	22%
Dodd Creek	131	1%	0%	0%	12%	76%	0%	11%	11%
Lower Kettle	148	2%	0%	5%	10%	59%	0%	24%	24%

Kettle Creek is predominantly a surface water driven system with a clay-rich till plain covering the majority of the watershed. The low permeability of the till cover tends to inhibit infiltration and produce large quantities of runoff during rain events. Flows in the creek, which pass quickly through the watershed due in part to the steep elevation drop between the headwaters in the north and the outlet to Lake Erie and the nature of the till cover, tends to result in low baseflows and flashy flood events. Groundwater has little influence on the surface water system except in the headwaters where Kettle Creek is fed by a groundwater maintained kettle lake and in the southeast corner where a shallow groundwater system contributes to a cool water fishery in Beaver Creek.

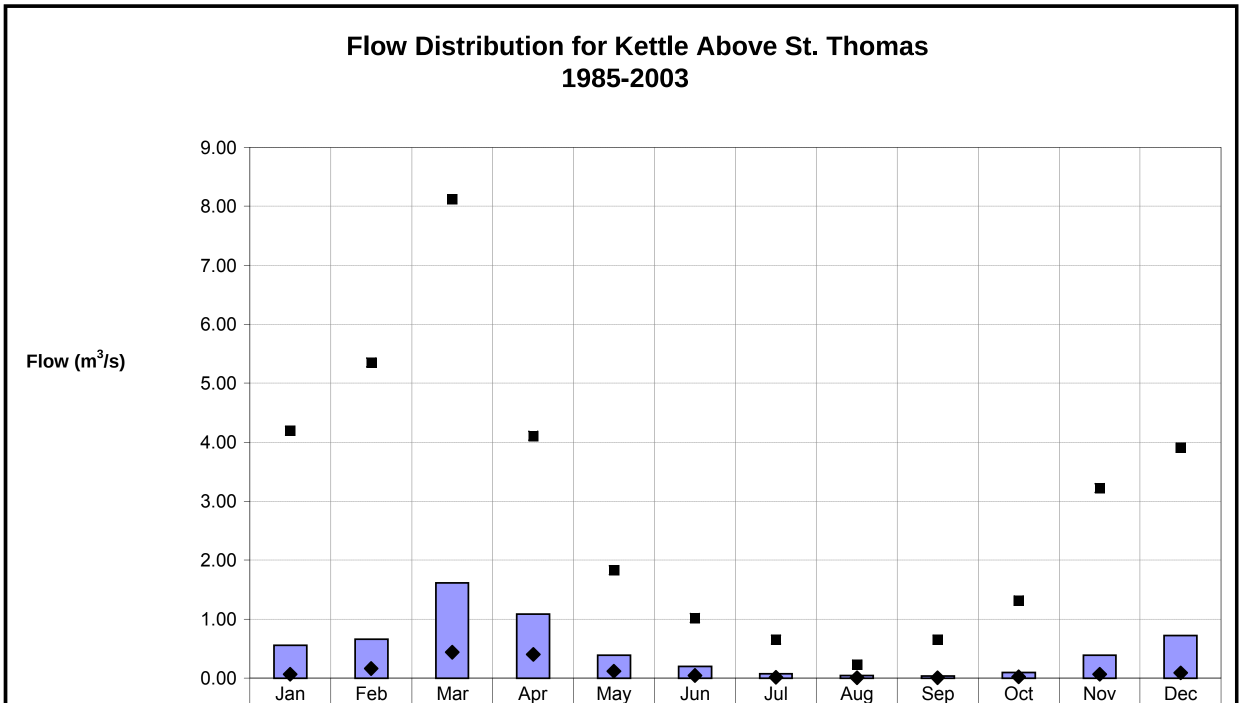
The following sections describe hydrologic conditions throughout the watersheds, and make reference to a series of charts summarizing monthly flow distributions at selected gauges. These charts show median monthly flow, the 10^{th} percentile monthly flow, and the 90^{th} percentile monthly flow. The median monthly flow can be considered to represent typical streamflow conditions. The 90^{th} percentile monthly flow can be considered to represent low flows, and the 10^{th} percentile monthly flow can be considered to represent high flows.

2.11.7.3.1 UPPER KETTLE CREEK

The main branch of Kettle Creek originates at Lake Whittaker in the northeast corner of the Watershed. The lake is an 11 ha, groundwater fed kettle lake that provides moderate baseflows to Kettle Creek throughout the year barring severe drought conditions. The subwatershed has clay and silt till soils, and has been cleared and drained for agriculture. The landscape produces high runoff and low recharge.

The Upper Kettle Creek Watershed contains the largest water storage reservoir in the watershed, Dalewood Reservoir. The reservoir's original purpose was to supply water to the City of St. Thomas, but has since been acquired by KCCA and is used for flood control and low flow augmentation.

There is a stream gauge located above St. Thomas on Kettle Creek. It captures a drainage area of 135 km^2 and has been in operation since 1985. The flow distribution for this gauge is shown on Figure 2.17. The Upper Kettle Creek subwatershed drains an area of approximately 200 km^2 before it joins with Dodd creek near St. Thomas.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	0.56	0.66	1.62	1.09	0.39	0.20	0.07	0.04	0.04	0.10	0.39	0.72
90th Percentile Flow	0.07	0.17	0.44	0.40	0.12	0.04	0.02	0.01	0.01	0.03	0.06	0.09
10th Percentile Flow	4.20	5.35	8.12	4.11	1.83	1.02	0.66	0.23	0.66	1.32	3.22	3.91

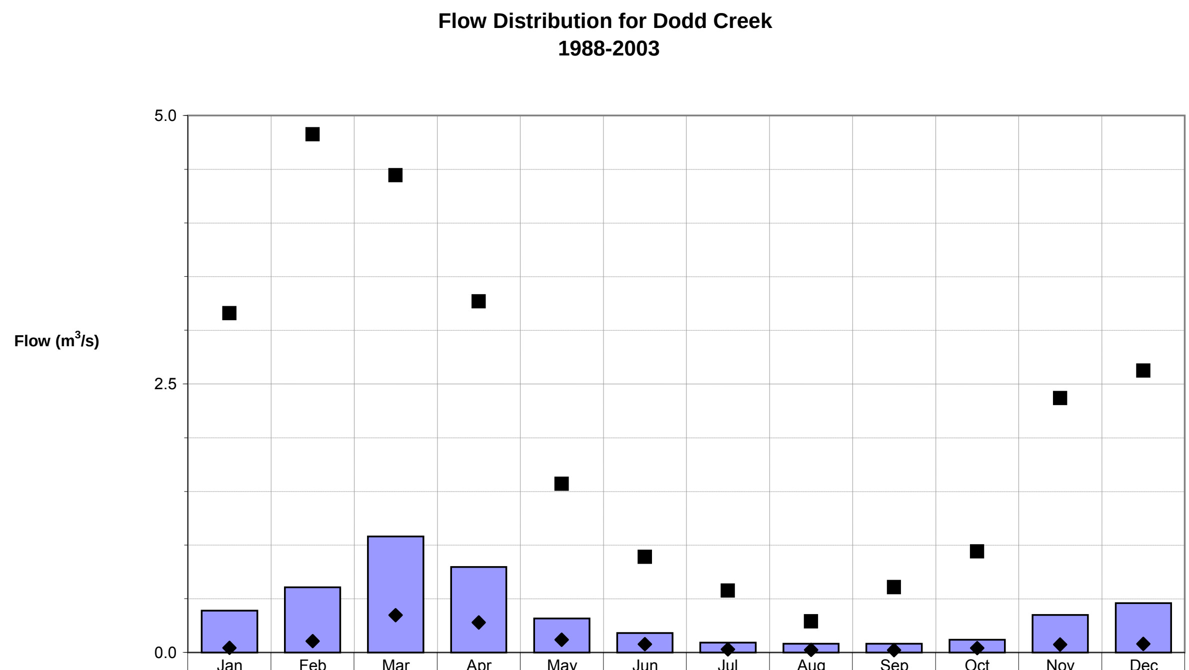
Figure 2.17 - Flow Distribution for Upper Kettle

2.11.7.3.2 DODD CREEK

Dodd Creek is Kettle Creek's largest tributary, with a drainage area of approximately 130 km^2. The headwaters of Dodd Creek are in the northwest corner of the watershed. The creek flows south and west until it joins with Kettle Creek near the City of St. Thomas. Land use in the subwatershed is primarily agricultural. This relatively flat clay plain has little vegetation cover and few wetland features. The subwatershed is characterized by high runoff and little groundwater recharge. As a result, there is little continuous baseflow.

There is one stream gauge located on Dodd Creek. The gauge is located below Payne's Mill and covers a drainage area of approximately 95 km^2. The Water Survey of Canada has used the gauge since 1987, and the gauge's flow distribution is illustrated on Figure 2.18.

High flows are very flashy as shown by the difference between median and 10th percentile flows and the low median flows. Baseflows, as shown with 90th percentile flows, are extremely low and variable throughout the year. This distribution is typical of a non-regulated, runoff dominated system.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	0.39	0.61	1.08	0.80	0.32	0.18	0.09	0.08	0.08	0.12	0.35	0.46
90th Percentile Flow	0.04	0.11	0.35	0.28	0.12	0.08	0.03	0.03	0.02	0.04	0.07	0.08
10th Percentile Flow	3.16	4.83	4.45	3.27	1.57	0.89	0.58	0.29	0.61	0.94	2.37	2.63

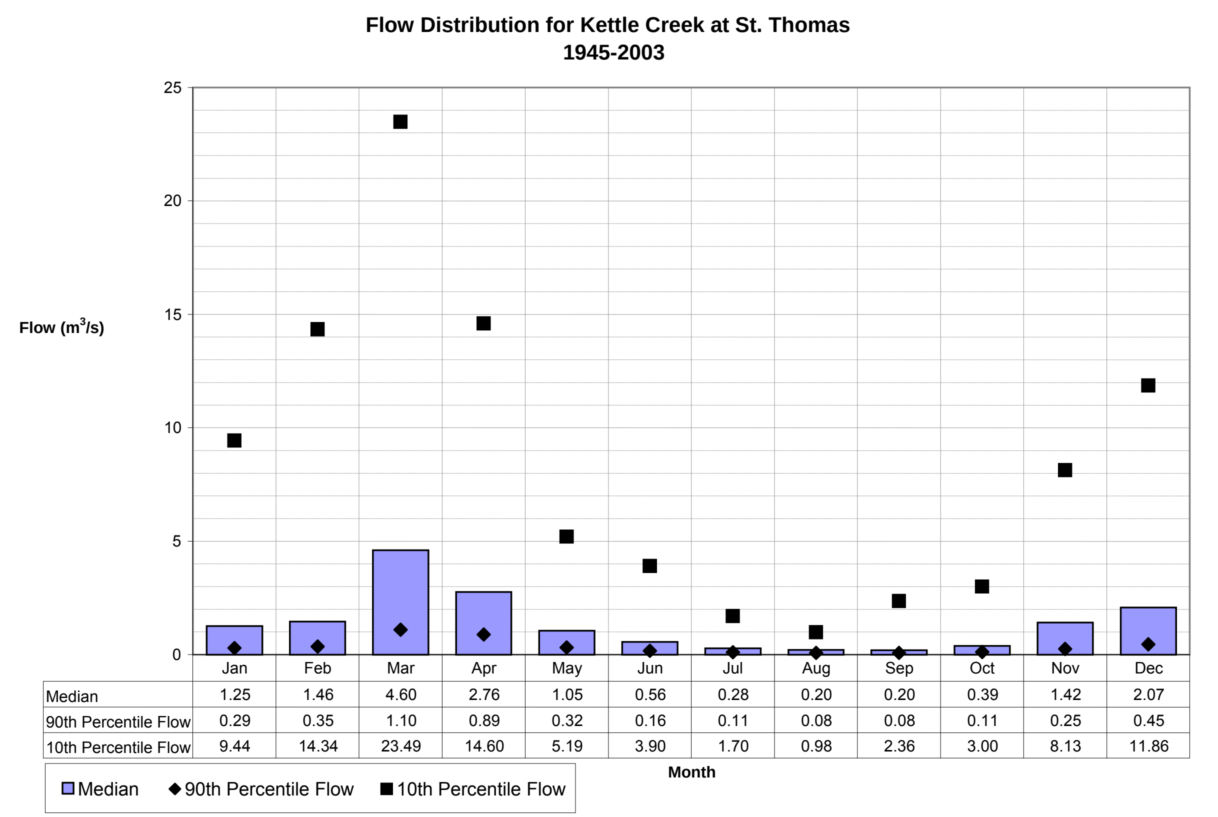
Figure 2.18 - Flow Distribution of the Dodd Creek Gauge

2.11.7.3.3 LOWER KETTLE CREEK

The Lower Kettle Creek Subwatershed begins at the confluence of Kettle Creek and Dodd Creek. The most southerly gauge on Kettle Creek is located near St. Thomas just downstream of the confluence of Dodd Creek and Kettle Creek. It has been in operation since 1945, and captures a drainage area of approximately 330 km^2 or 66% of the Kettle Creek watershed. The flow distribution for the Kettle Creek at St. Thomas gauge is shown in Figure 2.19.

High flows are flashy as shown by the difference between median and 10th percentile flows and the low median flows. Baseflows, as shown with 90th percentile flows, are very low throughout the year. This distribution is typical of a runoff dominated system and drainage characteristics of till plain.

Unlike the upper part of the watershed, Lower Kettle Creek contains more sandy soils. This part of the Watershed has higher recharge and lower runoff than the silt and clay tills of the upper portions. One example is Beaver Creek, a tributary of Kettle Creek which drains an area on the eastern side of the Watershed. Beaver Creek is a cool water fishery supported by forest cover, wetland features, and relatively high baseflows. Kettle Creek empties into Lake Erie at Port Stanley.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Median	1.25	1.46	4.60	2.76	1.05	0.56	0.28	0.20	0.20	0.39	1.42	2.07
90th Percentile Flow	0.29	0.35	1.10	0.89	0.32	0.16	0.11	0.08	0.08	0.11	0.25	0.45
10th Percentile Flow	9.44	14.34	23.49	14.60	5.19	3.90	1.70	0.98	2.36	3.00	8.13	11.86

Figure 2.19 - Flow Distribution for the Kettle Creek at St. Thomas Gauge

Numerous small watercourses along the Lake Erie shoreline drain directly into Lake Erie. They drain a total area of approximately 80 km^2 with the largest draining 11.5 km^2 and the smallest less than 0.5 km^2. These watercourses are extremely steep with well defined valley sections. There are no flow gauges located on any of these small watercourses.

2.12 WATER-SUPPLY SYSTEMS

2.12.1 Municipal Systems

Municipal water use is defined as the supply of water that is provided to community residents, commercial, institutional or other users through a central distribution system that is operated by a municipality. Municipal water use includes urban domestic use (indoor or outdoor), and also includes uses for industrial, commercial, institutional or other users that rely on municipalities for their water supply.

2.12.1.1 Long Point Region Conservation Authority

A large portion of the Norfolk Sand Plain lies within the Long Point Region. As discussed in previous sections, the Sand Plain contains a shallow unconfined aquifer system which is widely used for domestic and municipal water supply. Municipalities within the Long Point Region that rely on groundwater sources include the towns and villages of Simcoe, Tillsonburg, Courtland, Waterford, Norwich, Otterville, Springford, Straffordville, and Dereham Centre. Communities located adjacent to Lake Erie use the lake itself for municipal water. Communities reliant on Lake Erie for their water supply include Port Rowan, Port Dover, Hagersville, Jarvis and Townsend. Some communities to the west within the Municipality of Bayham, Township of Malahide, in Elgin County also obtain their water supplies from Lake Erie. Delhi has the only in-land surface water supply, and it obtains its water from North Creek, a tributary of Big Creek, but also obtains municipal water from groundwater wells. Municipal water use within the watershed is estimated at 10.4 million m^3/yr, and this volume services approximately 60,000 residents. Municipal wells and surface water intakes are illustrated on Map 2.19a and 2.20a, respectively.

2.12.1.1.1 VILLAGE OF DEREHAM

The Dereham Centre system services a population of approximately 48 people. A new groundwater supply well and treatment facility were constructed during fall 2004 and began operating in January, 2005. A new reservoir, pumphouse, all controls and monitoring equipment, standby power and distribution system water mains and curb stops were also installed. Water is treated with sodium hypochlorite for disinfection and sodium silicate for iron sequestration.

2.12.1.1.2 TOWN OF NORWICH

The Norwich water supply system consists of three groundwater supply wells (Wells 1, 2 and 4) that service a population of approximately 2,600 people. Well 3 was taken off-line in the late 1990’s due to poor water quality. The town has found that additional water resources were needed when Well 1 was abandoned due to its age and poor condition. Well 2 was rehabilitated in 2008, and a new well (Well 5) was drilled and tested. The town is faced with a few options to increase the capacity of the system including making adjustments to their existing permits and bringing Well 5 online, or the community can search for a new well and source. The wells, pumphouse and treatment facility are connected to a water tower which provides 1,818 m^3 of storage. Water is treated with sodium silicate to sequester iron.

2.12.1.1.3 VILLAGES OF OTTERVILLE AND SPRINGFORD

The Otterville-Springford water supply system consists of four groundwater wells. Springford and Otterville each have two wells and a treatment/pumping facility. A 1,440 m^3 water tower is located in Otterville. The communities are connected by a 3.3 km water main with no service connections between the communities.

2.12.1.1.4 TOWN OF TILLSONBURG

The Tillsonburg Well Supply consists of 10 overburden groundwater wells that are treated and distributed from six treatment facilities within and surrounding Tillsonburg. The system supplies drinking water to a population of approximately 14,000 people. Each pumphouse has one to three wells, a contact reservoir on site, disinfection and monitoring equipment. Each pumphouse can supply the distribution system directly and storage is provided by a 9,100 m^3 reservoir. Sodium silicate for sequestering iron is added at the Broadway, Bell Mill and Mall Road pumphouses. All water is treated with chlorine gas and sodium hypochlorite for disinfection.

Several of the wells (Wells 1A, 2, 4, 5, 7, 9 and 10) have been identified as Groundwater Under the Direct Influence of Surface Water (GUDI) wells, whereas Wells 6, 11 and 12 are found to be non-GUDI groundwater wells.

Wells 1A, 2, 9, 10, 11 and 12 lie to the southeast of Tillsonburg in the Norfolk Sand Plain. Wells 4, 5, 6 and 7 are located in the Township of South-West Oxford, to the north of Big Otter Creek and Stony Creek.

2.12.1.1.5 TOWN OF DELHI AND VILLAGE OF COURTLAND

The Delhi water supply system is supplied by both groundwater wells and surface water intakes that service the communities of Delhi and Courtland (population of approximately 6,000). There are two groundwater supply wells sources, a surface water filtration plant, and a water standpipe. The Delhi Surface Water Treatment Plant treats raw water from the Lehman Dam Reservoir (a surface water impoundment on North Creek, a tributary to Big Creek). The filtration plant has a rated capacity of 4,543 m^3/day.

Overburden in the area consists of glaciolacustrine silt and clay, glaciofluvial outwash sand and gravel, and glaciofluvial ice-contact deposits consisting of sand and gravel as well as some till and silt. The primary aquifer for the Delhi municipal groundwater wells is the sand and gravel deposits, which are intercalated with clay material. The aquifer thickness varies from 5 to 35 m, and both municipal wells are completed at 39 m depth (screened from 30 to 39 m below ground surface). The wells are located east of Delhi in an area where the shallow and deeper aquifer systems appear to be interconnected.

2.12.1.1.6 SIMCOE

The Simcoe municipal water supply is a well-based system which consists of 9 raw water well sources, an infiltration gallery, 2 reservoirs and an elevated water storage tower. Water treatment consists of the addition of the following chemicals: sodium hypochlorite, sodium silicate, and hydrofluorosilicic acid.

The primary aquifer for the Simcoe municipal wells are the sand and gravel deposits surrounding the area, which are often intercalated with silty clay soils. The thickness of these aquifers varies from 5 to 25 m and the shallow aquifer units are generally interconnected with adjacent surface water bodies.

2.12.1.1.7 WATERFORD

The Waterford community is reliant on two groundwater wells for their municipal water supply. The system consists of two wells (Well 3 and Well 4), a manganese and iron removal plant, a reservoir and a water standpipe. Water treatment consists of the addition of the following chemicals: sodium hypochlorite, sodium permanganate, and polyaluminum chloride.

The primary aquifer for the Waterford municipal wells consists of fine gravel and sand deposits that range in thickness from 4 to 8 m. The wells are both shallow with Well 3 obtaining its water at a depth of 7.6 to 10.66 m below ground surface, and Well 4 at a depth of 10 to 13.08 m below ground surface.

2.12.1.1.8 ELGIN AREA WATER SUPPLY SYSTEM (PORT BURWELL AND AREA)

The Elgin Area Primary Water Supply System (EAPWSS) is owned by the EAPWSS Joint Board of Management but operated and maintained by American Water Services Canada Corp. This facility is located in the Municipality of Central Elgin along the north shore of Lake Erie in the town of Union, 2 km east of Port Stanley. Treated water from the EAPWSS is distributed to 7 municipalities (Aylmer, Bayham, Central Elgin, London, Malahide, Southwold and St. Thomas) through distribution systems owned and operated by the receiving municipality. The water treatment plant has a rated capacity of 91,000 m^3/ day and serves a population of approximately 94,400 people.

The EAPWSS services portions of the eastern section of Long Point Region, including the community of Port Burwell.

2.12.1.1.9 PORT DOVER

The Port Dover Water Supply System is owned and operated by the Corporation of Norfolk County and located in the town of Port Dover. The Port Dover Water Supply System consists of two conventional water treatment plants which extract and treat water from Lake Erie, at a design capacity of 12,800 m^3/day, and services a population of approximately 5,800.

2.12.1.1.10 PORT ROWAN AND ST. WILLIAMS

The Port Rowan Water Treatment Plant, owned and operated by the Corporation of Norfolk County, is a package plant which uses conventional treatment and treats surface water extracted from the Long Point inner bay on Lake Erie. This is a relatively new plant commissioned in the summer of 1992 which has a design capacity of 3,000 m^3/day that serves a population of approximately 1,300 from the towns of Port Rowan and St. Williams.

2.12.1.1.11 NANTICOKE, HAGERSVILLE, JARVIS AND TOWNSEND

The Nanticoke Water Treatment Plant (WTP), built in the 1970's, is owned by the Corporation of Haldimand County but operated and maintained by the Ontario Clean Water Agency (OCWA). This facility is located southwest of the Hamlet of Nanticoke and it extracts surface water from Lake Erie. The treated water is supplied for use in the communities of Hagersville, Jarvis and Townsend. Additionally, water is supplied to the Ontario Power Generation (OPG) Nanticoke Plant, Lake Erie Industrial Park, the Steel Company of Canada (Stelco) Lake Erie Works and the Texaco Oil Refinery. This water treatment plant has a rated capacity of 300,000 m^3/day and a Permit to Take Water rated at 1,820,000 m^3/day.

2.12.1.2 Catfish Creek Conservation Authority

Brownsville (approximately 500 residents) has the only groundwater source for municipal water takings in the Catfish Creek Conservation Authority. All other municipalities receive their drinking water from Lake Erie from either primary or secondary water systems from the Elgin Area Primary Water Supply System intake in Lake Erie, located near Port Stanley. These communities include Aylmer (approximately 2,600 residents), and smaller communities in Central Elgin and Malahide Townships. Municipal water use in this area totaled 1.3 million m^3 in 2004. Municipal wells are included in Map 2.19b. There are no municipal surface water intakes located within Catfish Creek.

2.12.1.2.1 COUNTY OF OXFORD, BROWNSVILLE

The Brownsville municipal water supply system obtains its water from two groundwater wells (Well 5 and Well 6) and within a pumphouse that includes a 197 m^3 storage reservoir. Both wells are completed within a deep overburden aquifer, with Well 5 screened in a confined sand and gravel layer approximately 45 m below ground surface. Well 6 is also screened in a confined sand and gravel aquifer approximately 28 m below ground surface. Water is treated with sodium hypochlorite for disinfection.

2.12.1.2.2 ELGIN AREA WATER SUPPLY SYSTEM (AYLMER AND MALAHIDE)

The EAPWSS supplies the majority of serviced communities within Catfish Creek with drinking water, including Aylmer and the municipality of Malahide.

2.12.1.3 Kettle Creek Conservation Authority

Belmont (population of 1,800) contains the only groundwater source for municipal water takings in the Kettle Creek Conservation Authority. All other municipalities receive their water from Lake Erie from either primary or secondary water systems from the Elgin Area Primary Water Supply System intake in Lake Erie, located near Port Stanley. These communities include St. Thomas (40,000 residents), and smaller communities in both Central Elgin and Southwold (9,000 residents). The water that is distributed via pipelines running through Elgin County also supplies approximately 25-30% of the rural and urban districts of the City of London both within and outside of the watershed region. Municipal water use totaled six million cubic metres in 2004 in this region. The location of the municipal water wells and surface water intakes in this area are illustrated on Maps 2.19c and 2.20b respectively.

2.12.1.3.1 CENTRAL ELGIN, TOWN OF BELMONT

The drinking water supply system for the Town of Belmont consists of two deep artesian wells, a pumphouse, underground reservoir and distribution system. The overburden aquifer is sand and gravel and is confined by a thick layer of clay.

2.12.1.3.2 ELGIN AREA PRIMARY WATER SUPPLY SYSTEM (SOUTHWOLD, LONDON, ST. THOMAS, CENTRAL ELGIN)

The EAPWSS supplies the majority of serviced communities within Kettle Creek with drinking water, including Southwold, London, St. Thomas and Elgin.

2.12.2 Private Drinking Water Supplies

2.12.2.1 Surface Water Sources

The only drinking water intake which extracts surface water directly from a reservoir or tributary within the Long Point Region is the Deer Creek Conservation Area. The remaining private surface water intakes that service the Long Point Region obtain their water directly from Lake Erie.

The Deer Creek Conservation Area is a small non-municipal seasonal drinking water plant and thus is regulated under the Safe Drinking Water Act through O. Reg. 252. It is privately owned and operated by the LPRCA. It draws drinking water out of the Deer Creek Reservoir (a 32 ha water body created following the construction of the Deer Creek Dam), and water is distributed only within the Conservation Area. The treatment process consists of filtration and disinfection through chlorination.

2.12.2.2 Groundwater Sources

Many rural residents in the Long Point Region watersheds are reliant on private groundwater wells for their source of drinking water. The locations and depths of these private domestic wells are useful for understanding the reliance on either a regional overburden aquifer or a bedrock aquifer. The MOE water well information system (WWIS) was used to locate all the domestic wells in the three conservation authorities to characterize the private groundwater sources. The oldest wells in the Study Area date back to the 1930s and it is unknown how many of these older wells remain in operation for domestic use today. Many of the wells in the database may have been drilled to replace abandoned or decommissioned wells. However, if the wells were not properly decommissioned and reported to the MOE, the original wells and the replacement wells remain in the MOE dataset. As there is insufficient information on which wells are still in operation and which ones are not used, all the wells in the database were used to characterize the source of water for private groundwater wells in the Long Point Region watersheds.

2.12.2.2.1 LONG POINT REGION CONSERVATION AUTHORITY

A total of 7,613 domestic wells exist in the Long Point Region Conservation Authority jurisdiction. A total of 1,531 (20%) of these wells are bedrock wells, and 5,922 (78%) are overburden wells. Bedrock wells for domestic use are predominantly located on the eastern and northern watersheds of the Long Point Region, and along the shore of Lake Erie (Map 2.21a). These regions of the watershed are located on the clay plain and the till plain where drilling down to bedrock would be needed to find productive groundwater sources. The wells range in depth from 3.4 m to 112.9 m below ground surface with a median well depth of 25.9 m. There are some wells that have been completed into bedrock; however the majority of wells are within 30 m of the surface.

Overburden wells dominate in the west-central portion of the region, where the Norfolk Sand Plain is dominant and drilling into this will provide sufficient water resources for domestic purposes (Map 2.22a). There are virtually no overburden wells in some of the eastern subwatersheds, as clay plains have very low hydraulic conductivity, which limits their ability to supply water. Overburden wells are evenly spread out across the central and western subwatersheds, which also coincide with the Norfolk Sand Plain. This central and western region is also where the shallowest overburden wells are located, as it is not necessary to drill deep to find a productive aquifer. Overburden wells are also found in the till plain, but generally these wells tap into deeper overburden aquifers. Overburden wells in this region range from 1.8 to 83.8 m in depth, but the median is 11.9 m, indicating that sufficient water is available close to surface.

2.12.2.2.2 CATFISH CREEK CONSERVATION AUTHORITY

A total of 1,422 domestic wells are located in the CCCA official boundaries, with 15 (1%) of these wells being classified as bedrock wells and 1,395 (98%) as overburden wells. There are very few bedrock wells in this watershed, and they are scattered in the upper subwatershed, with the exception of one well in the southern basin. The bedrock wells are completed between 64 and 99 m below ground surface, except for a recently (2002) drilled well, which is only 36 m deep. The median well depth is 77.1 m, indicating that the bedrock is deep and thus may explain why there are few bedrock wells in this region used for domestic purposes. Domestic bedrock and overburden wells are illustrated on Map 2.21b and 2.22b, respectively.

Overburden wells are much more abundant, and are scattered throughout the watershed with clusters in the hamlet of Sparta and in Springfield. The median well depth is 25.6 m, and well depths range from 3.7 to 96 m. The Norfolk Sand Plain touches the southern portion of this watershed, and this is where the most shallow overburden wells are located. Further from Lake Erie, the well depth increases as the Sand Plain gives way to the till plains.

2.12.2.2.3 KETTLE CREEK CONSERVATION AUTHORITY

A total of 1,427 domestic wells are located in the KCCA official boundaries, with 54 (3.8%) of these wells being classified as bedrock wells and 1,349 (94.5%) as overburden wells. There are few bedrock wells in the Kettle Creek watershed; most are found along the very top of the watershed, as illustrated on Map 2.21c. Bedrock wells range in depth from about 40 m to almost 103 m in this region, with the median depth being 79.9 m.

Domestic overburden wells (Map 2.22c) are much more common and range in depth from 2.8 m to 97.0 m with a median depth of 24.4 m. The range of overburden well depths reflects the thick overburden sediments, and the widespread distribution of overburden aquifers in this area. Overburden wells were drilled throughout the watershed, with some wells clustered along the divide between Central Elgin and Southwold Townships. There are virtually no wells found in the City of St. Thomas, as the Lake Erie pipeline services this region.

2.12.3 Permits To Take Water

The MOE's Permit to Take Water (PTTW) Program has been in place since the early 1960's. The MOE requires that any person taking more than 50,000 L/day into storage, on any given day in a year, is required to hold an active PTTW. Exceptions are granted for domestic water use, livestock watering and water taken for firefighting purposes. Information such as geographic location of the source, maximum permitted volumes, and the general and specific purpose of the water taking, are stored within the PTTW database.

2.12.3.1 Long Point Region Conservation Authority

Long Point Region has one of the highest densities of permitted water takings in the Province. Without filtering for expired or cancelled permits, or permits from the Great Lakes, Long Point Region has 2650 individual permits, extracting water from 3740 different locations. The permits are focused primarily within the Norfolk Sand Plain as is illustrated on Map 2.23a.

Approximately 60% of the permits withdraw water from groundwater sources, 35% from surface water bodies, and 5% from both groundwater and surface water supplies. As shown in Table 2.17, agricultural irrigation accounts for over 90% of the total number of permits in the region, with permits for commercial uses (e.g. golf courses), municipal water supply systems, and miscellaneous other users comprising the remainder of the permits.

Table 2.17 - Permits to take Water in the Long Point Region Conservation Authority

Purpose of Taking	*Number of Permits*
Agricultural	2470
Commercial	44
Construction	2
Dewatering	6
Industrial	23
Institutional	2
Miscellaneous	43
Recreational	13
Remediation	4
Water Supply	43

2.12.3.2 Catfish Creek Conservation Authority

While CCCA does not have the same density of permits as LPRCA, there are numerous permits within the Conservation Authority's jurisdiction. Permits are focused along the portion of the Norfolk Sand Plain that extends into CCCA. There are a total of 200 individual permits within the watershed and these permits extract water from 315 different locations (Map 2.23b).

Of all the permits within the Catfish Creek Conservation Authority, 48% obtain their water from groundwater sources, while 35% rely on surface water bodies, and 17% from both groundwater and surface water supplies. As shown in Table 2.18, ninety percent of permitted water takings within the watershed are classified as agricultural irrigation, while permits for water supply and miscellaneous users make up the remaining 10% of permitted water takings.

Table 2.18 - Permits to take Water in the Catfish Creek Conservation Authority

Purpose of Taking	*Number of Permits*
Agricultural	178
Commercial	2
Construction	1
Miscellaneous	8
Water Supply	10

2.12.3.3 Kettle Creek Conservation Authority

Permitted water takings in the Kettle Creek Conservation Authority are generally limited to the southern portion of the area, where surficial granular materials are present. There are approximately 50 permits that extract water from 67 differing locations within the Kettle Creek Conservation Authority's jurisdiction (Map 2.23c).

Water takings are evenly supplied from groundwater and surface water sources. Table 2.19 shows that agricultural water takings comprise 45% of all takings, with water supply, commercial and miscellaneous uses making up the majority of the remaining permitted takings.

Table 2.19 - Permits to take Water in the Kettle Creek Conservation Authority

Purpose of Taking	*Number of Permits*
Agricultural	22
Commercial	7
Construction	2
Dewatering	2
Miscellaneous	6
Recreational	1
Remediation	2
Water Supply	7

2.12.4 Water Demand Estimates

An initial assessment of water use was completed for the LPRCA, CCCA, and the KCCA (GRCA, 2005a, b, and c). This assessment relied upon contacting municipalities for information on public water supplies, surveying non-agricultural PTTW holders, and utilizing Statistics Canada data to estimate rural domestic and agricultural water use. The following sections summarize these studies.

The water use studies were focused on determining the amount of water pumped by the various operations, not the amount of water that was consumed. The seasonality of a water taking sector was considered when estimating the annual volume of extracted water. This study also included information on water taking operations which draw upon Lake Erie, which will not be considered in this Study.

2.12.4.1 Long Point Region Conservation Authority

Of the 2650 PTTWs that are contained within the LPRCA boundaries, the water use study identified 50 which were not related to agricultural irrigation or municipal supplies and thought to be active. These permits included, but were not limited to, water takings for golf courses, aquaculture operations, industrial purposes and dewatering. Due to the relatively small number of such water takings, each permit holder was contacted via a phone survey. Twenty-six permit holders responded to the survey, and provided information that was used to refine the estimates of water use. The demand from the remaining permits was estimated from information contained within the PTTW database.

The LPRCA water use study identified the following top 10 water use sectors within the boundaries of the Conservation Authority.

Table 2.20 - Top 10 Water Users in the Long Point Region Conservation Authority (GRCA, 2005a)

Rank	*Purpose*	*Takings (m^3/year)*	*Percentage of Total Demand*
1	Agricultural Irrigation	31,983,000	55%
2	Municipal Water Supply	10,378,000	18%
3	Aquaculture	6,562,000	11%
4	Rural Domestic	3,505,000	6%
5	Agriculture (Livestock watering)	3,107,000	5%
6	Remediation	956,000	2%
7	Construction Dewatering	526,000	1%
8	Aggregate Washing	516,000	1%
9	Golf Course Irrigation	400,000	1%
10	Other Minor Uses	676,000	1%

As outlined in Table 2.20 above, agricultural irrigation demand accounts for over 50% of the total demand, and is the dominant water use within Long Point Region. Municipal supply is responsible for approximately 20% of the total demand; however, 36% of the total municipal supply is serviced by Lake Erie.

The highest amount of estimated actual water use was found to be in the Big Otter, Big Creek and Lynn River/Black Creek watersheds. Water use lessens to the east where the Haldimand Clay Plain is mapped as the surficial sediment.

2.12.4.2 Catfish Creek Conservation Authority

Of the 200 PTTWs within the Catfish Creek, the water use study identified 4 permits that were considered to be active non- agricultural or municipal water takers, and these permit holders were contacted via a phone survey. Two permit holders responded to the survey, and provided information that was used to refine the estimates of water use. The demand from the remaining two permits was estimated from information contained within the PTTW database.

There are seven water use sectors active within CCCA. Table 2.21 ranks the seven sectors by their proportion of total demand.

Table 2.21 - Top 10 Water Users in the Catfish Creek Conservation Authority (GRCA, 2005b)

Rank	*Purpose*	*Takings (m^3/year)*	*Percentage of Total Demand*
1	Agricultural Irrigation	2,551,000	42%
2	Municipal Water Supply	1,317,000	22%
3	Rural Domestic	1,026,000	17%
4	Agriculture (Livestock watering)	637,000	11%
5	Aquaculture	398,000	7%
6	Communal Water Supply	98,000	2%
7	Golf Course Irrigation	7000	0.1%

As outlined in Table 2.21 above, agricultural irrigation demand accounts for over 40% of the total demand, and is the dominant water use within the Conservation Authority. While municipal water supply is also a significant water use, over 97.5% of this demand is serviced by Lake Erie.

2.12.4.3 Kettle Creek Conservation Authority

Of the 50 PTTWs that are contained within the Kettle Creek watershed, the water use study identified 8 active non-agricultural or municipal water takers, and these permit holders were contacted via a phone survey. Four permit holders responded to the survey, and provided information that was used to refine the estimates of water use. The demand from the remaining four permits was estimated from information contained within the PTTW database.

There are only seven water use sectors active within the watershed, and Table 2.22 ranks the seven sectors by their proportion of total demand.

Table 2.22 - Top 10 Water Users in the Kettle Creek Conservation Authority (GRCA, 2005c)

Rank	*Purpose*	*Takings (m^3/year)*	*Percentage of Total Demand*
1	Municipal Water Supply	6,040,000	76%
2	Rural Domestic	760,000	10%
3	Agricultural Irrigation	565,000	7%
4	Agriculture (Livestock watering)	364,000	5%
5	Golf Course Irrigation	199,000	3%
6	Other – Dewatering	62,000	1%
7	Minor Uses	1000	<0.1%

Municipal water supply is the largest water use sector within the Conservation Authority, however over 96% of the municipal water is supplied from Lake Erie.

3.0 Water Demand

This section discusses the estimated surface water and groundwater demands for each subwatershed within the Long Point Region, Catfish Creek and Kettle Creek Conservation Authorities. A subwatershed-based understanding of water demand is a critical aspect in the development of a water budget framework. The following section determines water demand by quantifying municipal water demand, permitted water takings, and non-permitted domestic and livestock demand. Where available, reported water pumping rates are utilized to generate demand estimates, with estimated pumping rates generated by combining the permitted rate with the months of expected active pumping. Consumptive factors are then applied to determine the amount of pumped water that is not returned to the original source in a reasonable amount of time.

The estimated extent and variability of water use is needed to quantify the water use portion of a water budget and to provide insight for future planning efforts to refine the water budget tools in higher water demand areas.

3.1 PREVIOUS WATER USE ASSESSMENTS

As was described in the Watershed Characterization Section, water use assessments have been previously completed for LPRCA, CCCA, and KCCA:

- Long Point Region Water Use Study (GRCA, 2005a);
- Catfish Creek Water Use Study (GRCA, 2005b);
- Kettle Creek Watershed Water Use Study (GRCA, 2005c).

The studies above are collectively referred to in this section as the ‘Previous Water Use Assessments’. Sources of data used in these assessments included surveys of municipalities to obtain information on public water supplies, Statistics Canada data to estimate rural domestic and livestock water use, and Permits To Take Water for private water taking operations.

The Previous Water Use Assessments provided estimates of the total amount of water taken, or pumped, by various operations. In most cases these estimates do not account for water that may be immediately returned to a source or recycled and, therefore, do not estimate water consumption.

This study builds upon the Previous Water Use Assessments by including estimates of returned water into the consumptive use calculations. This study also focuses on groundwater and inland surface water sources, while the Previous Water Use Assessments included water taken from Great Lakes sources.

3.2 MUNICIPAL WATER USE

Municipal water takings within the Long Point Region, Catfish Creek and Kettle Creek Conservation Authorities include a mixture of Great Lakes, inland surface waters and groundwater sources. Table 3.1 shows the breakdown of municipal water use, by source, for each of the Conservation Authority’s.

Table 3.1 - Water Use By Source (GRCA, 2006a, b, c)

Conservation Authority	Inland Surface Waters	Groundwater	Great Lakes
Long Point	1%	61%	38%
Catfish Creek	0%	2.5%	97.5%
Kettle Creek	0%	2.7%	97.3

As concluded from the Previous Water Use Assessments, water taken for municipal supplies is a significant water use within the Study Area; it is second only to agricultural water use. To accurately quantify the amount of water taken for municipal purposes, municipal reported pumping rates were obtained. Takings from Great Lakes supplies (Nanticoke, Port Dover, Elgin Primary, etc...) were not included in this assessment. Table 3.2 summarizes all municipal water takings within the Study Area. The majority of this water is returned to the river system via wastewater treatment plant (WWTP) discharge.

Table 3.2 - Summary of Municipal Water Demands

Subwatershed	Municipality	System Name	Permit Number	Reported Average Taking (m^3/d)	Reported Year	Source Name	Source
Upper Kettle	Central Elgin	Belmont	2261-6PQHMY	225	2004	Well 1	Groundwater
Upper Kettle	Central Elgin	Belmont	2261-6PQHMY	225	2004	Well 2	Groundwater
Catfish Above Aylmer	Oxford County	Brownsville	00-P-1339	51	2006	Well #5	Groundwater
Catfish Above Aylmer	Oxford County	Brownsville	00-P-1339	45	2006	Well #6	Groundwater
Otter Above Maple Dell Road	Oxford County	Norwich	03-P-1086	0	2006	Well #1	Groundwater
Otter Above Maple Dell Road	Oxford County	Norwich	03-P-1086	0	2006	Well #2	Groundwater
Otter Above Maple Dell Road	Oxford County	Norwich	03-P-1086	784	2006	Well #4	Groundwater
Otter at Otterville	Oxford County	Otterville	88-P-1035	0	2006	Well 2-A	Groundwater
Otter at Otterville	Oxford County	Otterville	88-P-1035	137	2006	Well 3	Groundwater
Otter at Otterville	Oxford County	Otterville	88-P-1035	132	2006	Well 4	Groundwater
Otter at Tillsonburg	Oxford County	Tillsonburg	97-P-1077	1154	2006	WELL 1	Groundwater
Otter at Tillsonburg	Oxford County	Tillsonburg	97-P-1077	496	2006	WELL 2A	Groundwater
Otter at Tillsonburg	Oxford County	Tillsonburg	97-P-1077	928	2006	WELL 4	Groundwater
Otter at Tillsonburg	Oxford County	Tillsonburg	97-P-1077	492	2006	WELL 5	Groundwater

Subwatershed	Municipality	System Name	Permit Number	Reported Average Taking (m^3/d)	Reported Year	Source Name	Source
Otter at Tillsonburg	Oxford County	Tillsonburg	97-P-1077	361	2006	WELL 6A	Groundwater
Otter at Tillsonburg	Oxford County	Tillsonburg	97-P-1077	518	2006	WELL 7	Groundwater
Otter at Tillsonburg	Oxford County	Tillsonburg	97-P-1077	626	2006	WELL 10	Groundwater
Otter at Tillsonburg	Oxford County	Tillsonburg	97-P-1077	235	2006	WELL 11	Groundwater
Otter at Tillsonburg	Oxford County	Tillsonburg	97-P-1077	399	2006	WELL 12	Groundwater
Otter at Tillsonburg	Oxford County	Tillsonburg	97-P-1077	1056	2006	WELL 9	Groundwater
Spittler Creek	Oxford County	Dereham Center	Unknown	9	2006	WELL 2	Groundwater
Spittler Creek	Oxford County	Springford	1627-6RWJ7P	83	2006	Well TW1	Groundwater
Spittler Creek	Oxford County	Springford	1627-6RWJ7P	116	2006	Well TW2	Groundwater
Big Above Minnow Creek	Norfolk County	Delhi	7760-6MYTDD	1468	2004	Delhi Well 1	Groundwater
Big Above Minnow Creek	Norfolk County	Delhi	7760-6MYTDD	1032	2004	Delhi Well 2	Groundwater
North Creek	Norfolk County	Delhi	8735-67NL7Y	84	2003	Lehman Reservoir	Surface Water
Lynn River	Norfolk County	Simcoe	02-P-2040	2076	2004	Chapel St.	Groundwater
Lynn River	Norfolk County	Simcoe	80-P-2005	573	2004	Well #NW1	Groundwater
Lynn River	Norfolk County	Simcoe	97-P-2019	586	2004	Well NW#2	Groundwater
Lynn River	Norfolk County	Simcoe	97-P-2019	1654	2004	Well NW#3	Groundwater
Lynn River	Norfolk County	Simcoe	8003-5XCR4H	1905	2004	Cedar Street wells	Groundwater
Nanticoke Upper	Norfolk County	Waterford	77-P-2007	833	2004	Waterford #3	Groundwater
Nanticoke Upper	Norfolk County	Waterford	77-P-2007	933	2004	Waterford #4	Groundwater

3.3 PERMITS TO TAKE WATER

Originally designed to manage the fair sharing of water, data collected in support of the PTTW program can be used to estimate current water demands. Although the program is currently adapting to collect records of actual water takings, the datasets provided by the MOE only include maximum permitted water takings, and must be manipulated to estimate realistic water demands. When using the PTTW database to estimate actual water demands, the following considerations are made:

- When specifying the amount of water required for their specific use, Permit holders often request a volume of water that exceeds their requirements. This may be done to ensure compliance in dry years, or to secure sufficient water for possible future expansion of the operation;
- Permitted volume is often derived from the capacity of the pumping equipment rather than the requirements of the user, often significantly over-estimating the user's demand;
- The database does not maintain a record of seasonal water demand requirements;
- Multiple wells or sources may be included on a particular permit, and the permitted rate refers to the total for all sources associated with that permit. As an example, two nearby municipal wells may operate under one permit but the wells may never operate simultaneously. In this case, each well source could pump at the maximum permitted rate, but not at the same time. To estimate total demand, the total permitted rate should be logically divided amongst the active source locations;
- The spatial location of water taking sources is not always accurate;
- The PTTW database is not current with respect to the MOE's actual permitting activities (recent permit numbers may not be included within the database); and
- Historic water takings may be "grandfathered" and do not require a permit. As a result, there may be some significant water takings not reflected by the PTTW database.

The Ministry of Natural Resources (MNR) provided a copy of the PTTW database (Microsoft Access) to the GRCA in the Fall of 2006, which was current to approximately 2005. The GRCA has made significant improvements to this database since receiving it from the MNR, including: obtaining data provided in the PTTW paper applications, adding recent PTTWs, and incorporating reported water use rates gathered from the water use assessment studies or from MOE records. New permits which the GRCA has been notified about have been added to the database as well. Additionally, several errors in the database were detected and addressed through the current study. These errors include: incorrect descriptions for the purpose of taking, unit conversion errors with respect to the permitted rate, as well as keying errors.

Maps 3.1 and 3.2 illustrate the locations of all known active surface water and groundwater permits within the watersheds. Permits withdrawing water from Lake Erie have not been included in this analysis. It is estimated that approximately 1150 surface water takings and 1970 groundwater takings are active within the Study Area. Multiple water takings may be associated with a single permit. A listing of all water takings with a Permit To Take Water have been included in Appendix A.

3.3.1 Consumptive Water Use

As discussed in detail in Appendix D of the Water Budget and Water Quantity Risk Assessment Draft Guidance Module (MOE, 2007), water consumption refers to the amount of water removed from a hydrological system and not returned back to the same system in a reasonable time period. To assess the portion of pumped water that is being removed from the hydrologic system estimates of water demand must consider consumptive use, as opposed to the total amount of water that may be pumped from a system.

Estimating consumptive water demand requires a proper consideration of scale as well as the physical water taking operation. Some water takers may have large extraction volumes associated with their permits while actually consuming very little of that water. As an example, aggregate washing operations are permitted to pump large volumes of water between washing and settling ponds, and a relatively small percentage is lost to evaporation, or is removed offsite within the washed material. Another example is a dewatering activity where groundwater that is pumped to lower the water table is discharged to a nearby creek. At the scale of a subwatershed very little of this water is actually consumed; however, this water taking would be fully consumptive with respect to the pumped aquifer.

The following three consumptive factors were created (Appendix D, Water Budget Guidance Module) to represent the importance of scale when evaluating consumptive use:

1. **Consumptive with respect to the source** – if water is removed from a source and not returned to the same unit as it was withdrawn, the taking is assumed to be 100% consumptive with respect to the source. Groundwater takings usually fall into this category, where it is common for water to be taken from a deep groundwater aquifer and returned to a surface water feature. An opposite situation would exist where a small hydroelectric dam has a very high permitted rate along a river (source), but doesn't consume any water from that river. In this situation the taking is assumed to have a low consumption rate (minor losses due to enhanced evaporation only). Table 3.3 provides a list of default consumptive use factors (AquaResource, 2005, Kinkead, 2004) that were used for water takings where water is returned to the same source from which it is taken. These default values correspond to the 'Specific Purpose' assigned by the MOE to each permit. For the purposes of this study, the consumptive factor for agricultural purposes was modified to 0.75 based on Isidoro et al. (2003), which suggested that agricultural irrigation has a consumptive factor of 0.65-0.85.
2. **Consumptive with respect to the Subwatershed** – if water is taken and not returned to a water body within the same subwatershed it is assumed to be 100% consumptive at the scale of the subwatershed. Municipal supply wells or river intakes drawing water from one particular subwatershed and discharging via wastewater effluent to another subwatershed would be considered 100% consumptive at this scale. If the water is returned within the same subwatershed, the purpose specific consumptive factor is used (Table 3.3). Dewatering operations, which extract groundwater to lower local water levels, then discharging this water to the local surface water system, would be assigned a consumptive factor specific to dewatering operations.
3. **Consumptive with respect to the Watershed** – where a water taking removes water from the watershed and does not return it within the watershed, it is assumed to be 100% consumptive at that scale. Water bottling operations and other operations that place water into commercial products fall into this category. All other types of water taking operations would be assigned consumptive factors according to their specific purpose (Table 3.3).

Table 3.3 - Consumptive Use Factors

Category	Specific Purpose	Consumptive Factor	Category	Specific Purpose	Consumptive Factor
Agricultural	Field and Pasture Crops	0.75	Institutional	Hospitals	0.25
Agricultural	Fruit Orchards	0.75	Institutional	Other - Institutional	0.25
Agricultural	Market Gardens / Flowers	0.75	Institutional	Schools	0.25
Agricultural	Nursery	0.75	Miscellaneous	Dams and Reservoirs	0.1
Agricultural	Other - Agricultural	0.75	Miscellaneous	Heat Pumps	0.1
Agricultural	Sod Farm	0.75	Miscellaneous	Other - Miscellaneous	1

Category	Specific Purpose	Consumptive Factor	Category	Specific Purpose	Consumptive Factor
Agricultural	Tender Fruit	0.75	Miscellaneous	Pumping Test	0.1
Agricultural	Tobacco	0.75	Miscellaneous	Wildlife Conservation	0.1
Commercial	Aquaculture	0.1	Recreational	Aesthetics	0.25
Commercial	Bottled Water	1	Industrial	Manufacturing	0.25
Commercial	Golf Course Irrigation	0.7	Industrial	Other - Industrial	0.25
Commercial	Mall / Business	0.25	Industrial	Pipeline Testing	0.25
Commercial	Other - Commercial	1	Industrial	Power Production	0.1
Commercial	Snowmaking	0.5	Recreational	Fish Ponds	0.25
Construction	Other - Construction	0.75	Recreational	Other - Recreational	0.1
Construction	Road Building	0.75	Recreational	Wetlands	0.1
Dewatering	Construction	0.25	Remediation	Groundwater	0.5
Dewatering	Other - Dewatering	0.25	Remediation	Other - Remediation	0.25
Dewatering	Pits and Quarries	0.25	Water Supply	Campgrounds	0.2
Industrial	Aggregate Washing	0.25	Water Supply	Communal	0.2
Industrial	Brewing and Soft Drinks	1	Water Supply	Municipal	0.2
Industrial	Cooling Water	0.25	Water Supply	Other - Water Supply	0.2
Industrial	Food Processing	1			

Adapted from AquaResource, 2005 and Kinkead, 2004.

While these factors are generalized, they provide a consistent approach for the initial estimation of consumptive water use. It is recognized that within a specific water use sector the proportion of pumped water consumed may significantly vary between individual operations; the generalized factors, presented in Table 3.3, represent a significant source of uncertainty. This uncertainty is evident in the range of consumptive factors for agricultural irrigation, 0.65-0.85, as found by Isidoro et al (2003).

In this study, wastewater treatment flows are explicitly accounted for in the GAWSER models. No other treatments of consumptive flow explicitly account for return flow; they rely on the consumptive use factors summarized in Table 3.3.

3.3.2 Monthly Usage Factors

Monthly estimates of water use and supply are required to represent the seasonal changes in total water use across a subwatershed. The GRCA (GRCA, 2005d) previously estimated the months where a water taking is expected to be active, based on the purpose of that water taking. The active months of taking for different purposes, shown on Table 3.4, facilitates the estimate of actual water used in a subwatershed. It recognizes that many types of water taking operations only take water during a specific time period each year (e.g., snow making generally is active December, January and February).

Table 3.4 - Monthly Demand Adjustments

General Purpose	Specific Purpose	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agricultural	Field and Pasture Crops	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Fruit Orchards	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Market Gardens / Flowers	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Nursery	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Other - Agricultural	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Sod Farm	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Tender Fruit	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Tobacco	0	0	0	0	0	1	1	1	1	0	0	0
Commercial	Aquaculture	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	Bottled Water	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	Golf Course Irrigation	0	0	0	0	0	1	1	1	1	0	0	0
Commercial	Mall / Business	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	Other - Commercial	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	Snowmaking	1	1	0	0	0	0	0	0	0	0	0	1
Construction	Other - Construction	1	1	1	1	1	1	1	1	1	1	1	1
Construction	Road Building	1	1	1	1	1	1	1	1	1	1	1	1
Dewatering	Construction	1	1	1	1	1	1	1	1	1	1	1	1
Dewatering	Other - Dewatering	1	1	1	1	1	1	1	1	1	1	1	1
Dewatering	Pits and Quarries	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Aggregate Washing	0	0	0	0	1	1	1	1	1	1	1	0
Industrial	Cooling Water	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Food Processing	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Manufacturing	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Other - Dewatering	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Other - Industrial	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Pipeline Testing	1	1	1	1	1	1	1	1	1	1	1	1
Institutional	Other - Institutional	1	1	1	1	1	1	1	1	1	1	1	1
Institutional	Schools	1	1	1	1	1	1	0	0	1	1	1	1
Miscellaneous	Dams and Reservoirs	1	1	1	1	1	1	1	1	1	1	1	1
Miscellaneous	Heat Pumps	1	1	1	1	1	1	1	1	1	1	1	1
Miscellaneous	Other - Miscellaneous	1	1	1	1	1	1	1	1	1	1	1	1
Miscellaneous	Pumping Test	1	1	1	1	1	1	1	1	1	1	1	1
Miscellaneous	Wildlife Conservation	1	1	1	1	1	1	1	1	1	1	1	1
Missing	Missing	1	1	1	1	1	1	1	1	1	1	1	1
Recreational	Other - Recreational	1	1	1	1	1	1	1	1	1	1	1	1
Recreational	Wetlands	1	1	1	1	1	1	1	1	1	1	1	1
Remediation	Groundwater	1	1	1	1	1	1	1	1	1	1	1	1
Remediation	Other - Remediation	1	1	1	1	1	1	1	1	1	1	1	1
Water Supply	Campgrounds	0	0	0	0	1	1	1	1	1	0	0	0
Water Supply	Communal	1	1	1	1	1	1	1	1	1	1	1	1
Water Supply	Municipal	1	1	1	1	1	1	1	1	1	1	1	1
Water Supply	Other - Water Supply	1	1	1	1	1	1	1	1	1	1	1	1

3.3.3 Permitted Agricultural Water Use

As indicated in the Previous Water Use Assessments, agricultural irrigation is the most significant category of water use within the Study Area. Due to the high concentration of agricultural irrigation permits located within the Study Area, a reliable estimate of the total volume of water consumed for irrigation purposes is important.

There are three key factors to consider when estimating the volume consumed by an agricultural irrigation operation;

1. Timing - Months of Active Irrigation/Days of Pumping
2. Quantity - Volume of Water Pumped
3. Consumption - Proportion of water that returns to source

3.3.3.1 Timing

Irrigation is a category of water use that can vary significantly from year to year, and is almost exclusively determined by climate variability. Wet years may have little to no irrigation required, while dry years may require irrigation throughout the growing season.

Active irrigation is typically limited to the summer and early fall months. GRCA staff solicited feedback from the Canada-Ontario Water Supply Expansion Program (COWSEP) Steering Committee for "Coordinating Crop Irrigation Use Across the Norfolk Sand Plain" regarding typical irrigation months. This committee includes area irrigators, who indicated that most irrigators were typically active from June until September (COWSEP Steering Committee Minutes, July 31st. 2007). From this feedback, it was assumed that all agricultural permits had the potential to be active for these months.

While irrigation events may occur through the period of June to September, each irrigation system will not operate each day during this period. To estimate the number of days of pumping, in the absence of having reported pumping records, it is necessary to estimate the number of irrigation events (occurrence of the entire crop being irrigated), and the length of time required to fully irrigate the crop.

An irrigation model, previously generated by the GRCA and documented within the Grand River Water Use Study (GRCA, 2005d), was used to estimate the number of irrigation events that one could expect to occur in an average year. This irrigation model, built within a spreadsheet, relies on synthetic soil water content simulated by GAWSER to estimate when crops would become water-stressed. The irrigation demand model is only used to indicate when agricultural permits would be active.

An irrigation event is registered when the soil water content of a typically irrigated response unit drops below approximately 50% of the soil water storage, or halfway between the field capacity and wilting point. It is generally accepted that at 50% of available soil water storage, vegetation begins to become stressed due to lack of moisture and irrigation would be required (Schwab et al., 1981). If this threshold is reached during a month of active irrigation (June to September), an irrigation event is triggered and the soil water content is increased by a specified irrigated depth. The model then moves onto the next time step, where the added water undergoes an evaporative process. When the soil water content again drops below the specified threshold, another irrigation event is triggered, provided at least a week has passed since the previous irrigation event.

This result of the irrigation demand model is a daily time series, from 1961-2004, of when irrigation events would be required to sustain agricultural crops. This time series can now be used to determine when agricultural irrigation PTTWs would be active.

Sample output from the 2001 year is included in Figure 3.1. The number of irrigation events exhibit significant year-to-year variability, as displayed by the annual number of events for the Upper Lynn climate zone, included in Figure 3.2. As expected, the variability in predicted irrigation events is closely related to climate, with the dry years of 1998 and 2001 having a high number of predicted irrigation events, and wet years such as 2000, having a low number of predicted irrigation events. Depending on the particular climate zone, the total annual irrigation events can be as high as 16 (drought year), or as low as 0 (wet year). The median number of total annual irrigation events, as estimated by the irrigation demand model, is eight. These irrigation events are distributed through the summer months as follows:

- June – 1 event
- July – 2 events
- August – 3 events
- September – 2 events

Water demand is assigned to each month, based on the number of irrigation events for the particular month, combined with the number of days of active pumping required for each irrigation event.

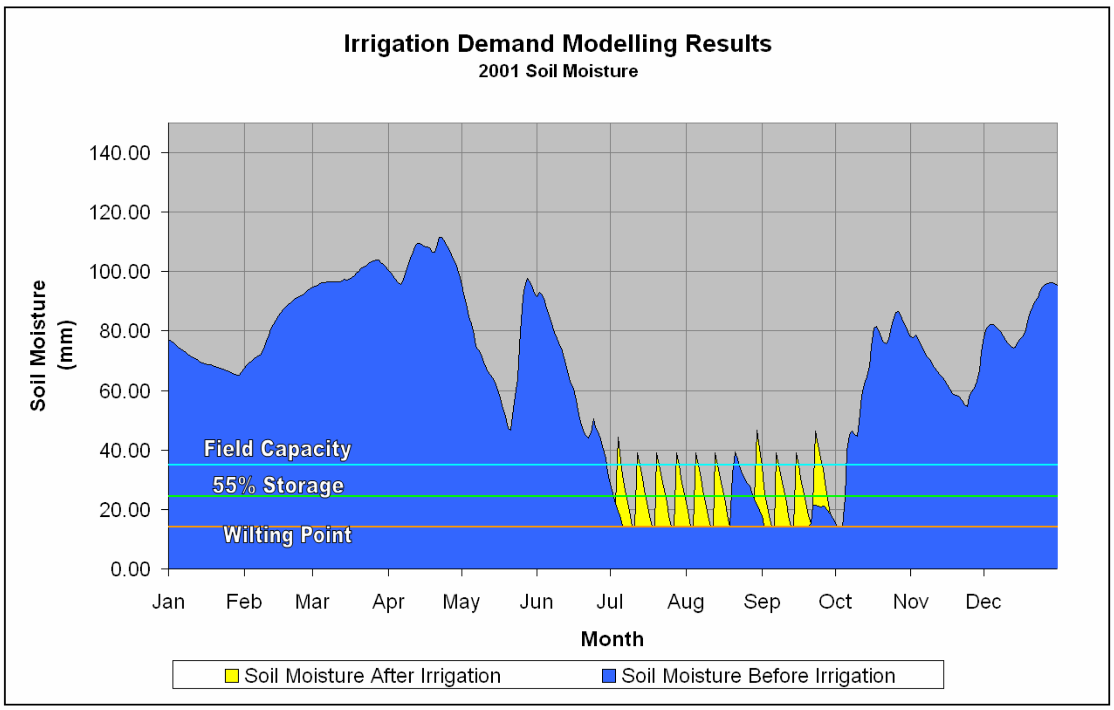


Figure 3.1 - Sample Irrigation Demand Results

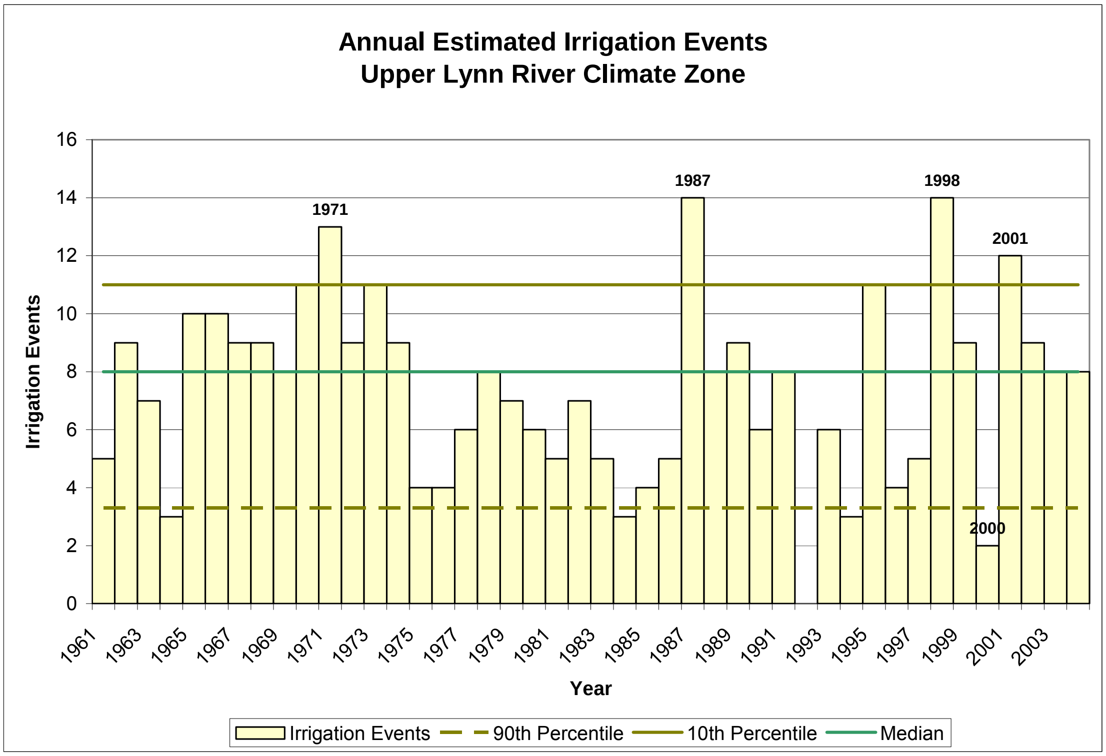


Figure 3.2 - Estimated Annual Irrigation Events

In addition to providing feedback on the months of active irrigation, the COWSEP group also provided input as to the period of days a farmer would require to fully irrigate the crop. While this number can vary, based on the amount of crop in rotation, it was suggested that 4 days was appropriate (COWSEP Steering Committee Minutes, July 31st, 2007).

By multiplying the number of days of active pumping for each irrigation event (4) with the median number of irrigation events (8), the typical irrigation system is estimated to be pumping water for 32 d. Because these days are averaged over the 122 d period (months of June-September), this effectively reduces the estimate of total water pumped to 26% of the permitted rate during this period. For drought periods, where the maximum number of irrigation events could be seen, the number of days with active pumping could be as high as 64, or double the average year's pumping days. Previous studies, such as the study to determine high use watersheds (AquaResource, 2005), did not have the scope to determine the number of days an irrigator may be active, and thus assumed that agricultural permits were active every day during the irrigation season. It should be noted that while the total amount of water pumped may be averaged to be 26% of that permitted over the 122 d period, the actual pumping rate, when active, may be higher than that.

3.3.3.2 Total Water Quantity

With the number of days with active irrigation estimated to be 32, for the average year, the total amount of water pumped can be determined by multiplying the pump rate (L/d) of each permit by the number of active days. It is recognized that the permitted rate may not be a good estimate of how much water is being withdrawn when actively pumping, and is almost always too high. To adjust the permitted rate, GRCA staff compared agricultural permits which had reported rates available, to the permitted rates for the same permits. Approximately 135 agricultural PTTWs within the LPRCA, CCCA and KCCA region have reported pump rates available. All permits with reported rates available were analyzed and were found to equal approximately 60% of the permitted rate for the associated permit during days of active pumping. While these 135 PTTWs only comprise approximately 5% of the total number of PTTWs within the Study Area, these are the only available reported pump rates that can be used to better characterize irrigation demand, and are assumed to be representative of the agricultural sector.

The total amount pumped was then estimated by multiplying each permitted rate by 60% and by the number of active pumping days. This volume was then assigned to each month with active irrigation (June-September), based on the number of expected irrigation events each month, to arrive at an average rate in units of m^3/d. Previous studies did not have access to the reported values of water use that are currently available, and thus had no modification of the permitted volume.

3.3.3.3 Consumptive Water Use

As discussed previously, consumptive water use is the portion of water taken from a source, which is not returned to that source in a reasonable amount of time. It is the consumptive water use that is used in the Tier 2 Water Quantity Stress Assessment (AquaResource, 2009a).

Previous literature has indicated the consumptive proportion of water taken for agricultural irrigation purposes ranged from 0.8-0.9. This indicated that 10-20% of the pumped water would eventually return to its original source, with the remaining 80-90% being transpired by the irrigated crops and lost from the subwatershed.

Feedback from the Peer Review Committee (Dr. Hugh Whiteley, Peer Review Meeting, May 31st, 2007) suggested that a consumptive factor of 0.8-0.9 was likely too high, and a more appropriate factor was 0.75. This factor was taken from Isidoro et. al. (2003), which estimated the consumptive factor of a "good" irrigation system to be from 0.65-0.85. The lower consumptive factor recognizes that any irrigation system will provide an uneven distribution of water, and to provide a minimum depth for the entire crop, some portions of the field will receive significantly more. In these more heavily irrigated areas, saturated soil conditions may develop and thus return water to the system.

3.3.3.4 Summary of Agricultural Water Use Assumptions

The assumptions outlined above result in a significant reduction in the estimated demand from agricultural irrigation as compared to previous estimates which relied solely on the permitted volume. Combining the reduction factors of: 26% of summer days (June-Sept) having active pumping; 60% of the permitted volume being actually pumped; and 75% of pumped water being consumed, the factors yield an estimated agricultural demand for irrigation permits that is equal to 11.7% of the permitted taking, for the months of June-September. Agricultural use is assumed to be insignificant outside of these summer months.

The assumptions utilized to generate estimates of water demand for agricultural irrigation are generalized, and likely significantly vary between individual irrigation operations. Factors such as, but not limited to, irrigated crop, soil type, individual farming practices, and type of irrigation equipment used would greatly impact the length of active pumping for one irrigation event, the time interval between irrigation events, and the duration of the irrigation season. Due to incomplete information available to fully characterize specific water taking characteristics, care has been taken to select values that would be appropriate for the "average" irrigator, and that are applicable for a regional-scale analysis.

3.3.4 Survey of Actual Water Use

The relatively small numbers of non-agricultural PTTWs in the Study Area allowed for a phone survey of these permit holders to be conducted in the winter of 2005. This work was carried out as part of the Previous Water Use Assessments. The phone survey was conducted to refine the water taking estimates, by requesting each water user to describe the timing and duration of their water use. Additionally, water sources and purpose of taking were clarified to gain a better understanding of taking characteristics for that water taking category. The survey generated a response rate of 50% of permit holders called; the other permit holders were either unable to be reached or the contact information was out of date.

Additionally, in the summer of 2006, in cooperation with the MOE district offices, GRCA staff collected information from PTTW paper files that improved the understanding of water sources and actual water takings by permit holders. A more complete understanding of each permit's activities was provided through information contained within the paper files, which may not have been recorded in the Provincial PTTW database. In addition to more detailed information on the water taking operation, reported rates from a number of irrigation operations were obtained. These paper records were also helpful in checking for errors in data entry in the PTTW database and to clarify information that may be erroneous by verification with the paper record.

Wherever possible, the reported water use rates, obtained from the phone survey and the MOE paper files, were used to quantify water demand.

3.4 UNPERMITTED WATER USE

In addition to permitted water use, there are various types of non-permitted water uses. These types of water uses include livestock watering, unserviced domestic use (typically rural residents) and any other use that is taking less than 50,000 L/d.

While there is no standard procedure for estimating the amount of water used by operations that are below the PTTW limit of 50,000 L/d, the GRCA developed a methodology to quantify non-permitted agricultural and unserviced domestic water use as part of the Grand River Water Use Study (GRCA, 2005d). The Previous Water Use Assessments also utilized the GRCA's approach to quantify non-permitted agricultural and rural domestic water. The estimates from the Previous Water Use Assessments are included below.

3.4.1 Non-Permitted Agricultural Water Use

Legal non-permitted agricultural water use includes livestock watering, equipment washing, pesticide/herbicide application or any other minor use of water. Kreutzwiser and de Loë (1999) developed a series of coefficients, that when applied to the Census of Agriculture Data, can be used to estimate agricultural water use. The Previous Water Use Assessments applied this methodology to estimate water use on a watershed basis. Table 3.5 (below) pro-rates these watershed-based estimates, by area, for each subwatershed. These values are thematically presented in Map 3.3

Table 3.5 - Non-Permitted Agricultural Water Use

Subwatershed		Non-Permitted Agricultural Demand L/s
Kettle Creek	Upper Kettle	5
	Dodd Creek	2
	Lower Kettle	5

Subwatershed		Non-Permitted Agricultural Demand L/s
Catfish Creek	West Catfish	6
	Catfish Above Aylmer	7
	Lower Catfish	2
	Silver Creek	2
Big Otter	Otter Above Maple Dell Road	6
	Otter at Otterville	5
	Otter at Tillsonburg	6
	Spittler Creek	7
	Lower Otter	4
	Little Otter	3
Lake Erie Tribs	South Otter	1
	Clear Creek	1
Big Creek	Big Above Cement Road	3
	Big Above Kelvin Gauge	2
	Big Above Delhi	6
	North Creek	0
	Big Above Minnow Creek	2
	Big Above Walsingham	2
	Venison Creek	2
	Lower Big	1
Lake Erie Tribs	Dedrick Creek	1
	Young/Hay Creeks	6
Lynn River	Lynn River	5
	Black Creek	4
Nanticoke Creek	Nanticoke Upper	3
	Nanticoke Lower	6
Eastern Tribs	Sandusk Creek	4
	Stoney Creek	3

Due to the census-based estimation technique, it is not possible to reliably determine the source of water for the agricultural water users. In the absence of this information, it is assumed that half of the demand is serviced through groundwater sources, and half is serviced through surface water sources.

The consumptive nature of the non-permitted agricultural water use is also an uncertainty. In the absence of such information, and to arrive at a conservative estimate of the consumptive non-permitted agricultural water demand, this study assumes that that 100% of the water taken is consumed. Based on the relatively small volumes estimated within this category as compared to the total consumptive water demand, this assumption is considered acceptable.

3.4.2 Un-serviced Domestic Water Use

Un-serviced domestic use is any household water use that is not supplied by a municipal water supply system. Typically unserviced homes are located in rural areas, and generally are supplied from private groundwater wells.

The Previous Water Use Assessments estimated the amount of water taken for unserviced domestic use, and closely followed the Grand River Water Use Study (GRCA, 2005d). These estimates were made by combining Census of Population data for areas known not to be serviced by a municipal system, with a per capita water use rate of 160 L/d/cap. A per capita rate of 160 L/d/cap was estimated by Vandierendonck and Mitchell (1997), and is consistent with the MOE Groundwater Studies Technical Terms of Reference (2001) which suggests an unserviced per capita rate of 175 L/d/cap. The estimates created within the Previous Water Use Assessments were pro-rated, by area, to the subwatershed areas used within the current study. These estimates on the subwatershed scale are included in Table 3.6. Map 3.4 also shows the unserviced domestic water use for each subwatershed.

Table 3.6 - Un-serviced Domestic Water Use

Subwatershed		Rural Domestic Demand L/s
Kettle Creek	Upper Kettle	5
	Dodd Creek	4
	Lower Kettle	14
Catfish Creek	West Catfish	10
	Catfish Above Aylmer	9
	Lower Catfish	7
	Silver Creek	7
Big Otter	Otter Above Maple Dell Road	3
	Otter at Otterville	3
	Otter at Tillsonburg	6
	Spittler Creek	4
	Lower Otter	7
	Little Otter	5
Lake Erie Tribs	South Otter	4
	Clear Creek	3
Big Creek	Big Above Cement Road	3
	Big Above Kelvin Gauge	2
	Big Above Delhi	5
	North Creek	2
	Big Above Minnow Creek	3
	Big Above Walsingham	4
	Venison Creek	3
	Lower Big	6
Lake Erie Tribs	Dedrick Creek	5
	Young/Hay Creeks	9
Lynn River	Lynn River	7
	Black Creek	4
Nanticoke Creek	Nanticoke Upper	3
	Nanticoke Lower	6
Eastern Tribs	Sandusk Creek	7
	Stoney Creek	5

Due to appropriate concerns about poor water quality, this unserviced domestic demand is almost exclusively obtained from groundwater. Therefore, it is assumed that all unserviced domestic demand draws water from groundwater supplies. Consistent with the water consumption ratios for other Water Supply categories included in Table 3.3, the consumptive ratio is assumed to be 0.2. For domestic water wells, this assumption implies that 80% of pumped water is returned to groundwater through septic systems.

3.5 WATER USE ESTIMATES

The following sections summarize total permitted and non-permitted water use estimates. Permitted rate, estimated pumped rate, and estimated consumed rate at each consumptive scale are presented.

3.5.1 Permitted Rate

Table 3.7 shows the total permitted rate of active permitted water takings categorized by subwatershed and source. The total permitted rates are 36 m^3/s for groundwater and 22 m^3/s for surface water sources, representing a total rate of 58 m^3/s. Maps 3.5 and 3.6 illustrate the permitted rates for both surface and groundwater, respectively, by subwatershed. Note that these values represent maximum permitted rates, and are much larger than actual usage rates.

Table 3.7 - Permitted Rate

Subwatershed		Permitted (m^3/s)		Permitted (mm)	
		Groundwater	Surface Water	Groundwater	Surface Water
Kettle Creek	Upper Kettle	0.12	0.02	20	3
	Dodd Creek	0.02	0.00	5	0
	Lower Kettle	0.14	0.23	23	38
Catfish Creek	West Catfish	0.01	0.00	2	0
	Catfish Above Aylmer	0.23	0.15	51	33
	Lower Catfish	1.31	0.72	402	220
	Silver Creek	0.96	0.71	325	240
Big Otter	Otter Above Maple Dell Road	0.57	0.31	182	99
	Otter at Otterville	0.69	0.50	291	210
	Otter at Tillsonburg	1.39	1.41	286	291
	Spittler Creek	0.07	0.07	19	18
	Lower Otter	0.57	1.52	108	285
	Little Otter	1.15	0.89	309	239
Lake Erie Tribs	South Otter	1.23	1.88	324	496
	Clear Creek	1.41	0.61	512	220
Big Creek	Big Above Cement Road	0.28	0.12	97	41
	Big Above Kelvin Gauge	1.91	0.08	937	39
	Big Above Delhi	4.90	2.09	1000	427
	North Creek	1.00	1.04	545	565
	Big Above Minnow Creek	2.65	1.02	1156	443
	Big Above Walsingham	1.89	2.32	486	596
	Venison Creek	1.76	1.84	570	593
	Lower Big	0.68	0.64	224	209
Lake Erie Tribs	Dedrick Creek	1.27	1.20	291	275
	Young/Hay Creeks	1.48	0.94	387	247
Lynn River	Lynn River	3.70	0.92	680	168
	Black Creek	0.61	0.03	144	6

Subwatershed		Permitted (m^3/s)		Permitted (mm)	
		Groundwater	Surface Water	Groundwater	Surface Water
Nanticoke Creek	Nanticoke Upper	4.20	0.61	1160	168
	Nanticoke Lower	0.01	0.00	5	0
Eastern Tribs	Sandusk Creek	0.19	0.00	32	0
	Stoney Creek	0.00	0.02	1	3
Total		**36**	**22**		

3.5.2 Pumped Rate

Table 3.8 summarizes the estimates of the volume of water pumped, expressed as an annual average rate, for all users. The table shows the breakdown of pumped water estimated from the PTTW database, or Census data, versus the portion that has been estimated from reported pumping rates (i.e., municipal takings, water use surveys). Subwatersheds with a higher proportion of reported water pumping than estimated water pumping have a greater certainty associated with water demand estimates. The total pumped rate is the average annual amount of water that has been withdrawn from watercourses or aquifers, without allowing for the consumptive nature of the taking. The difference between permitted and estimated pumping is large. Pumped rates take into account the permitted rate only for active months of pumping for each permit, in addition to using reported pumping rates where available. Further, agricultural pumped rates also take into account only the active days of pumping per month and the 60% actual pumping factor described in Section 3.3.3.2. Pumped demand shows approximately 4 m^3/s pumped on an annual average basis, compared to 58 m^3/s that is permitted. This large difference is attributed primarily to the agricultural permits, which are the dominant water use within the region. The average volume pumped for both surface and groundwater is illustrated on Maps 3.7 and 3.8.

Table 3.8 - Average Rate Pumped

Subwatershed		Groundwater m^3/s			Surface Water m^3/s		
		Estimated	Reported	Total*	Estimated	Reported	Total*
Kettle Creek	Upper Kettle	0.02	0.01	0.02	0.01	0.00	0.01
	Dodd Creek	0.01	0.00	0.01	0.00	0.00	0.00
	Lower Kettle	0.03	0.00	0.03	0.01	0.00	0.02
Catfish Creek	West Catfish	0.01	0.00	0.01	0.00	0.00	0.00
	Catfish Above Aylmer	0.02	0.00	0.02	0.01	0.00	0.01
	Lower Catfish	0.05	0.00	0.05	0.04	0.00	0.04
	Silver Creek	0.04	0.00	0.04	0.06	0.00	0.06
Big Otter	Otter Above Maple Dell Road	0.03	0.01	0.04	0.07	0.00	0.07
	Otter at Otterville	0.03	0.00	0.03	0.02	0.00	0.02
	Otter at Tillsonburg	0.07	0.08	0.15	0.06	0.00	0.06
	Spittler Creek	0.01	0.00	0.01	0.01	0.00	0.01
	Lower Otter	0.03	0.00	0.03	0.05	0.00	0.05
	Little Otter	0.07	0.00	0.07	0.02	0.00	0.03
Lake Erie Tribs	South Otter	0.05	0.00	0.05	0.07	0.00	0.07
	Clear Creek	0.06	0.00	0.06	0.02	0.00	0.02

Subwatershed		Groundwater m^3/s			Surface Water m^3/s		
		Estimated	Reported	Total*	Estimated	Reported	Total*
Big Creek	Big Above Cement Road	0.02	0.00	0.02	0.01	0.00	0.01
	Big Above Kelvin Gauge	0.14	0.00	0.14	0.00	0.00	0.00
	Big Above Delhi	0.21	0.00	0.21	0.11	0.00	0.12
	North Creek	0.11	0.00	0.11	0.08	0.01	0.09
	Big Above Minnow Creek	0.11	0.03	0.14	0.04	0.00	0.04
	Big Above Walsingham	0.06	0.00	0.06	0.31	0.01	0.31
	Venison Creek	0.06	0.00	0.06	0.07	0.01	0.08
	Lower Big	0.03	0.00	0.03	0.03	0.00	0.03
Lake Erie Tribs	Dedrick Creek	0.05	0.00	0.05	0.47	0.00	0.47
	Young/Hay Creeks	0.07	0.03	0.10	0.14	0.04	0.18
Lynn River	Lynn River	0.16	0.08	0.24	0.04	0.00	0.04
	Black Creek	0.02	0.02	0.05	0.00	0.00	0.00
Nanticoke Creek	Nanticoke Upper	0.15	0.03	0.18	0.01	0.00	0.02
	Nanticoke Lower	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Tribs	Sandusk Creek	0.02	0.00	0.02	0.00	0.00	0.00
	Stoney Creek	0.01	0.00	0.01	0.01	0.00	0.01
Total		**1.74**	**0.31**	**2.05**	**1.78**	**0.09**	**1.86**

* Total = Estimated +Reported. Due to rounding errors, small summing discrepancies may exist.

3.5.3 Consumptive Use (Hydrologic Source Scale)

Table 3.9 summarizes the estimated consumptive demand (source scale) within each subwatershed. The source specific consumptive use is the amount of water withdrawn from a specific source (either groundwater or surface water) and not returned to that same source in a reasonable amount of time. This recognizes that a dewatering operation, while inherently not consumptive with respect to overall volume, is 100% consumptive with respect to the aquifer from which it is dewatering.

The table shows the maximum and minimum monthly and average annual demand for both surface water and groundwater sources. On an average annual basis, 1.57 m^3/s of water is estimated to be consumed from aquifers and 0.87 m^3/s is consumed from rivers and creeks. The August consumptive demand from surface water sources is included in Map 3.9. The average annual and maximum monthly demands from groundwater sources are included in Maps 3.10 and 3.11.

There is significant monthly variability within most subwatersheds in the Study Area due to the dominant agricultural sector, which removes water only during the summer months. Consumptive demands for groundwater are larger than for surface water due to the fact that groundwater takings are not recycled back to the aquifer.

Table 3.9 - Consumptive Demand (By Hydrologic Source Unit)

Subwatershed		Groundwater Demand (m^3/s)			Surface Water Demand (m^3/s)		
		Maximum Monthly	Minimum Monthly	Average Annual	Maximum Monthly	Minimum Monthly	Average Annual
Kettle Creek	Upper Kettle	0.04	0.01	0.02	0.00	0.00	0.00
	Dodd Creek	0.00	0.00	0.00	0.00	0.00	0.00
	Lower Kettle	0.05	0.01	0.02	0.04	0.00	0.01
Catfish Creek	West Catfish	0.01	0.01	0.01	0.00	0.00	0.00
	Catfish Above Aylmer	0.03	0.01	0.01	0.02	0.00	0.01
	Lower Catfish	0.15	0.00	0.04	0.09	0.00	0.03
	Silver Creek	0.10	0.00	0.02	0.08	0.00	0.03
Big Otter	Otter Above Maple Dell Road	0.09	0.01	0.03	0.04	0.00	0.02
	Otter at Otterville	0.10	0.00	0.03	0.07	0.00	0.02
	Otter at Tillsonburg	0.25	0.09	0.13	0.18	0.00	0.06
	Spittler Creek	0.02	0.01	0.01	0.01	0.00	0.01
	Lower Otter	0.08	0.00	0.02	0.17	0.00	0.05
	Little Otter	0.17	0.03	0.06	0.08	0.00	0.02
Lake Erie Tribs	South Otter	0.15	0.00	0.03	0.23	0.00	0.07
	Clear Creek	0.19	0.00	0.04	0.06	0.00	0.02
Big Creek	Big Above Cement Road	0.04	0.00	0.01	0.02	0.00	0.01
	Big Above Kelvin Gauge	0.32	0.05	0.11	0.01	0.00	0.00
	Big Above Delhi	0.67	0.01	0.16	0.26	0.01	0.08
	North Creek	0.20	0.06	0.09	0.11	0.01	0.04
	Big Above Minnow Creek	0.40	0.02	0.11	0.12	0.00	0.04
	Big Above Walsingham	0.20	0.00	0.05	0.25	0.04	0.10
	Venison Creek	0.20	0.00	0.05	0.17	0.00	0.05
	Lower Big	0.08	0.00	0.02	0.06	0.00	0.02
Lake Erie Tribs	Dedrick Creek	0.15	0.00	0.03	0.12	0.05	0.07
	Young/Hay Creeks	0.24	0.03	0.08	0.13	0.01	0.05
Lynn River	Lynn River	0.60	0.07	0.20	0.14	0.00	0.04
	Black Creek	0.09	0.02	0.04	0.01	0.00	0.00
Nanticoke Creek	Nanticoke Upper	0.54	0.02	0.14	0.06	0.00	0.02
	Nanticoke Lower	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Tribs	Sandusk Creek	0.01	0.01	0.01	0.00	0.00	0.00
	Stoney Creek	0.01	0.00	0.00	0.01	0.00	0.00
	Total			1.57			0.87

3.5.4 Subwatershed Consumptive Demand Estimates

Table 3.10 summarizes estimated consumptive demands at the subwatershed scale. Whereas the source specific consumptive demand estimated the amount of water not returned to its original source, the subwatershed consumptive demand estimates the amount not returned to the subwatershed from which it was taken. In this case, continuing the example from Section 3.5.3, although a dewatering taking may be 100% consumptive with respect to the source, it would have a very small consumptive proportion with respect to the subwatershed due to the majority of water being returned in the same subwatershed from which it is taken.

The rate shown in this table is the estimated amount of water pumped and not returned at any location within the subwatershed. The estimates represent water losses due to crop transpiration of irrigated water, water consumed for industrial processes (cooling water or concrete production) or water bottling.

Table 3.10 - Subwatershed Scale Consumptive Demand

Subwatershed		Groundwater Demand (m^3/s)		Surface Water Demand (m^3/s)	
		Maximum Monthly	Average Annual	Maximum Monthly	Average Annual
Kettle Creek	Upper Kettle	0.02	0.01	0.00	0.00
	Dodd Creek	0.00	0.00	0.00	0.00
	Lower Kettle	0.04	0.01	0.04	0.01
Catfish Creek	West Catfish	0.01	0.01	0.00	0.00
	Catfish Above Aylmer	0.03	0.01	0.02	0.01
	Lower Catfish	0.15	0.03	0.09	0.02
	Silver Creek	0.10	0.02	0.08	0.02
Big Otter	Otter Above Maple Dell Road	0.08	0.02	0.04	0.02
	Otter at Otterville	0.09	0.02	0.07	0.02
	Otter at Tillsonburg	0.17	0.05	0.18	0.04
	Spittler Creek	0.01	0.01	0.02	0.01
	Lower Otter	0.08	0.02	0.16	0.04
	Little Otter	0.17	0.06	0.08	0.02
Lake Erie Tribs	South Otter	0.15	0.03	0.23	0.05
	Clear Creek	0.19	0.04	0.05	0.01
Big Creek	Big Above Cement Road	0.04	0.01	0.02	0.01
	Big Above Kelvin Gauge	0.29	0.07	0.01	0.00
	Big Above Delhi	0.67	0.15	0.26	0.06
	North Creek	0.14	0.04	0.11	0.03
	Big Above Minnow Creek	0.38	0.09	0.12	0.03
	Big Above Walsingham	0.20	0.05	0.25	0.08
	Venison Creek	0.20	0.05	0.15	0.04
	Lower Big	0.08	0.02	0.07	0.02
Lake Erie Tribs	Dedrick Creek	0.15	0.03	0.11	0.06
	Young/Hay Creeks	0.21	0.05	0.12	0.04
Lynn River	Lynn River	0.52	0.14	0.13	0.03
	Black Creek	0.07	0.02	0.01	0.00
Nanticoke Creek	Nanticoke Upper	0.52	0.12	0.06	0.01
	Nanticoke Lower	0.00	0.00	0.00	0.00
Eastern Tribs	Sandusk Creek	0.01	0.01	0.00	0.00
	Stoney Creek	0.00	0.00	0.01	0.00
	Total		**1.21**		**0.70**

The estimated total consumptive demand at the subwatershed scale is 1.91 m^3/s, which is slightly less than the source-specific consumptive demand (2.64 m^3/s reported in Table 3.9) and significantly lower than the total rate of water pumped (3.91 m^3/s reported in Table 3.8). The difference between permitted, estimated pumped volume, and volume consumed (for the unit and subwatershed scales) is presented graphically on Figures 3.3, 3.4 and 3.5 for the LPRCA, KCCA, and CCCA, respectively.

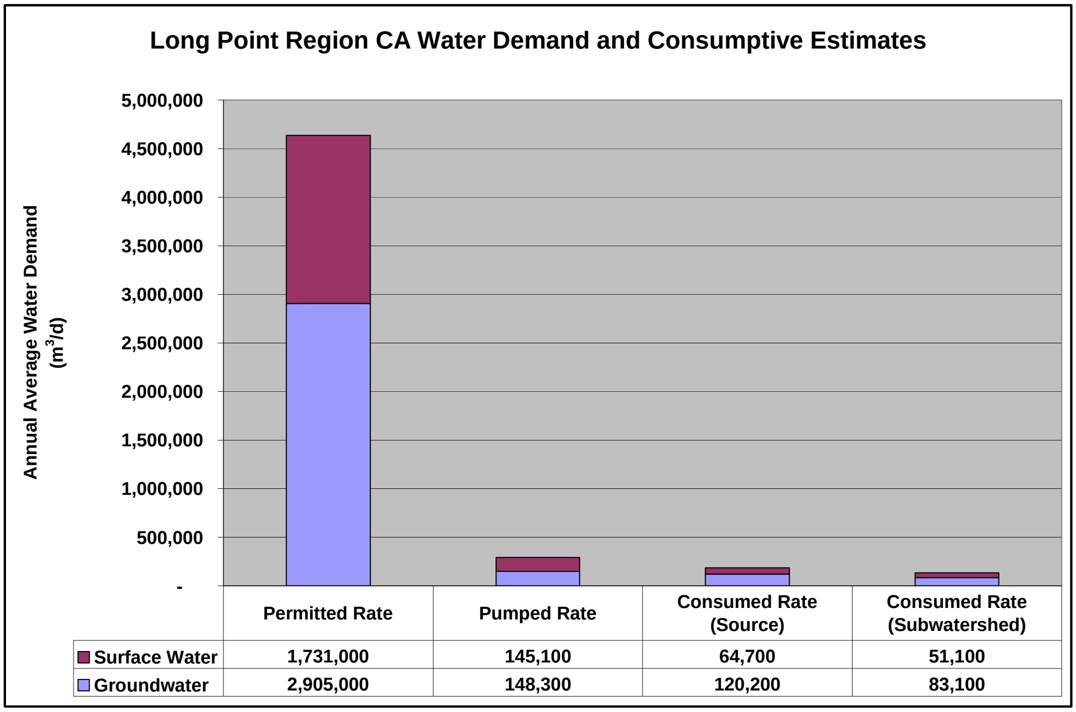
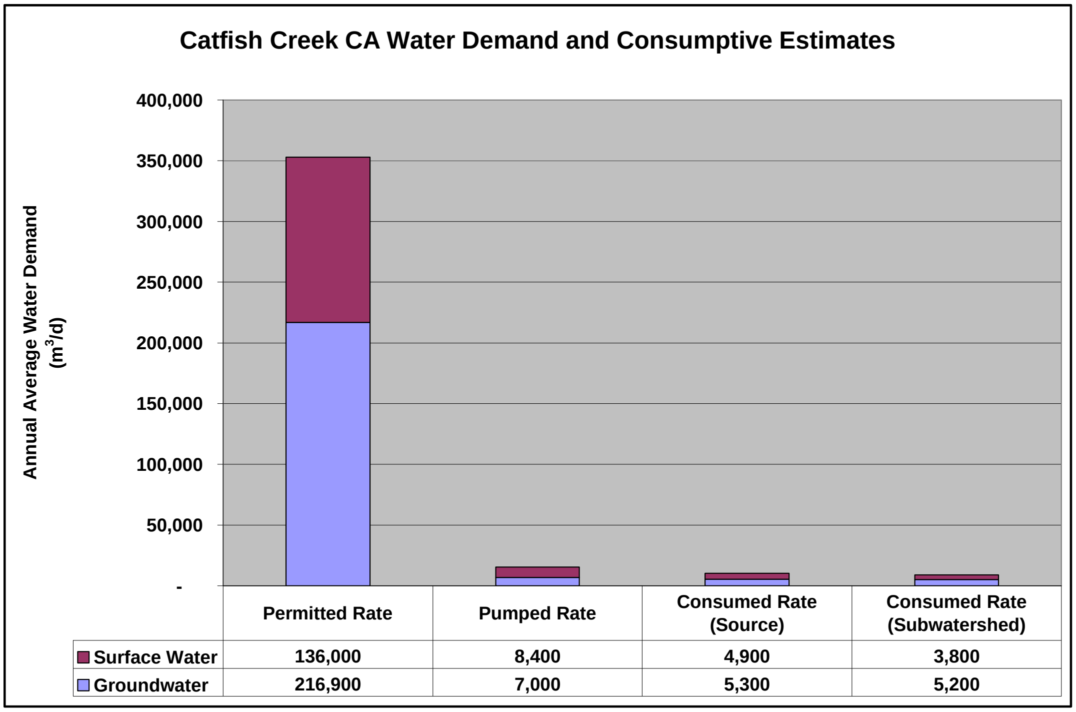
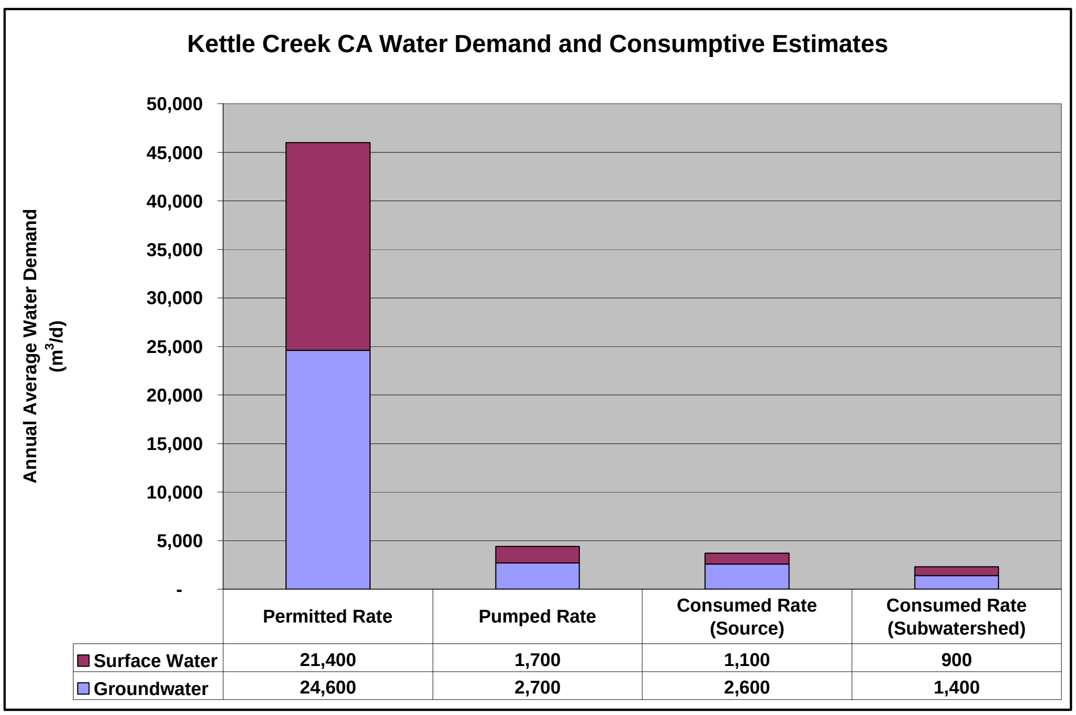


Figure 3.3 - Long Point Region Consumptive Water Demand Estimates



	Permitted Rate	Pumped Rate	Consumed Rate (Source)	Consumed Rate (Subwatershed)
Surface Water	136,000	8,400	4,900	3,800
Groundwater	216,900	7,000	5,300	5,200

Figure 3.4 - Catfish Creek Consumptive Water Demand Estimates



	Permitted Rate	Pumped Rate	Consumed Rate (Source)	Consumed Rate (Subwatershed)
Surface Water	21,400	1,700	1,100	900
Groundwater	24,600	2,700	2,600	1,400

Figure 3.5 - Kettle Creek Consumptive Water Demand Estimates

3.6 UNCERTAINTY

Efforts to survey non-agricultural permit holders to determine actual water use rates have reduced uncertainty associated with total pumping rates for those permit holders. All municipal takings, and many non-agricultural operations, have submitted water taking information which was utilized in this analysis. Additionally, the conservation authorities obtained relevant information contained within agricultural PTTW applications from the MOE, as well as a number of actual water use reports. This information was critical in forming a number of the assumptions used for estimating agricultural demand, although based on a small sample.

The methodology for estimating agricultural irrigation demand has relied upon generalizations and assumptions meant to describe the water use for the typical irrigator. These include; a standard soil water trigger for when a typical crop will require irrigation; a common irrigation season extending from June to September; a standardized number of pumping days per irrigation event, and a single consumptive factor. The application of these standard assumptions is a significant source of uncertainty, as differing cropping and irrigation practices between irrigators will introduce variation in the factors discussed above. This uncertainty was minimized by obtaining input from the agricultural community on typical irrigation practices, as well as utilizing published values.

Assumptions utilized for generating estimates of agricultural water use were further tested by incorporating water use estimates within the GAWSER and FEFLOW models, and will be described in the following section. The ability of the surface and groundwater models to represent the consumptive demands, and reasonably predict observed hydrologic conditions, suggests that the consumptive water demand estimates are appropriate.

While the approach followed in this section to estimate consumptive water demand reduces the overall uncertainty of estimated water demand, there remains sparse information relating to actual water taking practices; this is a significant source of uncertainty with respect to water demand. MOE's current PTTW reporting requirements will reduce the uncertainty associated with estimating total pumping rates when available, but will not necessarily reduce the uncertainty in estimating consumptive water use.

The agricultural sector within the Norfolk Sand Plain is currently in a state of flux. The dominant crop responsible for water taking (tobacco) is currently in decline, and the replacement crop(s) is not yet known. Due to this shift, current estimates of water demand may not be valid in the near future, and any analysis utilizing these demand estimates for future scenarios will be inherently uncertain.

Uncertainty is also present in the water use estimates for the non-permitted uses (domestic use, and livestock use). However, due to the relatively small quantities of these estimated takings this uncertainty is a less significant component of the overall subwatershed water budget.

4.0 GAWSER Models

A comprehensive hydrologic model is required to quantify and characterize the key hydrologic components within a subwatershed. Although a model is a simplification of the movement of water through the watershed, an appropriate model should be able to make valid inferences regarding the key hydrologic processes. In order to provide a general overview of the surface water flow component of the hydrologic cycle, a basic description of the key physical processes is given below.

4.1 SUMMARY OF THE HYDROLOGIC CYCLE

The hydrologic cycle refers to the movement of water through the earth-atmosphere system. This cycle is initiated with water vapour, created by evaporation from land/water including water evaporated (transpired) from vegetation. Water vapour is released from the atmosphere when it condenses (clouds) and is returned to the earth by precipitation. At the earth's surface, the precipitation is stored on the surface (e.g., rivers, lakes, oceans) or below the surface (groundwater) or is evaporated or transpired to repeat the next cycle.

The hydrologic cycle begins with rain or snow (precipitation) falling to the ground. The amount and rate of precipitation that arrives at the ground surface is governed by the prevailing weather system that generated the precipitation on a regional scale. At the more localized scale, topography and land use cover influence the actual precipitation amounts arriving at the ground surface.

Liquid water arriving at the ground surface as rain, or produced there as snowmelt, either fills small depressions, and then runs across the surface to enter a surface watercourse, or remains trapped on the surface until it evaporates, or infiltrates into the ground. The amount of water that actually infiltrates is controlled by the rate of precipitation input (rainfall or snowmelt), soil type (e.g., clay, silt, sand or gravel), ground surface conditions (e.g., frozen, cracking) and vegetative cover (e.g., pasture, forests). Water infiltrating into the ground may follow a number of processes including: remain in soil water storage under dry conditions, return to the atmosphere by evapotranspiration, discharge relatively quickly to surface water through interflow, or percolate into deeper soils and recharge groundwater systems. In some areas (e.g., hummocky ground), the surface topography has created large depressions, which require up to several metres of water to pond before overland flow occurs. Consequently, water in these depressions either percolates downward and contributes to groundwater and subsurface storage or evaporates back to the atmosphere.

Runoff water collects in stream channels leading to larger channels or discharge to ponds, wetlands or lakes. While in these ponds or lakes, a portion of this water returns to the atmosphere by evaporation, or it may percolate into the ground, or spill to downstream channels. The travel time of flow in these stream channels is governed by the length, slope, roughness and cross-sectional shape of these channels. If the flow is high and fast enough, water may overtop the channel banks, flooding the adjacent land area.

Anywhere along the length of these stream channels, discharge from groundwater storage (either regional, localized, or interflow) can contribute to the flow in the channel. These groundwater contributions to streamflow are governed by the surrounding topography, surficial geology and bedrock geology.

4.2 MODEL SELECTION

As described in Section 1.4, continuous GAWSER models have been constructed for all three CAs to simulate the hydrology of the respective watersheds. All three hydrologic models have been completed by Dr. Harold Schroeter, in 2006. Full descriptions of the models are provided in Schroeter and Associates, (2006a, b, and c). The primary objective of the models was to provide estimates of flow for watershed management, as well as provide the ability for flood forecasting. The Long Point and Catfish models were newly constructed models, whereas the Kettle Creek model was an update of an earlier flood forecast version.

The Guelph All-Weather Storm-Event Runoff (GAWSER) model (Schroeter and Associates, 2004) is a deterministic storm-event hydrologic model which can be used to simulate major hydrologic processes, or streamflow hydrographs resulting from precipitation inputs for the purpose of planning, designing or evaluating the effects of physical changes in the drainage basin. GAWSER has been applied widely in Ontario for planning, design, real-time flood forecasting, and evaluating the effects of physical changes in the drainage basin (Schroeter & Associates, 2004). Precipitation inputs can be defined in terms of rainfall, snowmelt or a combination of both. For simulation, drainage basins can be divided into a series of linked elements representing watersheds, channels and reservoirs. The physical effects of each element are simulated using efficient numerical algorithms representing tested hydrologic models.

The snowmelt sub-model uses a temperature index approach to calculate melt and refreeze, simulates compaction and computes the liquid water holding capacity of the snowpack. Spatially variable infiltration at the soil surface, percolation rates within the soil and overland runoff estimates are accounted for by considering a catchment comprising impervious and pervious areas. Each pervious zone is modelled as two soil layers, and the Green-Ampt equation is used for infiltration calculations. Overland runoff routing is accomplished by the area/time versus time method or two linear reservoirs in series, and the outflows from subsurface and groundwater (baseflow) storage are simulated using a single linear reservoir approach. To replicate how groundwater can be recharged in one catchment, and discharge in a downstream catchment, GAWSER has the capability to route a portion of recharge to a subwatershed separate from the original one. Two channel routing methods are available: lag and route and Muskingum-Cunge. The storage indication or Puls method is used for reservoir routing. For details on the routines included in GAWSER, readers can refer to the GAWSER Training Guide and Reference Manual (Schroeter and Associates, 2004).

4.3 MODEL DEVELOPMENT

This section summarizes the relevant aspects of the development of the GAWSER models for Long Point Region, Catfish Creek and Kettle Creek. Readers are encouraged to read the model reports (Schroeter and Associates, 2006a, b, c).

4.3.1 Climate Data

As discussed in Section 2.4, precipitation is spatially variable across the watershed and to represent this variability, each Conservation Authority is divided into “Zones of Uniform Meteorology” (ZUMs), as shown in Maps 4.1-4.3. Each ZUM is a grouping of catchments which are assumed to have similar climate characteristics. Because the discretization of ZUMS is limited by the number of climate stations, the full climatic variability experienced within the Study Area is not able to be represented within the model, and is an approximation.

Due to climate monitoring network cutbacks, Dr. Schroeter did not have long term climate stations available for each ZUM. Consequently, meteorologic datasets from St. Thomas, Aylmer, Delhi CDA and Simcoe were used to represent climate within GAWSER, but were adjusted on an individual basis for each ZUM. This adjustment was based on comparisons of available historical data to data collected at one of the 4 long term stations. For example, if a comparison between the long-term dataset and historical data collected within a particular ZUM determined that the ZUM had a climate 1 degree cooler, and received 10% more precipitation, the long term dataset was adjusted accordingly (-1^{o}C, +10%precip) for use within the particular ZUM. This comparison, and subsequent adjustment, was done for all ZUMs. This approach takes full advantage of short-term historical data to represent climate variability.

Raw climate datasets typically include data gaps and errors due to temporary closure of stations or equipment malfunction. When constructing the models, Dr. Schroeter used data from adjacent stations to "fill-in" gaps in the St. Thomas, Aylmer, Delhi CDA and Simcoe datasets, using a process described in a technical paper by Schroeter et al. (2000). For the purposes of this study, there exists a filled-in climate dataset from November 1960 to November 2004, which allows streamflow or water budget components to be estimated for the entire period, or any portion of the period. This period includes two severe droughts, in the early 1960's and in the later 1990's.

4.3.2 Catchment Delineation

There are a large number of catchments within all 3 models. The Long Point GAWSER model has 298 catchments, ranging in size from 0.7 km^2 to 56 km^2, with the average being 8.8 km^2. The Catfish Creek model has 75 catchments, which range in size from 0.9 km^2 to 16 km^2, with the average size being 6.5 km^2. The Kettle Creek model has 38 catchments, ranging in size from 0.4 km^2 to 42 km^2, with the average size being 13.7 km^2. This level of discretization is much finer than what is usually seen in other regional studies, but has the advantage of outputting hydrographs virtually anywhere within the watersheds. Not all watercourses were included in the GAWSER models. A number of very small watercourses, which drain directly into Lake Erie and termed "gullies", were not explicitly modelled. Maps 4.4-4.6 illustrate the spatial resolution of the catchments used.

4.3.3 Response Units

In order to simulate how a particular catchment would respond to a precipitation event, the physical makeup, in terms of soils/geologic materials and land cover, of the catchment must be represented in the model. The hydraulic conductivity of the soil and the depth to the water table then determines how the catchment will respond to a precipitation event, whether it will quickly produce large volumes of runoff (low hydraulic conductivity or high water table position), or if there is a delayed, subdued response in stream flow (high hydraulic conductivity coupled with adequate depth). Hydraulic conductivity varies by soil type and also by soilwater status, a variable that changes from event to event. GAWSER has a monthly adjustment factor for hydraulic conductivity that accounts for factors such as freezing and temporal changes in vegetation affecting evapotranspiration.

The methodology for creating the response units used for the Catfish and Kettle Creek models differ from the methodology used for the Long Point model, and as such, will be discussed separately.

4.3.3.1 Catfish and Kettle Creek

The procedure for delineating response units for Catfish and Kettle Creeks closely followed the methodology used within the GRCA Integrated Water Budget Study (AquaResource, 2009b). As with Water Budget methodology employed by the GRCA, quaternary geology, as opposed to soil mapping, was used as the basis to define soil types within the model. This decision was made due to the fact that quaternary geology is more representative of the factors affecting groundwater recharge than soils. To reduce the number of quaternary geology types requiring simulation, geology types were assigned into groupings which react similarly, in a hydrologic sense, to a precipitation event. This classification scheme is very broad and is done from a point of view of hydrologic modelling. All quaternary geologic types were assigned to one of five groupings; Impervious; Clay Tills; Silt Tills; Sand Tills; and Sand & Gravels. The geology types that were assigned to each grouping can be found in Table 4.1. It should be noted that this grouping was done on a hydrologic basis, and may differ from the geologic definition of the materials.

Table 4.1 – Catfish/Kettle Quaternary Geology Grouping

Geologic Grouping	Quaternary Geology Description
Impervious[1]	Amabel Lockport Formations, Bertie Formations, Clinton & Cataract Groups, Dundee & Onondaga & Bois Blanc Formations, Guelph Deposits, Salina Formation, Open Water
Clay Tills	Glaciolacustrine Deep Water Deposits, Man-Made Deposits, Tavistock Till Fluvial Deposits[2], Modern Fluvial Deposists[2]
Silt Tills	Port Stanley Till, Stratford Till
Sand Tills	Wentworth Till
Sand and Gravels	Eolian Deposits, Glaciofluvial ice-contact Deposits, Glaciofluvial Outwash Deposits, Glaciolacustrine Deposits Beach Bar, Glaciolacustrine Deposits Shallow Water, Modern Beach Deposits

[1] Due to the regional nature of the hydrologic model, exposed bedrock was assumed to be impervious. There may be localized areas where exposed bedrock can be an important source of recharge.
[2] Pervious deposits immediately adjacent to rivers and streams were assumed to have low infiltration due to high water tables and therefore lumped with the poorly drained clays.

Similar to geology, land cover was summarized into hydrologically similar groupings. The land cover data utilized was taken from LANDSAT imagery obtained from the Great Lakes Conservation Blueprint Project for Terrestrial Biodiversity project, which was produced by MNR's Natural Heritage Information Centre (MNR, 2003). The land cover categories were as listed in Table 4.2.

Table 4.2 – Catfish/Kettle Land Cover Grouping

Land Cover Grouping	Land Cover Classification
Urban	Settlement and Developed Land
Wetland	Conifer Swamp, Deciduous Swamp, Freshwater Coastal Marsh/Inland Marsh, Open Fen
Low Vegetation	Cropland
Medium Vegetation	Pasture and Abandoned Fields, Sparse Deciduous Land
High Vegetation	Coniferous plantation, Dense Coniferous Forest, Dense Deciduous Forest, Mixed Forest Mainly Coniferous, Mixed Forest Mainly Deciduous

With both quaternary geology and land cover grouped into manageable categories, the datasets were overlain to create Hydrologic Response Units (HRUs). This overlay created a total of 18 classifications of HRUs as shown on Table 4.3. Each of these HRUs was further classified as being hummocky or non-hummocky. This overlay creates a very detailed coverage over the watershed, and is used to define the hydrologic response of each individual catchment within the model. An example of the HRU spatial distribution for the Lower Catfish Creek area is included in Map 4.7.

Each HRU is assumed to have similar hydrologic characteristics, which include such parameters as infiltration rates, depression storage depths, and wilting point/field capacity. Water which infiltrates and subsequently percolates through the entire modelled soil column, past the evaporative root zone, is considered groundwater recharge, and is routed to either a fast-responding groundwater reservoir, or a slow-responding groundwater reservoir. The fast-responding reservoir is intended to represent shallow groundwater flow systems that respond quickly to rainfall events, typically seen in less permeable materials (interflow or tile drainage). The slow-responding reservoir represents the deeper groundwater flow systems typically associated with more pervious materials. It is recognized that pervious materials can, and do, have a quick responding groundwater system, just as less permeable materials have a slower responding groundwater system. The model is generalizing the groundwater flow component, by only allowing pervious deposits to supply water to the slow responding system, and tighter materials to the quick responding system, and limitation of this generalization should be recognized by the reader. Recharge rate estimates from GAWSER include recharge to both reservoirs. Streamflow hydrographs are generated by combining the outflows from both reservoirs, as well as overland runoff.

Table 4.3 - Summary of Catfish/Kettle Creek HRUs

HRU	Description	Groundwater Reservoir	HRU	Description	Groundwater Reservoir
1	Impervious	NA	10	Sand Till Medium	Fast
2	Wetland	Fast	11	Sand Till High	Slow
3	Clay Till Low Vegetation	Fast	12	Sand Gravel Low	Slow
4	Clay Till Medium Vegetation	Fast	13	Sand Gravel Medium	Slow
5	Clay Till High Vegetation	Slow	14	Sand Gravel High	Slow
6	Silt Till Low Vegetation	Fast	15	Urban Clay	Fast
7	Silt Till Medium Vegetation	Fast	16	Urban Silt	Fast
8	Silt Till High Vegetation	Slow	17	Urban Sand	Slow
9	Sand Till Low Vegetation	Fast	18	Urban Sand Gravel	Slow

The hydrologic response of a catchment is determined by selecting the top 8, by area, pervious HRUs, and one impervious HRU. Typically, selecting the top 8 pervious HRUs, accounts for more than 90% of a catchment's drainage area. The remaining area in HRUs is typically very small and is prorated across the top 8.

Hydrologic calculations, such as evapotranspiration, runoff, and recharge are calculated on the individual HRU basis, and then summed to the catchment scale. This allows reporting of most water budget parameters at either the HRU or catchment scale. The sum of all HRUs for a particular catchment, weighted by area, produces the outflow hydrograph for a catchment. Outflow hydrographs from other catchments are summed, and then routed to downstream locations, where calibration to observed streamflow is possible.

4.3.3.2 Long Point Region

Response units for the Long Point GAWSER model differed from the Catfish and Kettle Creek models in that they relied upon soils mapping rather then quaternary geology. In the case of Norfolk County, soils mapping has been done to a very high level (OMAFRA, 1984), and represents the best available data. The grouping of the soils data was done in the same fashion as the grouping of the quaternary geology. Soils which respond hydrologically similar to a precipitation event were grouped into one of the following categories; Clays or Clay Tills; Silts and Silty Clays; Sandy Soils; and Sands & Gravels.

The land cover classification also differed from the Catfish and Kettle GAWSER models. The "Medium" vegetation land cover was removed, as it was often not used in analysis, and all forests were grouped into either a "High" infiltration forest or a "Low" infiltration forest, based on the underlying soils. This modification allowed a number of new land cover groupings to be created, namely the "natural" low vegetative cover (grasslands) and "disturbed" low vegetative cover (croplands), as well as a grouping specific to tobacco crops.

The Long Point GAWSER model is divided into two sections with differing response units. The response units used in all watercourses west of Nanticoke Creek are included in Table 4.4.

Table 4.4 - Response Units used For Western Watersheds in LPRCA

HRU	Groundwater Reservoir	Description
1	NA	Impervious surfaces
2	Fast	Wetlands
3	Fast	Clays, clay till with low vegetative cover
4	Fast	Silts, and silty-clays with low vegative cover
5	Slow	Sandy soils with ‘natural’ low vegetative cover
6	Slow	Sandy soils with ‘disturbed’ low vegetative cover
7	Slow	Sand and gravels with tobacco vegetative cover
8	Fast	Slow infiltration soils with forest cover (includes clays, and silty-clays)
9	Slow	Fast infiltration soils with forest cover (includes sands and gravels)

The response units used in watersheds east of, and including, Nanticoke Creek are included in Table 4.5

Table 4.5 - Response Units used For Eastern Watersheds in LPRCA

HRU	Groundwater Reservoir	Description
1	NA	Impervious surfaces
2	Fast	Wetlands
3	Fast	Clays, clay till, with low ‘natural’ vegetative cover
4	Fast	Clays, clay till, organic matter with low ‘disturbed’ vegetative cover
5	Fast	Silts, and silty-clays with low vegative cover
6	Slow	Sandy soils with low vegetative cover
7	Slow	Sand and gravels with tobacco vegetative cover
8	Fast	Slow infiltration soils with forest cover (includes clays, and silty-clays)
9	Slow	Fast infiltration soils with forest cover (includes sands and gravels)

4.3.4 Seasonal Variation

The large seasonal changes in temperature that Canada is so well known for dramatically affects several hydrologic characteristics, and must be represented in any modelling.

Seasonal shifts are particularly noticeable in reference to infiltration parameters. The difference in infiltration rates between a frozen and a thawed soil may be very significant. With frozen ground conditions, areas dominated by soils with normally high infiltration rates may produce a large proportion of runoff.

To account for this, GAWSER has been developed with the ability to vary a number of infiltration parameters with season. Monthly adjustment factors are used to continuously modify the base infiltration rate, as the model progresses through the year. These factors have been determined through Dr. Harold Schroeter‘s modelling experience in other southern Ontario watersheds and are representative of typical average monthly conditions. The limitation of specifying average monthly adjustment factors to vary with season is that deviations from “normal” monthly conditions cannot be accurately represented. With the prevalence of mid-winter thaws in Southwestern Ontario, and the associated change in hydrologic parameters, this limitation is a source of uncertainty.

4.3.5 Disconnected Drainage

Hummocky topography, typically associated with moraine features, can result in disconnected drainage patterns. Disconnected drainage affects the hydrology by trapping runoff that would drain to the stream network in large depressions, and allowing it to infiltrate over an extended period of time. Having no local drainage, this water can only infiltrate into the ground or evaporate. Even in areas with tighter soils, clays or silts, the landscape’s ability to trap and retain runoff will increase the amount of water available for infiltration.

Disconnected drainage is typically replicated within the GAWSER model by overlying the hummocky topography dataset delineated on the Ontario Ministry of Northern Development and Mines (MNDM) quaternary mapping with the GAWSER subcatchments. Recharge ponds are used to represent the proportion of each catchment with hummocky topography. Over these ponds, infiltration is increased, runoff is decreased and the simulated flow regime more closely represents observed conditions.

There is minimal hummocky topography within Long Point, and was therefore not considered. There exists some hummocky areas within Catfish and Kettle Creek, predominately associated with the till moraines located near the watershed divides. During construction of the Catfish and Kettle models, Dr. Schroeter found that the hydrologic response of the watersheds was not what one would expect from a watershed with significant amounts of disconnected drainage. Due to this, Dr. Schroeter lowered the effective disconnected drainage to 20% of the mapped hummocky topography. It is important to note that hummocky topography was not delineated with the expressed purpose of identifying closed drainage areas. Hummocky topography has in the past been used as a surrogate for closed drainage areas; however hummocky topography may not be synonymous with closed drainage areas for all areas in Ontario.

4.3.6 Evapotranspiration

Evapotranspiration is one of the most dominant hydrological processes in southwestern Ontario and on average accounts for more than 50% of the annual precipitation.

Evapotranspiration is calculated within GAWSER by applying a specified Potential Evapotranspiration rate to the soil column. Water that is held within depression storage is first available for evapotranspiration. When water held in depression storage is reduced to zero, the evapotranspiration routines begin to remove soil water from the first modelled soil layer. Water is removed from the second soil layer when the first soil layer reaches half of its water holding capacity. After both soil layers reach wilting point, no additional water can be evaporated or transpired until the soil water is replenished. This approach, of removing the most readily available water first, progressing to deeper soil water, and then having evapotranspiration stop altogether when soil water reaches wilting point, most closely matches the physical process of evapotranspiration. This approach to handling evapotranspiration within a water budget is shared by other hydrologic models such as HSPF (Bicknell et al., 1997).

There are currently two methods for specifying potential evapotranspiration rates within GAWSER. Traditionally, average monthly lake evaporation rates for the general area are input into GAWSER, and are assumed to be representative of potential evapotranspiration rates. Through linear interpolation, these average monthly rates are used to generate daily estimates of potential evapotranspiration.

GAWSER also has the capability of utilizing the Linacre evapotranspiration model, a derivative of the Penman equation. For a detailed explanation of the Linacre evapotranspiration model see Linacre (1977). The Linacre model uses a number of assumptions, relating maximum and minimum temperatures (widely collected values) to solar radiation and dew point temperatures (infrequently collected values). The Penman equation, which requires solar radiation and dew point temperature, is simplified and can be used with the basic climate values. This methodology of estimating potential evapotranspiration has the benefit of being able to represent variation in potential evapotranspiration due to climatic conditions. This can be particularly important during a particularly warm late fall or early spring, where potential evapotranspiration may be higher than average. Furthermore, the ability of representing variable potential evapotranspiration rates is essential when attempting to simulate climate change, where future potential evapotranspiration may look markedly different. This evapotranspiration method is used in all three GAWSER models.

4.3.7 Wastewater Treatment Plant Flows

Any modelling of the watershed must take into account significant human influences. Many of the watercourses within Long Point, Catfish and Kettle Creeks are used as repositories for wastewater treatment plant effluent, which artificially elevate streamflow. While this addition is not as significant as in other river systems in Southern Ontario, it will nonetheless affect the streamflow hydrograph, and needs to be considered.

In order to account for this all wastewater treatment plant discharges have been obtained from the municipalities and are incorporated into the GAWSER model. Wastewater treatment plant outflow hydrographs are summed with the streamflow hydrograph at the point of discharge.

4.4 MODEL REVISIONS

As part of the Integrated Water Budget Report, a number of revisions were made to the GAWSER models and are discussed below.

4.4.1 Water Use

The inclusion of water takings within the GAWSER model was a recent revision made to the model code during the construction of the Long Point model. Water takings for Catfish and Kettle Creek were also incorporated using the same algorithm. This algorithm was limited, however, by its inability to reflect the increased need for water (during times of drought) or the decreased need (during wet periods). To better represent year-to-year variability, a revised methodology for incorporating water use into the Catfish and Long Point GAWSER models was adopted. The methodology was not applied to Kettle Creek model, due to the low number of permits within the watershed. The revised methodology relied upon creating daily hydrographs of water demand for the 1961-2004 period, outside of the GAWSER models, using permitted rates from surface water takings and shallow groundwater takings. These hydrographs were then imported into the models and subtracted from the outflow hydrographs from each of the stress assessment subwatersheds used.

The water demand hydrograph was created by using the irrigation demand model created by the GRCA, documented in the Grand River Water Use Study (GRCA, 2005d), and discussed in Section 3. The irrigation demand model tracks simulated soil water content, output from GAWSER, and predicts when an irrigation event is likely to occur during the months of June-September. This estimate is done on a daily basis, for the entire simulation period of 1960-2004, effectively creating a time series of irrigation events. The time series of irrigation events is used to determine when the water takings located within the subwatershed are active or not. For very wet years, where no irrigation is estimated to occur, the amount withdrawn from streamflow hydrographs will be zero. For very dry years, the amount withdrawn from the streamflow hydrograph will be higher than average.

The rate of water takings was determined by summing the maximum permitted rate of all irrigation permits with surface and shallow groundwater sources in each subwatershed. Based on the comparison of reported rates to permitted rates, as was discussed in Section 3, a reduction factor of 0.60 was applied to the permitted rate. A consumptive factor of 0.75 was also applied, resulting in a composite reduction factor of 0.45, or a reduction of 55% of the permitted rate.

For each irrigation event, water takings are assumed to be active for 4 d, which is consistent with the approach used in the Water Demand Chapter. Recognizing that the impact of all water takings would not be immediately seen at the subwatershed outfall, the total volume of water removed for each 4 d cycle of pumping is evenly distributed over 8 d for surface water takings, and 30 d for shallow groundwater takings.

The averaging period of 8 d for surface water takings is generalized and is a source of uncertainty. The averaging period used for surface water recognizes that irrigation operations are not evenly distributed throughout a particular watershed, and that water taking impacts from a particular operation will take a certain length of time to propagate through the surface water network to the outfall. Additionally, it is highly unlikely that all irrigation operations would begin pumping at the same day. By averaging the pumping rate over an 8 d period, these considerations are accounted for.

The averaging period for groundwater is also a source of uncertainty. The longer averaging period for groundwater recognizes the effect of aquifer storage on buffering the receiving watercourse from water taking impacts. This period would ideally vary between individual groundwater wells, based on such factors as the distance from the receiving watercourse and aquifer properties. While the 30 d averaging period is generalized, it is thought this value is appropriate for regional scale analysis. Variations on this 30 d averaging period were investigated, with the averaging period increased up to a maximum of 60 d. When a demand hydrograph, created using a 60 d averaging period, was input into GAWSER, October simulated flows were much lower than observed. This suggests that the 60 d averaging period was causing water takings to impact streamflows later in the season then observed, and that a smaller averaging period was appropriate.

Utilizing the time series of irrigation events, length of active pumping per irrigation event and the averaging periods discussed above, hydrographs of water demand were generated, and imported into GAWSER to be subtracted from streamflow hydrographs. It is important to note that irrigation events, as predicted from the irrigation demand model, are solely based on a set of logical rules that are applied to estimated soil water. The irrigation demand model, does not, and can not, consider the effect of “human” factors when predicting when irrigation events are expected to occur (farmers may have individual irrigation preferences that differ from the thresholds used). Because of this, it is probable that there are inconsistencies in the timing of the estimated and actual irrigation events. With the estimated irrigation events being used to represent water takings within GAWSER, the uncertainty associated with the timing of the irrigation events would also be present within the simulated flows, particularly the low flows.

Initial GAWSER simulations, using the non-reduced permitted rate to estimate pumping, resulted in summer streamflows reduced to zero for most years. Because this is known not to occur, it confirms the fact that using only the permitted rate to estimate demand, far overestimates the amount of water withdrawn for agricultural purposes. Subsequent simulations with the demand reduction factors, as discussed above, did improve simulated streamflow, although flows during drought periods (1998-1999) were still predicted to be close to zero. Streamflow records did not show this to be the case. To achieve a proper representation of streamflow conditions, it was necessary to introduce an additional water use reduction factor, beyond the consumptive and pumping factors described earlier, which through calibration was found to be 0.66, for a reduction of 33%. This additional reduction factor lowered the extraction rate, when pumps are on, from 0.45 of the permitted rate to 0.30 of the permitted rate, for a total reduction from the maximum permitted rate of approximately 70%. This further reduction may be due to natural storage buffering the watercourses from water taking impacts, water takings being lower than expected, or irrigators being physically, or legally, unable to take water during extreme low flow periods (permits generally limit taking to 10% of water flowing past that point). Included in Figure 4.1 is a plot of daily simulated streamflows illustrating the impact of the water takings on the simulated flow series.

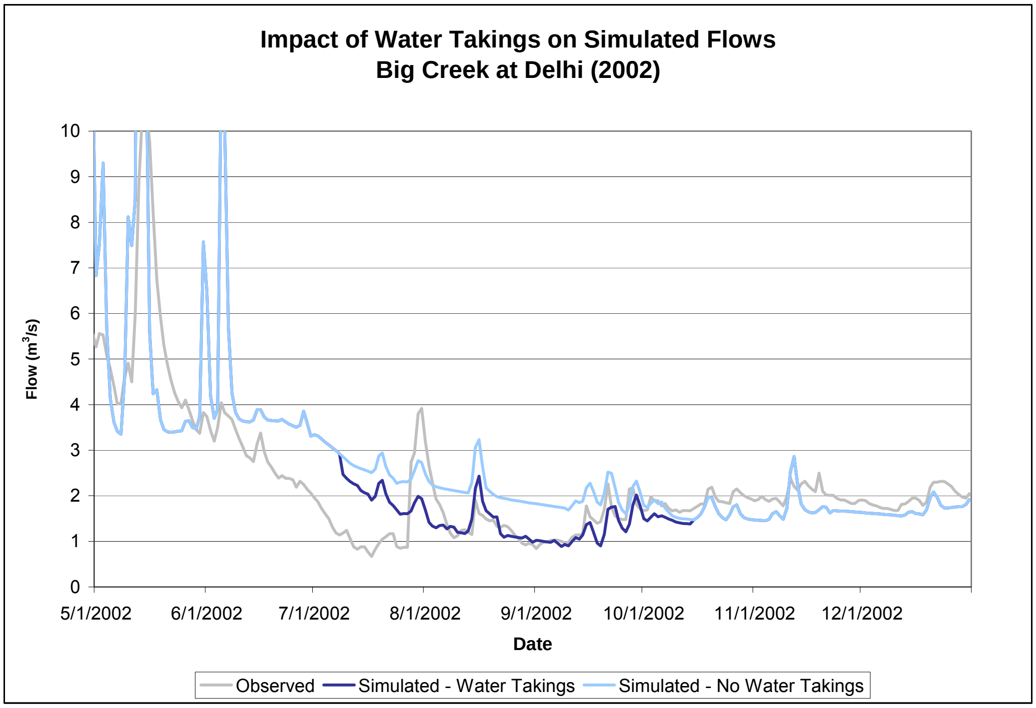


Figure 4.1 - Impact of Water Takings on Simulated Flow

Besides representing a critical aspect of the flow regime within the Norfolk Sand Plain, this exercise had the secondary benefit of serving to validate the assumptions used to estimate agricultural demand. The fact that water taking rates within GAWSER had to be adjusted downwards by only 15%, beyond the reductions utilized in the Water Demand section, suggests that the agricultural demand assumptions are reasonable. The necessary 15% reduction is not likely entirely due to lower than expected water takings, but rather a combination of storage buffering water taking impacts, inability of irrigators to take water during extreme low flow events, as well as lowered water takings.

4.4.2 Response Unit Revisions

A critical component of an integrated water budget is the coupling of the surface and groundwater models via groundwater recharge rates. A significant update to the groundwater model, which was carried out as part of this project, was the updating of recharge rates, to estimates produced from the three GAWSER models. The spatial unit used to provide estimates of recharge to the groundwater model was the HRU.

When recharge estimates from the Long Point GAWSER model were input into the groundwater model, simulated heads in excess of 1,000 m above sea level, were output. This often occurs when the underlying geologic materials cannot accept the volume of recharge specified within the model. These groundwater “mounds” were focused in the Black Creek subwatershed, and within some portions of the Big Otter Watershed Area in Oxford County. A comparison of the soils mapping against the quaternary geology mapping indicated that in these areas of groundwater mounding, there was mapped pervious soil deposits overlying tighter quaternary deposits. With Long Point GAWSER recharge estimates based from soil coverage, not quaternary geology, the groundwater model was attempting to reconcile sand-based recharge rates with glaciolacustrine/till deposits surficial materials. Map 4.8 illustrates pervious soil deposits that overlie tighter quaternary deposits.

To address this issue and retain the integrated modelling system, another HRU was added to the Long Point GAWSER to simulate a permeable material overlying a less permeable material. GAWSER’s infiltration routine utilizes two soil layers; each layer has separate and distinct hydraulic properties that affect how water enters and percolates through the soil layers. The revised HRU was assigned hydrologic characteristics from a sand based HRU for the upper soil layer, with the second layer hydrologic characteristics taken from a silt-based HRU. While water will easily infiltrate into the upper soil layer, the underlying tighter soil layer will be the limiting factor in producing groundwater recharge. This results in a HRU which produces more runoff and less groundwater recharge than a pervious HRU.

The effect on streamflow from the HRU revision was relatively minor. Figure 4.2 illustrates the difference between mean monthly streamflow for the original HRUs, the revised HRUs and the observed flow for Big Otter at Calton. The HRU revision had the overall effect of increasing spring flow, and decreasing summer flow. For the Big Otter at Calton gauge, this produced simulated flows that were in slightly better agreement with observed streamflow than previous. Due to the low proportion of this particular geology/soil combination in Big Otter, the overall effect on streamflow is rather small. The impact of the HRU revision on Black Creek, the most significantly affected subwatershed, is shown on Figure 4.3. Due to the lack of a streamflow gauge on Black Creek, one is not able to tell if this impact improved the model’s ability to replicate observed streamflows. Recharge rates from this revised methodology, when input into the FEFLOW, did succeed in eliminating the areas where groundwater levels in excess of 1000 m existed.

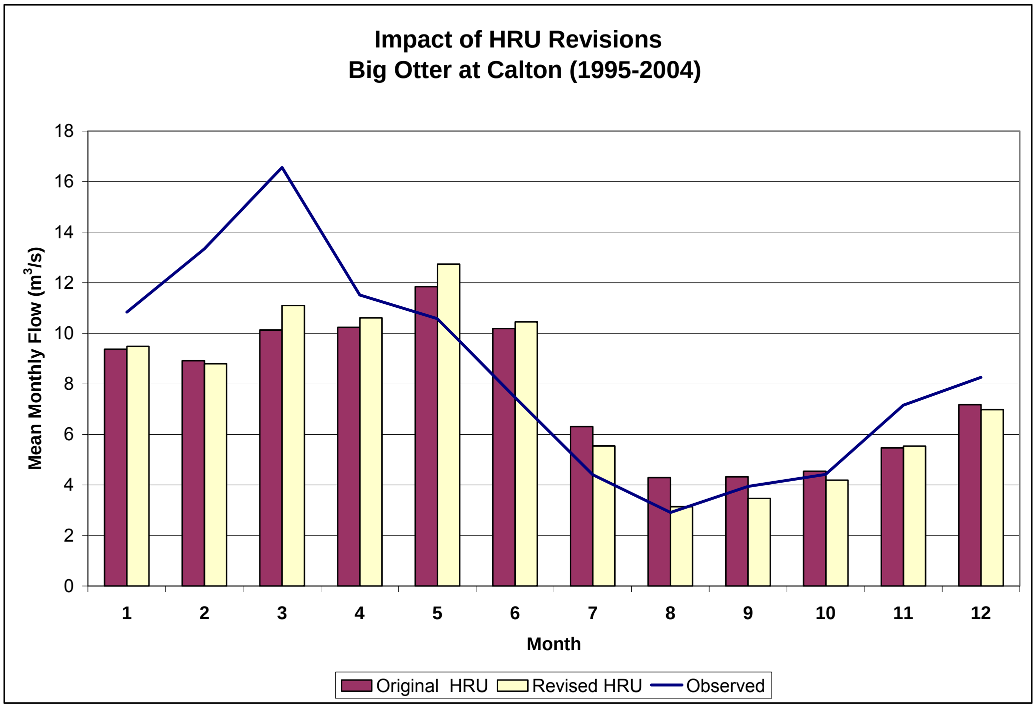


Figure 4.2 - Impact of Long Point HRU Revisions (Big Otter)

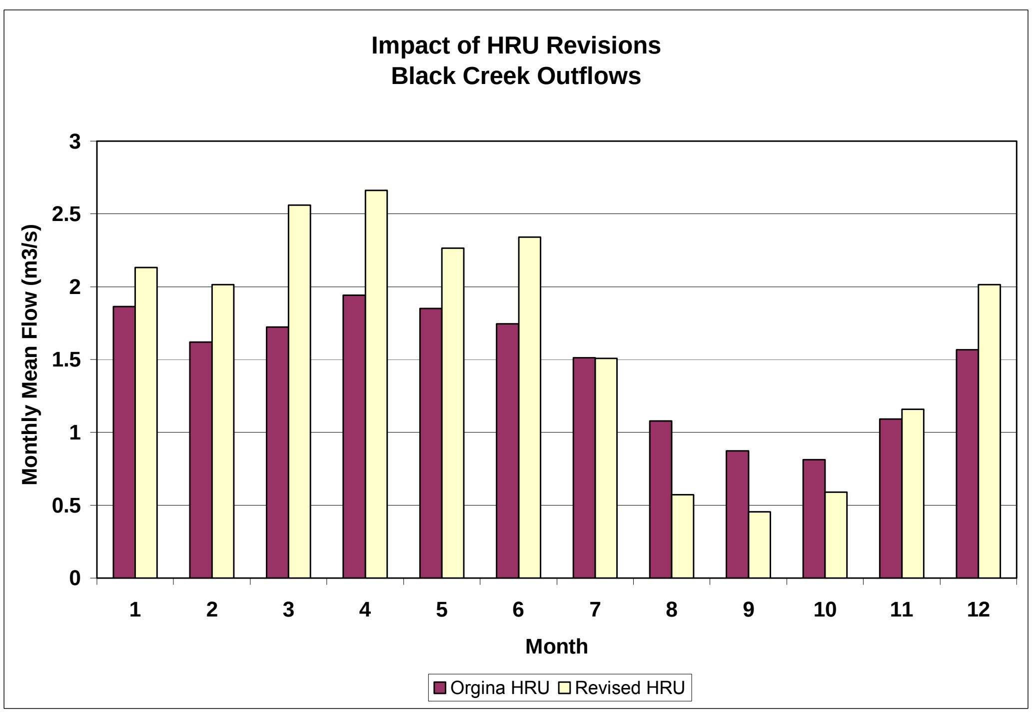


Figure 4.3 - Impact of Long Point HRU Revisions (Black Creek)

4.5 CALIBRATION

While all three GAWSER models have been recently created, they have undergone substantial calibration/verification. During the initial model creation, Dr. Schroeter verified each of the 3 models against, at a minimum, 8 historical events occurring in 2004 and 2005. Additionally, each model was tested in continuous mode for a minimum of 10 years. The selected period utilized by Dr. Schroeter varied between models, to take advantage of periods which had the highest amount of flow data available.

Past calibration exercises for the continuous GAWSER models approached the calibration in a structured hierarchical approach. The model was typical calibrated to a longer temporal scale, and then sequentially moved to a shorter temporal scale. By starting to calibrate to annual volumes, moving to monthly volumes, then finally to daily flows, large problems such as climate data inputs were remedied before groundwater contributions, for example. In addition to comparing annual, monthly and daily volumes, ranked duration curves were compared for both the simulated and observed flow series, as well as ranked difference curves, which plotted the actual difference between simulated and observed flows.

Due to model revisions, as described in Section 4.4, it was required that the calibration/verification be revisited to ensure simulated streamflow reasonably matched observed streamflow.

Although the model was simulated for the entire climate period ranging from 1960 to 2004, the results for January 1995-November 2004 were considered for calibration. Because PTTW information from 2005 was used to represent water taking within GAWSER, the 1995-2004 period was selected for calibration. This ensures that the PTTWs used will be representative of the water taking characteristics over the calibration period.

4.5.1 Parametric vs. Non-Parametric Statistics

Previous calibration exercises, as described above, focused primarily on parametric statistics (i.e., mean flow) to compare simulated and observed flow volumes. Calibrating to a mean annual or monthly flow is an important first step, as it satisfies an initial objective to ensure that the total available water budget and climate dataset is reflective of observed conditions. However, due the fact that streamflow follows a lognormal statistical distribution, the mean annual or monthly flow reflects higher streamflows that are only observed over a short period of time, rather than streamflow that are most commonly observed (baseflow).

By definition, median flow is a non-parametric statistic representing streamflow which is observed 50% of the time. The median flow is, therefore, more reflective of baseflow conditions and as a result, is a better calibration target when trying to estimate groundwater recharge. In the current study, the calibration approach focused on matching median flows to better represent monthly low flow conditions.

4.5.2 Calibration Results

The exercise focused on processes that could affect the low flow component of the hydrograph, namely the recession factors for the groundwater reservoirs and the seasonal adjustment factors, which vary water's movement through the soil column, with month. Particular attention was paid to the seasonal adjustments for the months that act as a transition between cold and warm seasons, and are critical for proper representation of recharge. Care was taken to ensure summer median flows are being represented accurately.

Generally, the models represent mean and median monthly streamflow reasonably. The seasonal variation with highs in spring and fall are replicated, as are the summer low flow periods. However, a trend is present in gauges which drain the Norfolk Sand Plain, where the elevated flows from the spring freshet are extended into late spring/early summer. This extended period of higher flows is likely due to the majority of upstream response units providing water to the “Slow” groundwater reservoir, with very little to no response units providing water to the “Fast” groundwater reservoir. Recall that the fast responding reservoir is intended to represent shallow groundwater flow systems that respond quickly to rainfall events, with the slow responding reservoir representing deeper, slower responding groundwater flow systems. Due to a GAWSER code limitation, response units can only provide water to a single reservoir, not both. Due to the homogeneity of the Norfolk Sand Plain, the majority of upstream response units (sands) are assigned to the slow reservoir. This causes insufficient water to be provided to the fast reservoir, which results in lower then expected flows during or immediately following the spring freshet, with higher than expected flows in late spring/early summer. It should be noted that this issue follows the partitioning of precipitation into evapotranspiration, runoff and recharge, and is a limitation of the groundwater routing component of GAWSER, rather than an issue with partitioning of precipitation. Given that all surface water models have simplified groundwater components, such limitations are expected. From analysis of the monthly mean and median plots, it can be seen that simulated flows match reasonably well for the low flow months of July, August and September.

Comparison of simulated and observed monthly median and mean streamflow, as well as mean monthly depths, for the 1995-2004 period can be found in Figures 4.4-4.18 for Kettle Creek at St.Thomas, Catfish Creek at Sparta, Big Otter Creek at Calton, Big Creek at Delhi and Nanticoke Creek at Nanticoke. Comparison of the median and 90th percentile flows for each of the presented gauges is also included in Table 4.6.

Table 4.6 - Comparison of Median and 90th Percentile Flows

Gauge	50th Percentile (Median)		90th Percentile		Figure
	Simulated Flow	Observed Flow	Simulated Flow	Observed Flow	
Kettle At St. Thomas	1.1	0.9	0.14	0.11	4.4 - 4.6
Catfish at Sparta	1.2	0.9	0.09	0.13	4.7 - 4.9
Big Otter at Calton	5.5	4.8	1.8	2.1	4.10 - 4.12
Big Creek at Delhi	2.7	3.1	0.8	1.2	4.13 - 4.15
Nanticoke Creek at Nanticoke	1.2	1.0	0.06	0.15	4.16 - 4.18

While differences between the simulated and observed flow datasets do exist, it is important to keep in mind that any model is a simplification of reality. Models are not designed to simulate every process that may affect hydrology. Differences between simulated and observed data should be expected, due to both simplified representations of reality and measurement error in observed datasets. That being said, by comparing observed and simulated flows, it can be said with some confidence that the GAWSER models are reasonably predicting the hydrologic response for areas within the Study Area.

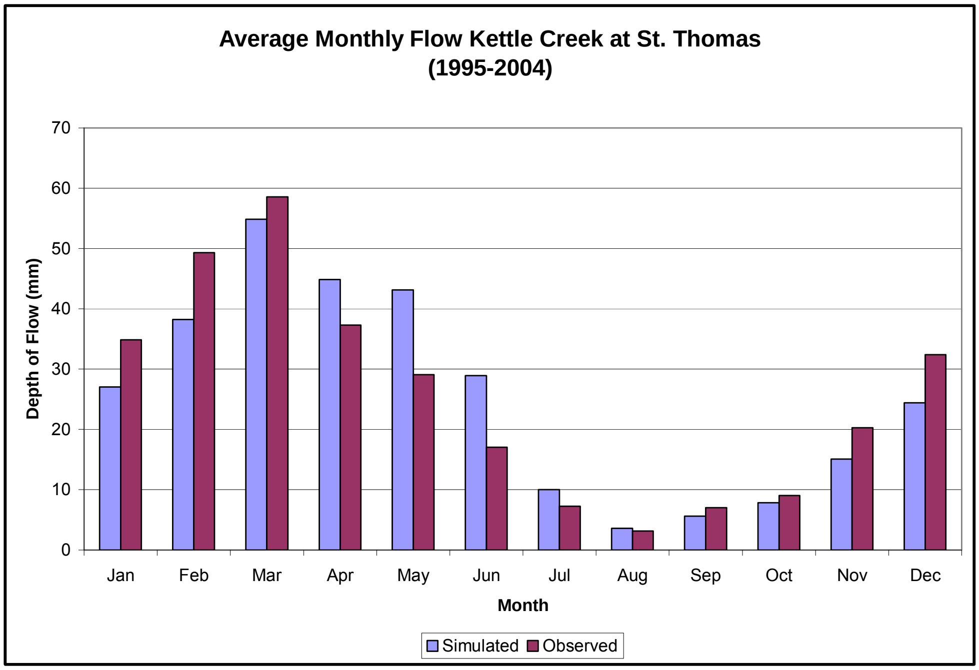


Figure 4.4 - Monthly Mean Flow Depth for Kettle Creek at St. Thomas

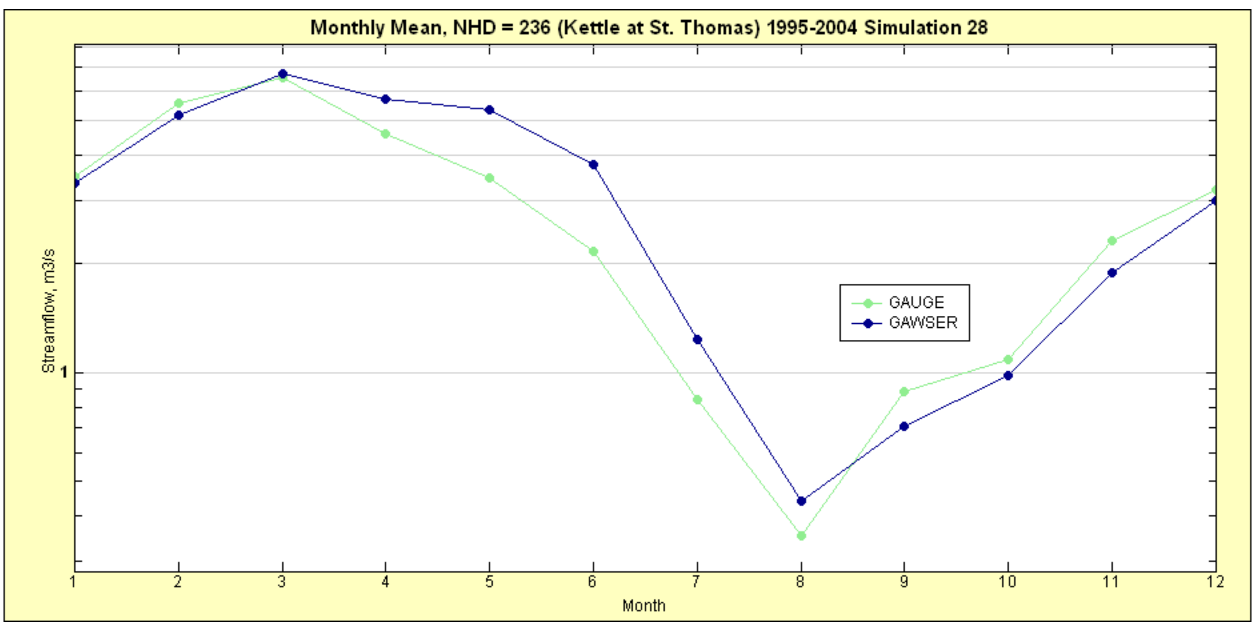


Figure 4.5 - Kettle Creek at St. Thomas Monthly Mean Flow

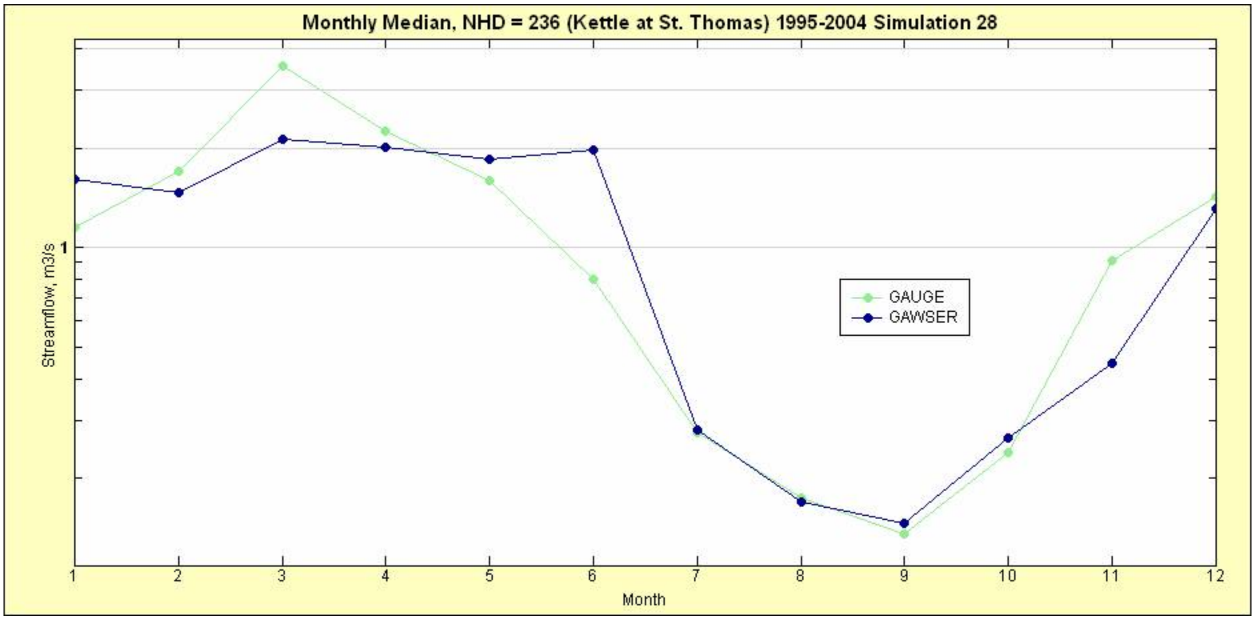


Figure 4.6 - Kettle Creek at St. Thomas Monthly Median Flow

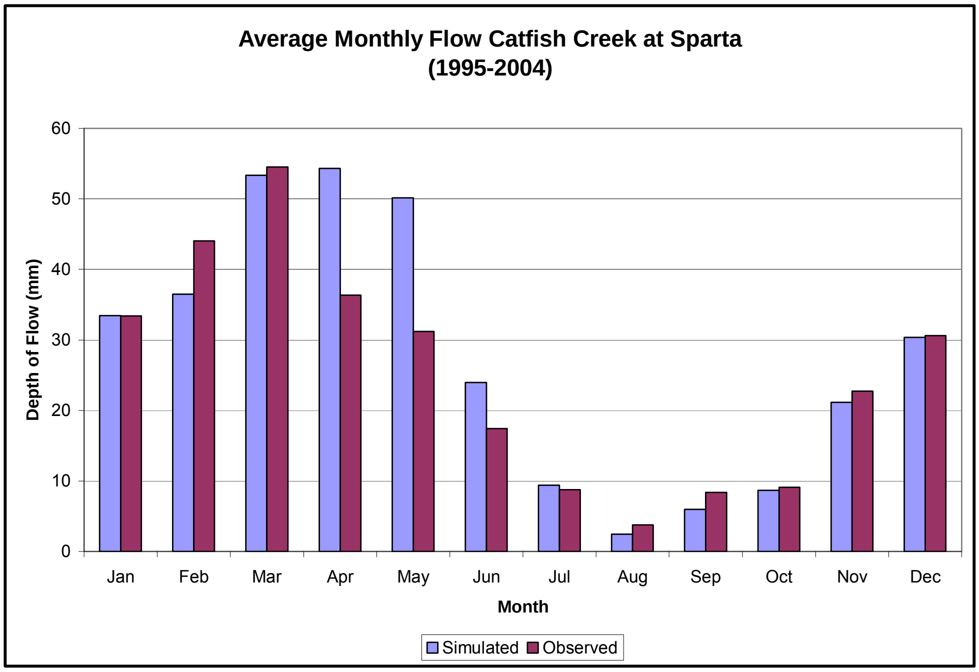


Figure 4.7 - Monthly Mean Flow Depth for Catfish Creek at Sparta

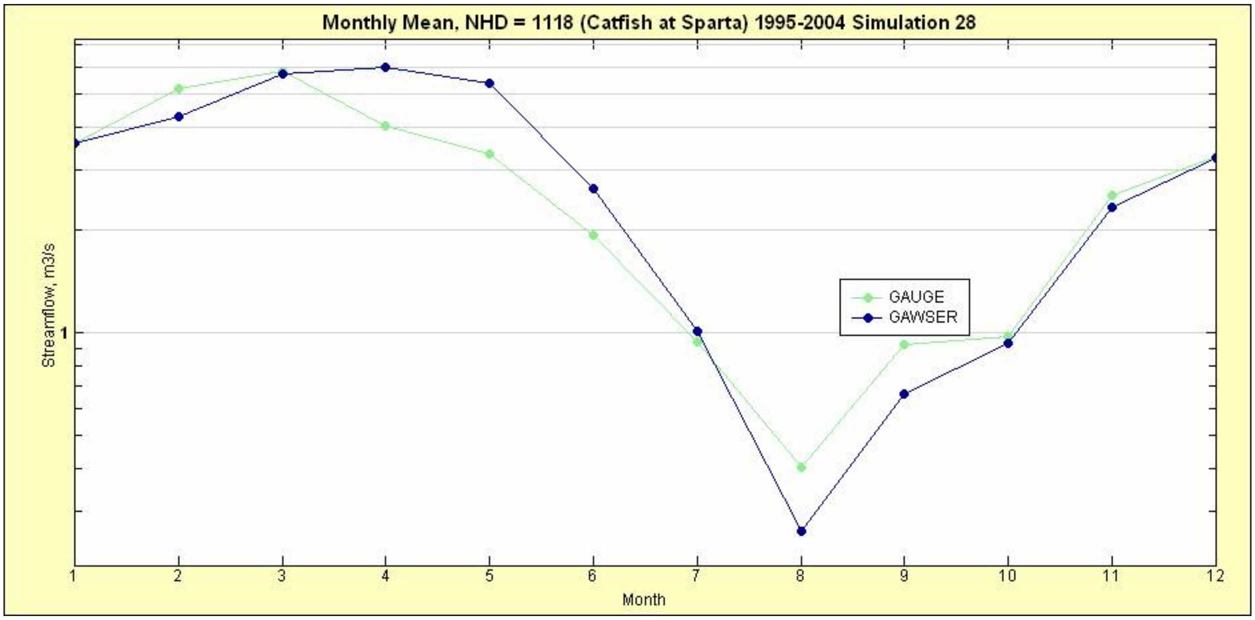


Figure 4.8 - Catfish Creek at Sparta Monthly Mean Flow

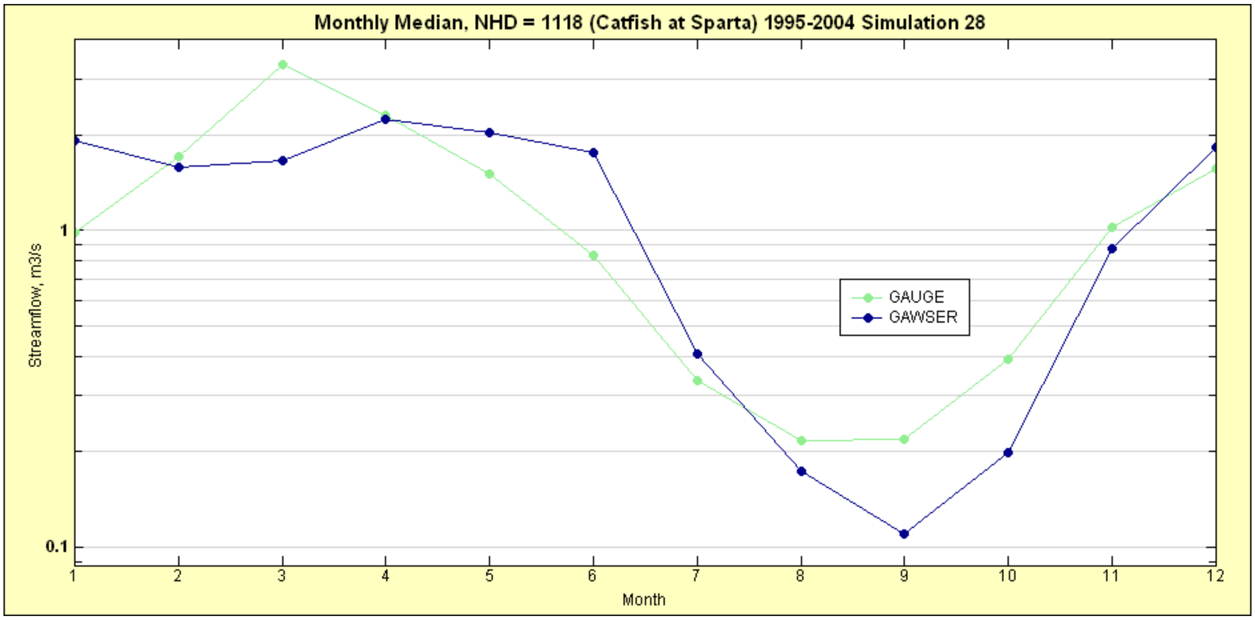


Figure 4.9 - Catfish Creek at Sparta Monthly Median Flow

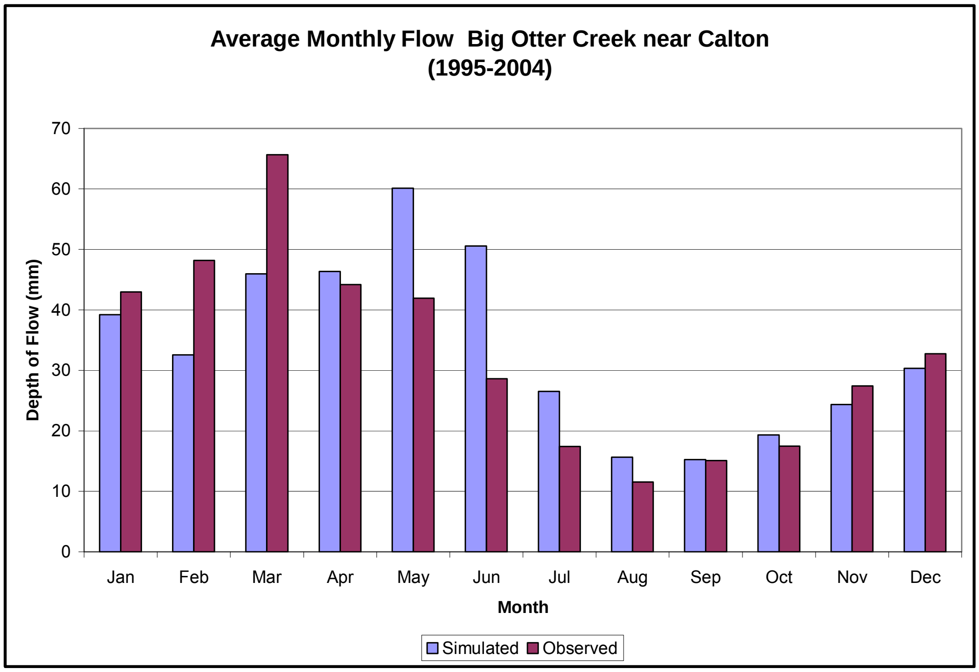


Figure 4.10 - Monthly Mean Flow Depth for Big Otter near Calton

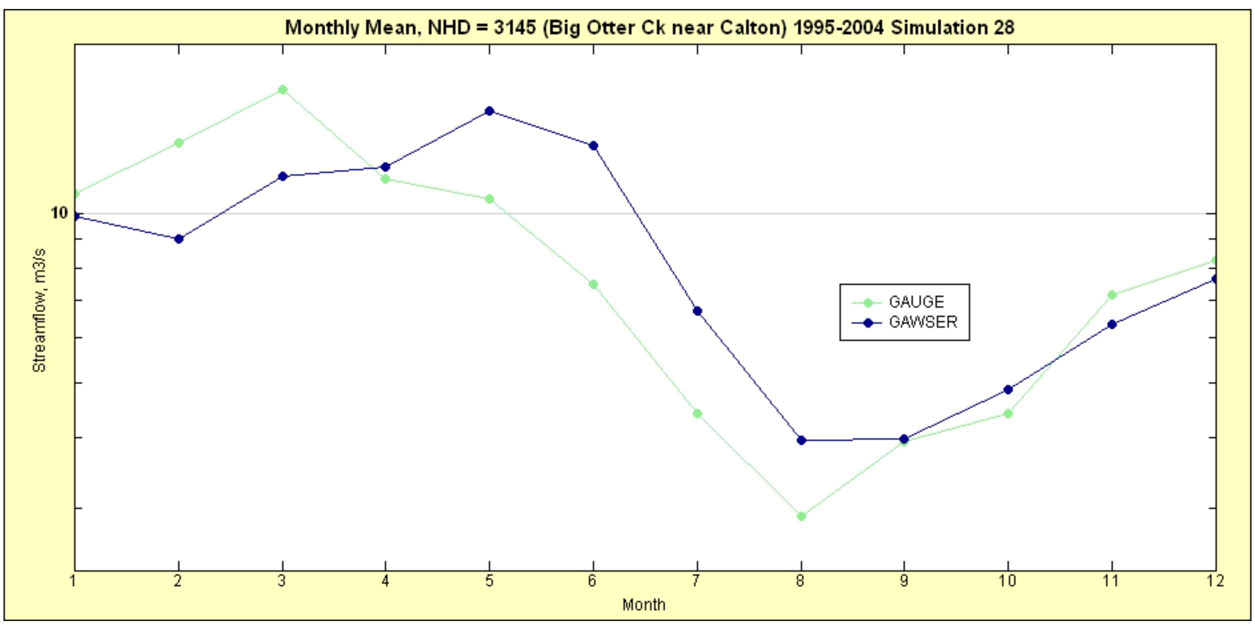


Figure 4.11 - Big Otter Creek at Calton Monthly Mean Flow

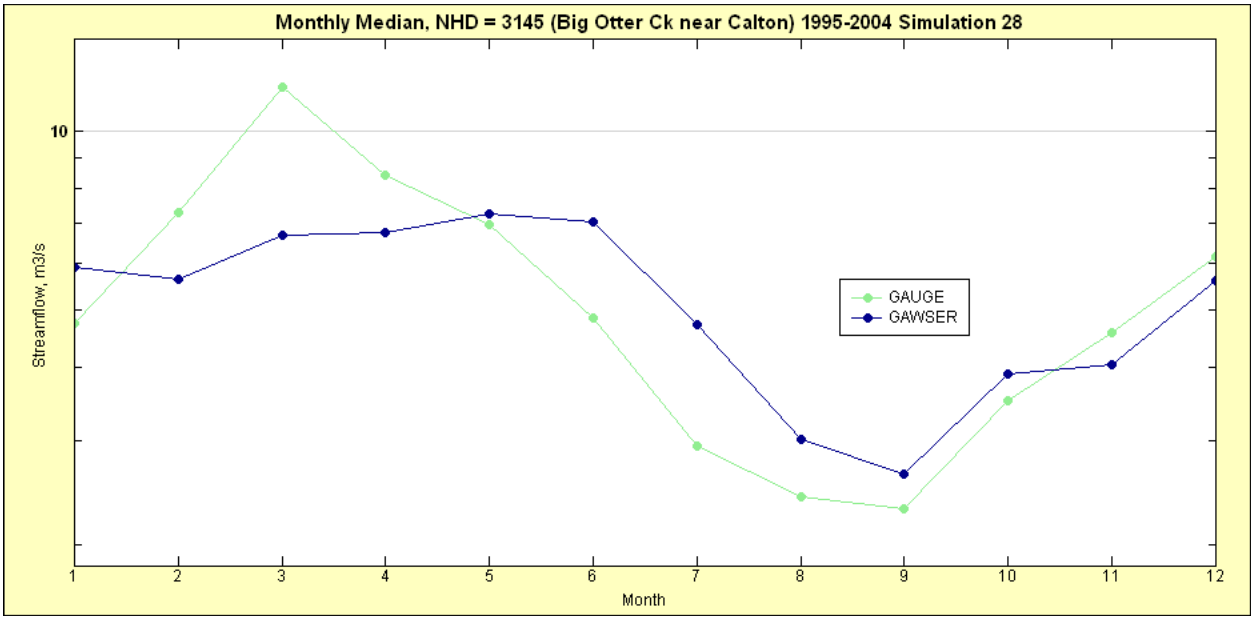


Figure 4.12 - Big Otter Creek at Calton Monthly Median Flow

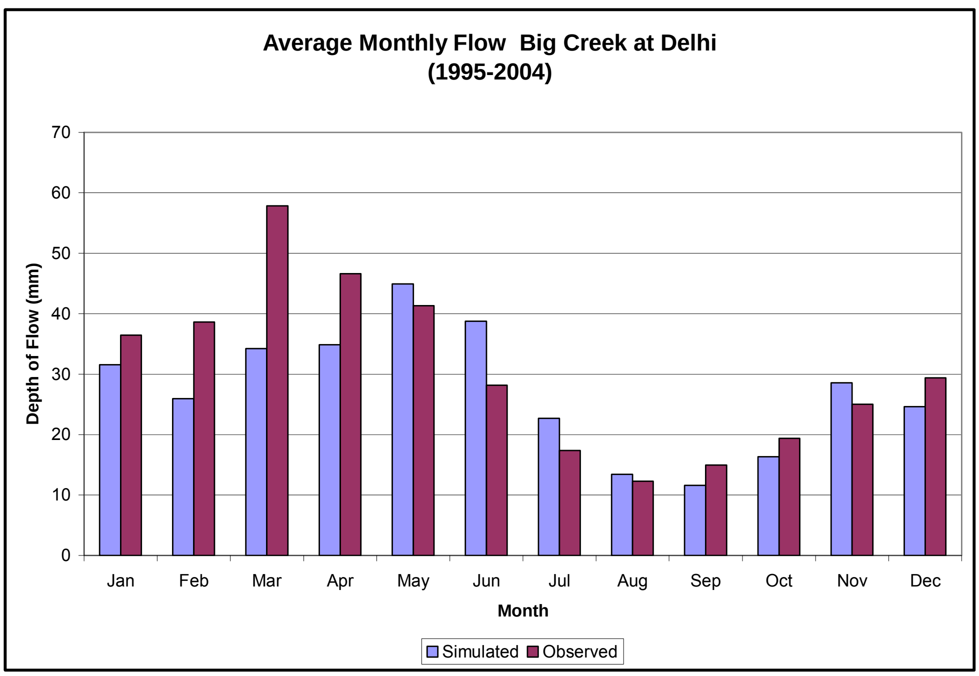


Figure 4.13 - Monthly Mean Flow Depth for Big Creek near Delhi

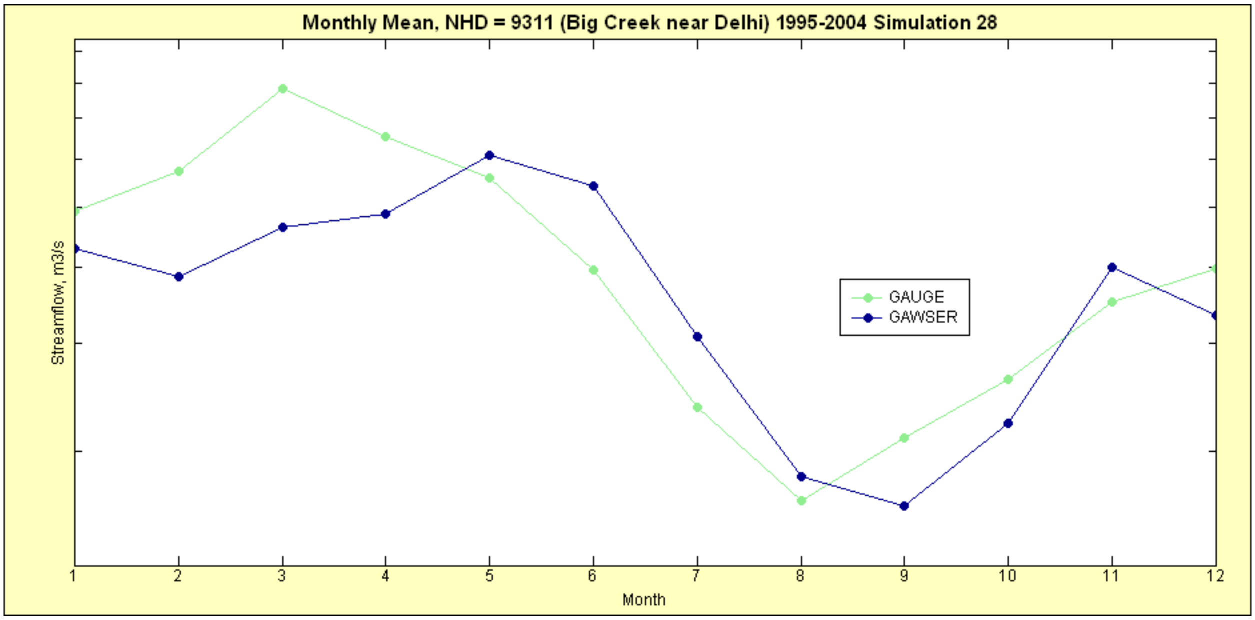


Figure 4.14 - Big Creek at Delhi Monthly Mean Flow

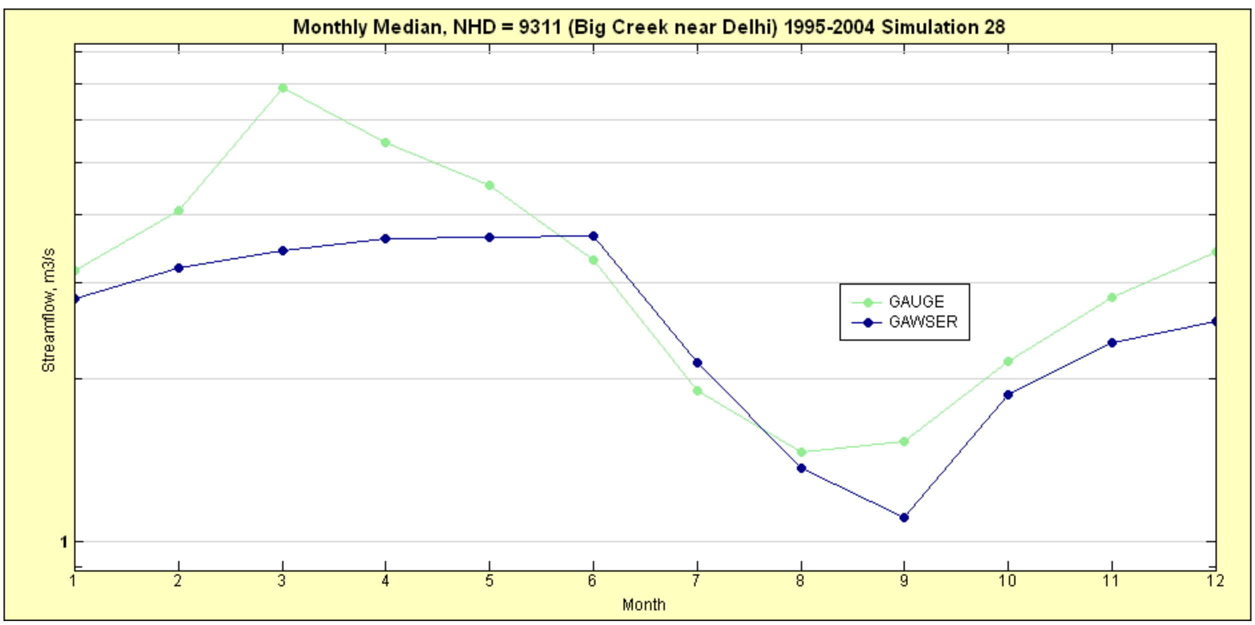


Figure 4.15 - Big Creek at Delhi Monthly Median Flow

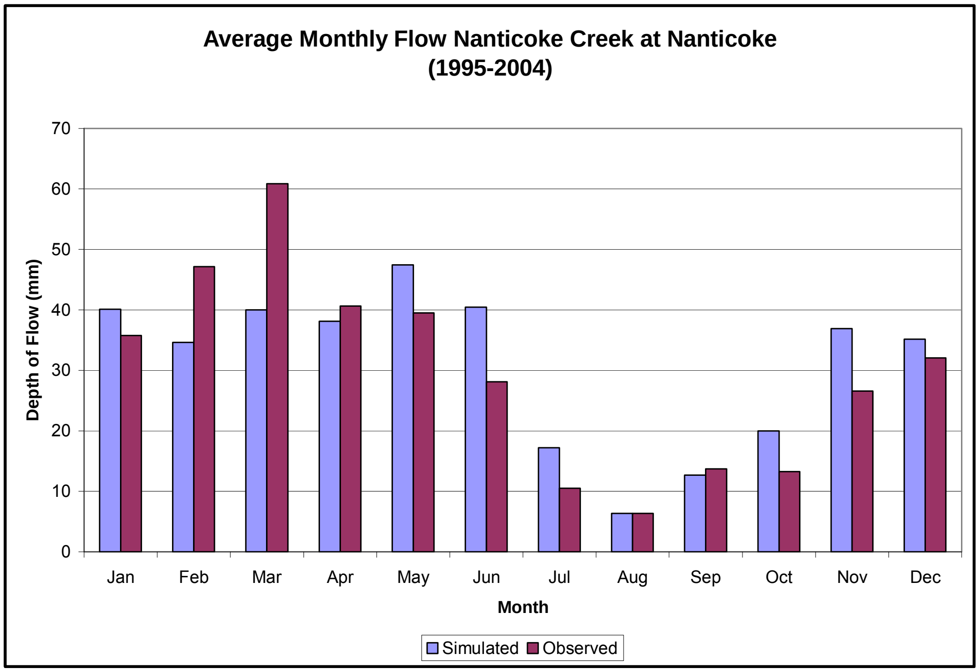


Figure 4.16 - Monthly Mean Flow Depth for Nanticoke Creek at Nanticoke

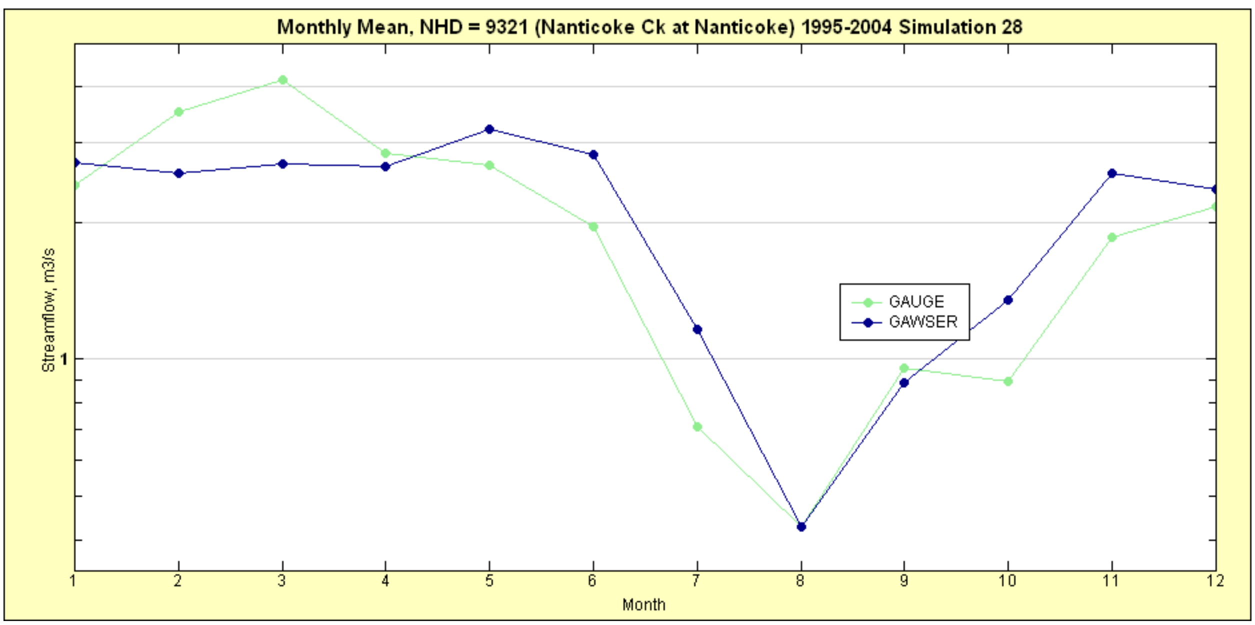


Figure 4.17 - Nanticoke Creek at Nanticoke Monthly Mean Flow

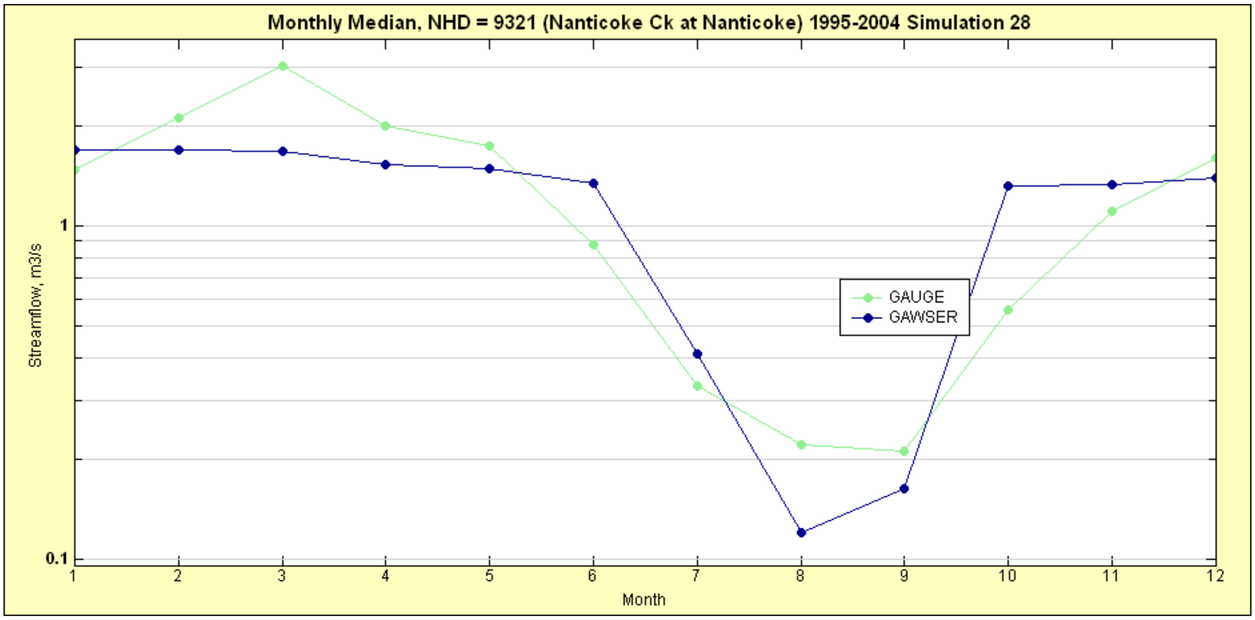


Figure 4.18 - Nanticoke Creek at Nanticoke Monthly Median Flow

4.6 SUMMARY OF GAWSER OUTPUT

As described previously, GAWSER continuously computes the primary water budget parameters for each of the HRUs found within the watershed. This allows for a daily record of such hydrologic parameters as: infiltration; groundwater recharge; soil water content; direct overland runoff; evapotranspiration; and depression storage, for the period from November 1960-November 2004, or any period within. An example of such output is included in Figure 4.19. This graph, presented with two Y-axes, illustrates the response of Silty Till with Low “Natural” Vegetation for the Delhi area for the 1998 year. The right Y-axis, in reverse order, shows how soil water (expressed as a depth of water held within the 1st soil layer simulated within GAWSER) and infiltration vary throughout the year. When infiltration occurs following a precipitation event, the soil water content correspondingly increases. Overland runoff, groundwater recharge and evapotranspiration are plotted with respect to the left Y axis. For the year of 1998, overland runoff is shown to occur only during the winter, spring and isolated periods during the fall. This type of seasonal distribution of runoff is typical, although given extreme precipitation events, runoff events can occur during summer months. Groundwater recharge is limited to those periods where soil water content is above the field capacity of the soil. Evapotranspiration being limited by available soil water content is illustrated, as evapotranspiration moves to zero with lowered soil water content. As the soil water content is replenished due to infiltration, evapotranspiration rises. In addition to the individual water budget parameters at the HRU scale, GAWSER can also output the simulated hydrograph for any junction point between two simulated catchments.

Included in Maps 4.9 and 4.10 are the annual totals of groundwater recharge and runoff on a HRU basis. Recharge and runoff rates for unmodelled gully areas, as explained in Section 4.3.2, were provided from similar HRUs located in adjacent catchments. As expected, recharge rates increase and runoff amounts decrease with higher permeability soils. Higher vegetation coverage has the effect of reducing runoff and increasing recharge. The hydrology of urban HRUs tends to be characterized by having very high runoff and low recharge rates. Wetland HRUs have a simulated average hydrologic response similar to clay tills.

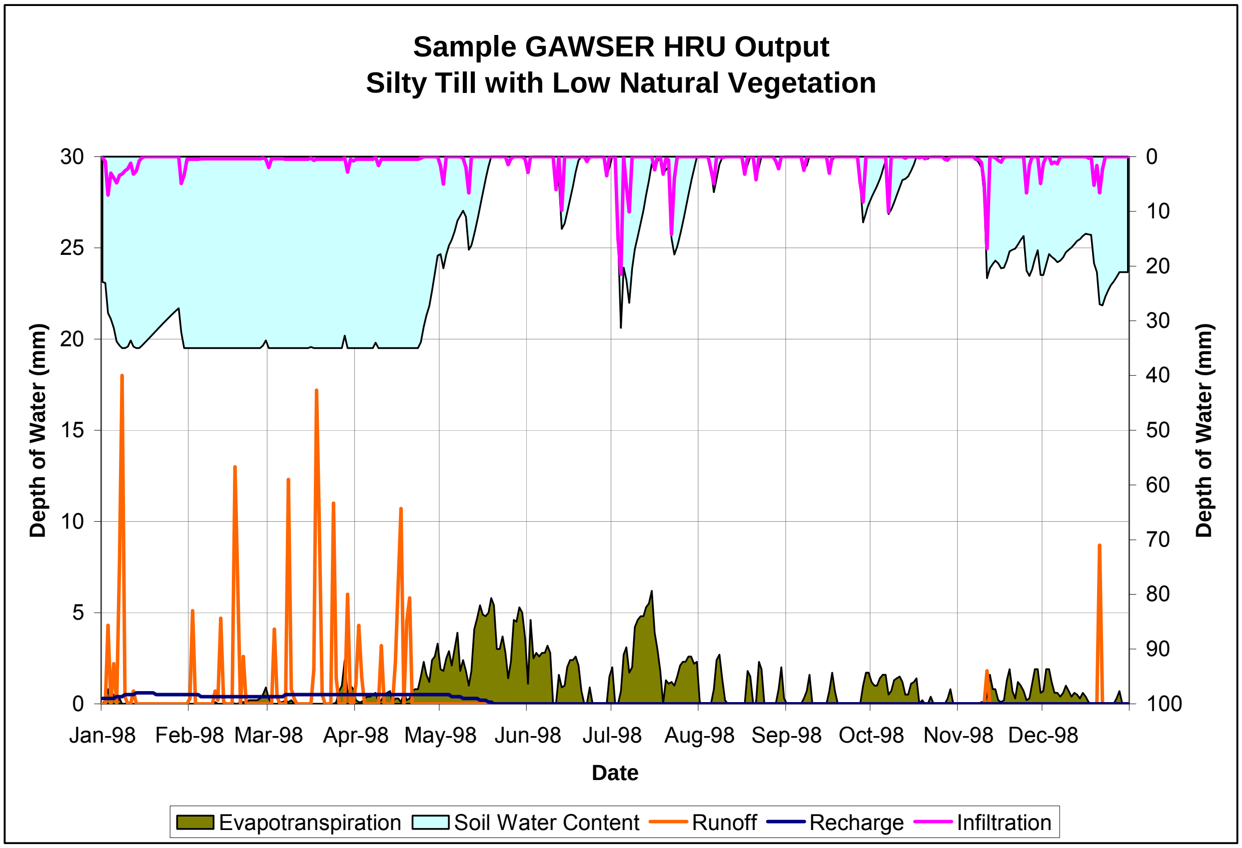


Figure 4.19 - Sample HRU Output

Evapotranspiration is the single largest component of a subwatershed's water balance, and as seen in Figure 4.19, is largely dependant on the amount of water contained within the soil layer. As soil water content drops to zero, so does estimated actual evapotranspiration. In areas of limited water supply (all areas other than groundwater fed wetlands or lakes), estimated actual evapotranspiration will be significantly less than potential evapotranspiration. To illustrate the difference between estimated actual and potential evapotranspiration, Table 4.7 is included. Table 4.7 displays the annual average estimated actual and potential evapotranspiration rates over the 1980-2004 period.

Table 4.7 - Potential and Estimated Actual Evapotranspiration Rates

Subwatershed		Geologic Composition*			GAWSER Estimated Evapotranspiration		Ratio (AET/PET)
		Clay	Silt Till	Sands	Potential (mm/yr)	Actual (mm/yr)	
Kettle Creek	Upper Kettle	10%	80%	7%	845	608	72%
	Dodd Creek	12%	76%	11%	846	602	71%
	Lower Kettle	10%	59%	24%	847	615	73%
Catfish Creek	West Catfish	16%	80%	4%	852	560	66%
	Catfish Above Aylmer	16%	59%	22%	854	568	67%
	Lower Catfish	10%	40%	47%	855	586	69%
	Silver Creek	3%	40%	55%	854	585	69%

Subwatershed		Geologic Composition*			GAWSER Estimated Evapotranspiration		Ratio (AET/PET)
		Clay	Silt Till	Sands	Potential (mm/yr)	Actual (mm/yr)	
Big Otter	Otter Above Maple Dell Road	7%	42%	47%	805	542	67%
Big Otter	Otter at Otterville	27%	32%	39%	806	541	67%
Big Otter	Otter at Tillsonburg	6%	38%	51%	806	498	62%
Big Otter	Spittler Creek	14%	70%	14%	806	529	66%
Big Otter	Lower Otter	15%	37%	46%	805	535	66%
Big Otter	Little Otter	3%	14%	82%	805	552	69%
Lake Erie Tribs	South Otter	3%	6%	89%	806	564	70%
Lake Erie Tribs	Clear Creek	3%	9%	87%	805	562	70%
Big Creek	Big Above Cement Road	7%	49%	43%	807	534	66%
Big Creek	Big Above Kelvin Gauge	4%	15%	79%	807	545	68%
Big Creek	Big Above Delhi	3%	13%	82%	807	549	68%
Big Creek	North Creek	2%	2%	95%	807	565	70%
Big Creek	Big Above Minnow Creek	4%	1%	94%	805	564	70%
Big Creek	Big Above Walsingham	7%	12%	80%	805	563	70%
Big Creek	Venison Creek	3%	7%	89%	805	563	70%
Big Creek	Lower Big	22%	20%	44%	806	490	61%
Lake Erie Tribs	Dedrick Creek	12%	15%	63%	803	551	69%
Lake Erie Tribs	Young/Hay Creeks	18%	4%	77%	805	563	70%
Lynn River	Lynn River	11%	0%	85%	856	584	68%
Lynn River	Black Creek	86%	0%	13%	856	566	66%
Nanticoke Creek	Nanticoke Upper	27%	0%	70%	856	553	65%
Nanticoke Creek	Nanticoke Lower	89%	0%	2%	858	514	60%
Eastern Tribs	Sandusk Creek	95%	0%	0%	858	505	59%
Eastern Tribs	Stoney Creek	95%	0%	0%	858	506	59%

* Minor categories were omitted (wetlands, urban), therefore percentages will not sum to 100%

The ratio of estimated actual evapotranspiration (AET) to potential evapotranspiration (PET) is a value that is affected by a number of factors that include, but are not limited to; the volume of the soil water reservoir held within the soil column; the ability of the soil water reservoir to be replenished by infiltration; and climatic conditions. The subwatershed characteristic most responsible for the volume of the soil water reservoir, as well as the ability of the soil water reservoir to be replenished, is the proportion of the watershed that is comprised of silty tills or clays. The relationship between the proportion of silty tills and clays to the AET/PET ratio is shown in Figure 4.20.

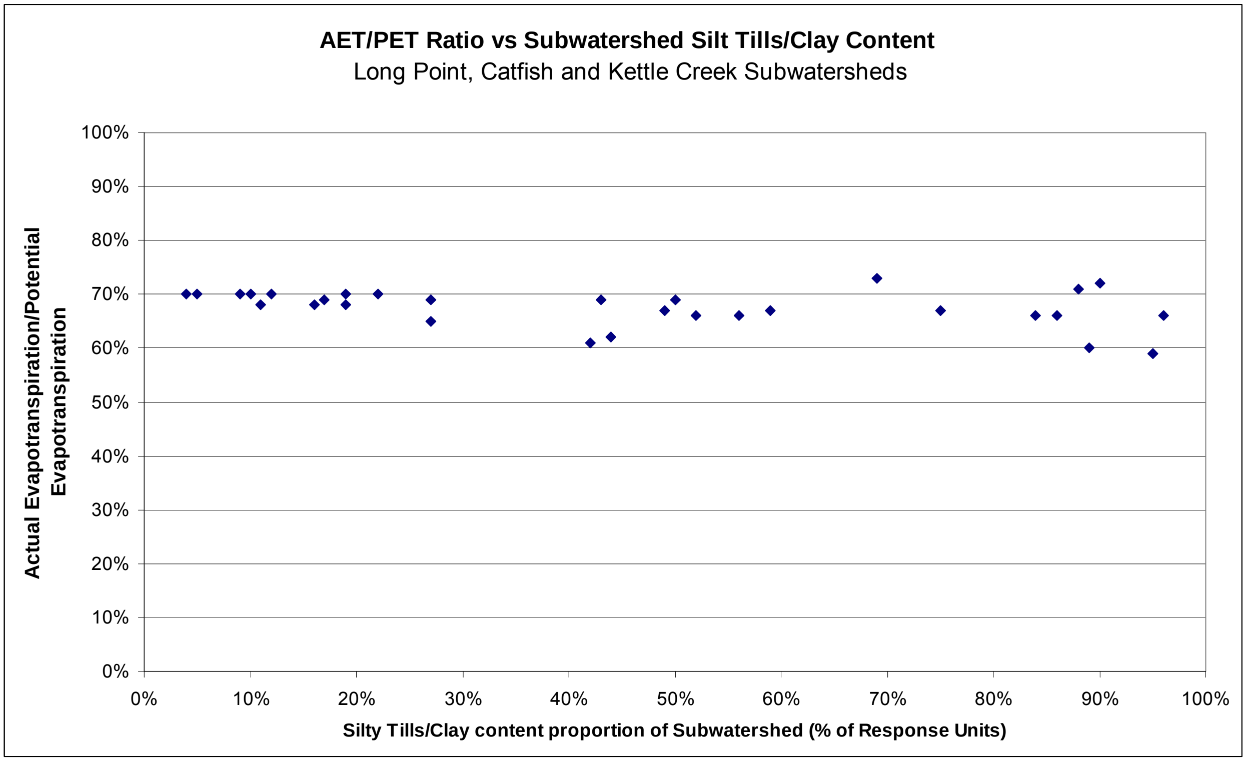


Figure 4.20 - AET/PET Ratio to Silt Till/Clay Content

There is strong support from past studies of evapotranspiration that show actual ET should be highest in subwatersheds with higher available soil water content (Patra, 2000; Woodward et al, 2001; Federer, 2003; Brutsaert, 2005). Soil water content is the volume of water that is held within the soil column against gravity (field capacity) minus the amount of water that cannot be removed by natural means (wilting point). Materials with high available soil water contents are typically characterized as silty clay soils, with clay-rich soils having slightly lower available soil water content, and sands having the lowest available soil water content. Based on this description, silty-clay soils should have the highest AET with respect to PET, and sand-based soils should have the lowest AET with respect to PET. This difference in AET between silty-clay soils and sandy soils may be up to 50 mm. The results from GAWSER show a weak trend in the opposite direction, which indicate that ET for pervious subwatersheds may be over-predicted, and is a source of uncertainty.

4.6.1 Temporal Variability of GAWSER Predictions

The water budget parameters reported up to this point in the document have been determined based on average results over the 1980-2004 the simulation period. Although the underlying calculations are more detailed, the results provide insight into the spatial variability of water budget parameters across the Study Area, and into the average hydrologic response associated with combinations of geology and land cover. However, hydrologic conditions exhibit a high degree of temporal variability. Hydrologic parameters including runoff and stream flow exhibit variability that can be measured on a scale of hours, while the variability of hydrogeologic parameters can be considered over a longer period.

4.6.1.1 Annual Variability - Recharge

Figure 4.21 and 4.22 show the annual recharge rates for the HRUs 'Fast Infiltration with Forests' and 'Slow Infiltration with Forests' for the Delhi area. These HRUs were selected only to assist in visualizing the annual variability that one should expect in determining Water Budget parameters. These plots show that the annual variability of groundwater recharge rates is very significant, and that the average values considered do not fully represent the actual range that may be encountered.

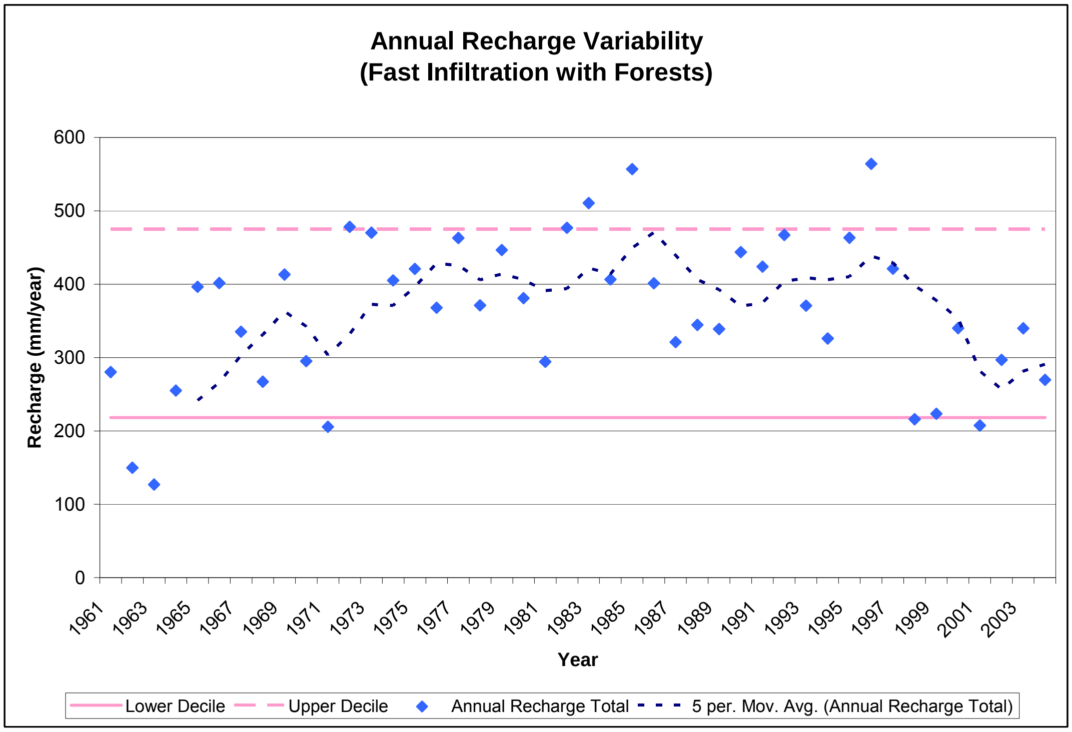


Figure 4.21 - Annual Recharge Variability (Fast Infiltration with Forest)

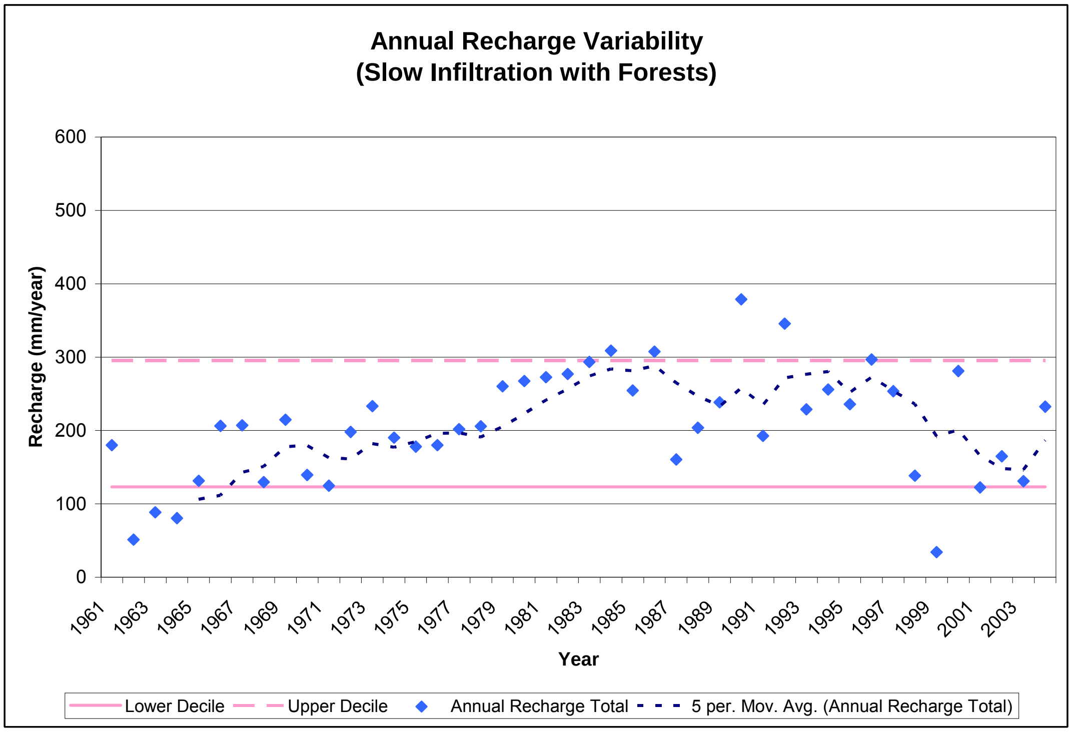


Figure 4.22 - Annual Recharge Variability (Slow Infiltration with Forest)

In spite of the great annual variability in amounts of recharge, the output from the groundwater flow systems is moderated by the large storativity of the groundwater system. On the regional scale the response of the groundwater system to high or low recharge years is spread over several subsequent years. The plots included in Figure 4.21-4.22 show the 10^{th} and 90^{th} percentile lines, which encompass 80% of the annual recharge estimates. In addition, a 5-y moving average of the annual recharge estimate is shown. This moving average period was arbitrarily selected to represent a time-period where groundwater systems may show significant response to a long-term change in recharge. The 5 y moving average seems to reflect the 30-y drought cycle, with reduced values predicted in the 1960's and the late 1990's.

4.6.1.2 Monthly Variability - Recharge

While steady-state estimates of groundwater recharge are typically made to satisfy groundwater investigations and assessments, monthly variations of recharge are important for shallow localized groundwater systems and ecological systems.

Figure 4.23 presents a box and whisker diagram summarizing the variability of monthly recharge for a 'Fast Infiltration with Forest' HRU in the Delhi area. This HRU was selected to assist in visualizing the monthly variability that water budget parameters can experience. Similar to the case for the annual recharge variability, there is a large spread between the minimum and maximum estimates for each month. However, the differences between the 1^{st} and 3^{rd} quartiles are not as large, and the median estimates demonstrate a clear seasonal groundwater recharge trend. Most of the annual recharge occurs in the March-April (Spring) period, followed by the November-December (Fall) period. Frozen ground conditions during the winter months of January and February cause groundwater recharge to be lowered. Recharge rates in the summer time are typically zero when soil water is lower than field capacity. Isolated higher estimates can occur during periods of extended rainfall when soil water content is raised above the soil field capacity.

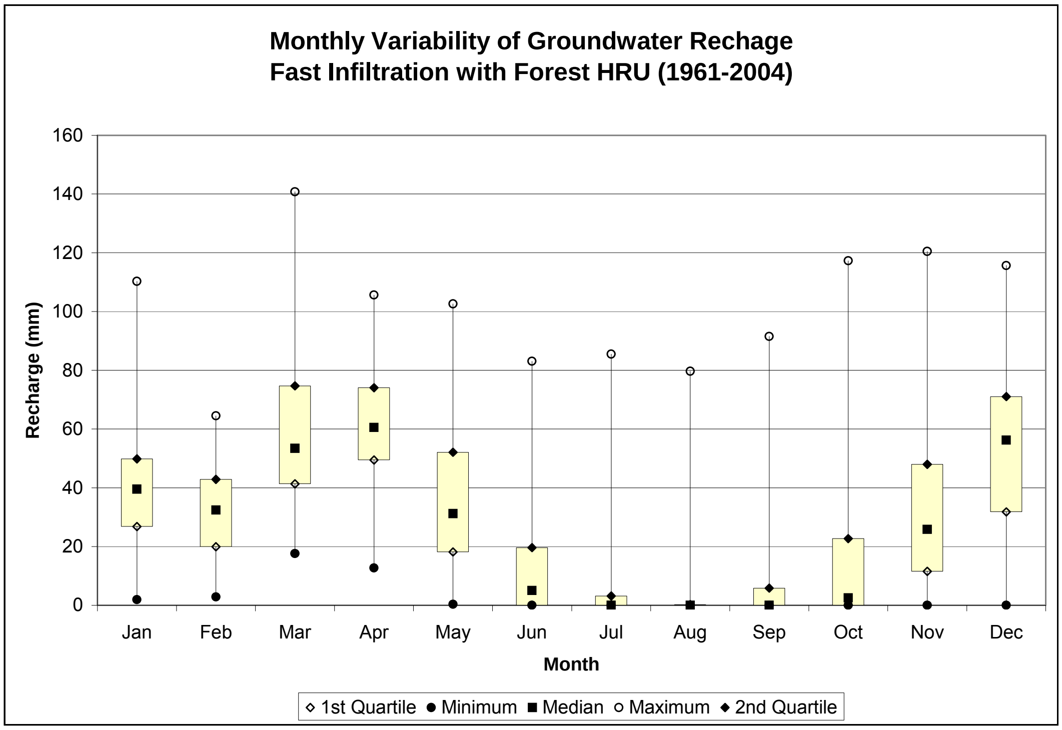


Figure 4.23 - Monthly Variability of Recharge

4.7 UNCERTAINTY

Many elements of the water budget modelling process using GAWSER are subject to uncertainty. Although the calibration process is performed in an attempt to reduce uncertainty, the model results and water budgets reflect the uncertainty in the input parameters.

The following sections summarize some of the uncertainties associated with the GAWSER modelling process and discuss some of the potential impacts of this uncertainty.

4.7.1 Watershed Characterization

The GAWSER model is designed to reflect general characteristics of each catchment relating to land cover, soils and vegetation, and stream and river hydraulics. All model parameters are generally assigned and calibrated to represent streamflow across the watershed; however, in many areas of the watershed the level of characterization has not been refined in support of local-scale calibration and as a result, local streamflow estimates may be subject to higher levels of uncertainty. The lack of a local-scale calibration does not reflect the inadequate refinement of the models, but rather reflects the lack of observed streamflow data at this scale.

Important watershed characterization elements subject to uncertainty are listed below:

- Hydrologic Response Units

The hydrologic response of the watersheds is determined by grouping landuse, vegetation, and surficial geology into similar responding combinations. This allows the models to account for the variability in regional conditions across the watershed. This simplification accounts for larger-scale differences in land cover, but may not exactly reflect local conditions. The effects of slope on hydrologic response were not considered within HRU type and this may also affect local areas. There is also uncertainty with respect to the revisions made to the Long Point HRU coverage regarding pervious soils overlying glaciolacustrine/till deposits. While this revision slightly improved the simulated flows for Big Otter, the overall impact on Black Creek, which was the most heavily affected watershed, was not able to be determined, due to a lack of streamflow data.

- Water Use

While the procedure for incorporating surface water takings into GAWSER, and the impacts those takings have on streamflow, is fairly straight-forward, the procedure for groundwater takings is not. The time lag, from when groundwater pumping begins, to the time that the surface water network are impacted, is extremely difficult to characterize on a regional basis. This lag time would be dependent on a number of factors; including proximity to the receiving watercourse; storage characteristics of the source aquifer; and the hydraulic connection of the pumped aquifer to the watercourse. The generalized time lag used, 30 days, is likely not valid for all groundwater takings, and the impact that this time lag has on how simulated low-flows are affected by pumping is a source of uncertainty.

The incorporation of water use into the GAWSER models, without complete knowledge of actual water taking practices, has introduced a component of uncertainty into the models. The uncertainty has been reduced wherever possible by relying upon the best available water use information, including reported takings and input from the agricultural sector. Without detailed information concerning the amount of water extracted, the consumptive nature of the takings, as well as impact of the extraction on the watercourses, this uncertainty will remain.

- Hummocky Topography Representation

Hummocky topography mapping was used to delineate areas of the watershed that do not have outlets directly connecting to the surface water drainage system. Runoff from such areas is directed to recharge ponds, which represent the large scale depressions, or potholes, that are commonly found in areas with hummocky topography. There is uncertainty regarding the exact area of hummocky topography. Inconsistent approaches to delineate hummocky areas also introduce uncertainty into how these areas are represented in the model. Due to the minimal hummocky topography in Long Point, and the small proportion of effective hummocky topography in Catfish and Kettle Creek, the uncertainty associated with hummocky topography is minimal.

- Snow Processes

Snow accumulation, evaporation/sublimation, redistribution and melt are extremely significant hydrologic processes in Canadian watersheds. The rates of these processes are determined by the inter-relation of many factors, including: land cover, albedo, solar radiation, wind speed/direction, cloud cover, temperature fluctuations, rainfall amount/temperature and new snow density. While GAWSER has been recognized as having one of the more advanced snow-related algorithms available, the simulated processes still represent a simplification of reality. The state of science with respect to the impact of these factors, and their effect on snow processes introduces a level of uncertainty into hydrologic modelling.

- Small Reservoirs / Online Ponds

  There are small reservoirs/online ponds within the Study Area that are not explicitly included within the GAWSER model. These ponds typically have no active reservoir operations, and are run-of-river structures. While these structures do not alter infiltration processes responsible for precipitation partitioning, they may have an impact on in-channel routing. This may introduce a small level of uncertainty into the simulated hydrographs that are used for event-based calibration purposes. However, these effects are considered small when averaging over the longer term.

- Wetlands

  The GAWSER model assigns a single hydrologic response to all wetlands, regardless of the specific hydrologic function of each wetland. Wetlands found within a groundwater discharge area, may have an unlimited supply of water to sustain vegetation growth and high evapotranspiration rates. These types of wetlands would likely have an outlet to allow surface runoff/groundwater discharge to reach watercourses. Wetlands may also serve as groundwater recharge areas, may also have high evapotranspiration rates, but may not have an outlet to the surface water system. At the subwatershed scale, due to the low proportion of wetlands within the Study Area, the uncertainty associated with the model's representation of wetlands is not significant; however, these effects may be more significant when evaluating local scale hydrologic conditions.

- Urban systems

  Urban systems, and their associated storm water management infrastructure (storm water ponds, infiltration galleries, etc.), are not explicitly modelled within the regional GAWSER model. Urban areas are represented within the model as having high imperviousness, and the assumption of not including stormwater drainage would have an impact on the model's dynamic response to precipitation events. Due to a lack of large-scale urban areas within the Study Area, the uncertainty associated with this assumption is not very significant at the subwatershed scale, but will be more important at the local scale within urban areas.

4.7.2 Climate Data

The GAWSER model relies on climate data collected at discrete locations (climate stations) that are assumed to be representative of conditions over a specified geographic area. The current density of climate stations with long term datasets is not sufficient to fully reflect all spatial climate variability, particularly during the summer months, where extremely localized precipitation events are common (thunderstorms).

Further uncertainty is introduced into the process by the measurement error in climate observations themselves. Uncertainty with the precipitation measurement has been estimated by Cumming Coburn Limited (2000) to be approximately ±10%, with uncertainty during winter months reaching ±20%. Precipitation measurement in winter months has a higher uncertainty due to the difficulty of measuring snowfall, which can be highly affected by wind. These levels of uncertainty must be considered, particularly when calibrating the model to short term rainfall events.

4.7.3 Streamflow Data

Streamflow measurements have varying degrees of uncertainty which must be considered when calibrating a model. Manual flow measurements, which are used to generate rating curves (allowing the translation of river stage to river flow), may contain errors of approximately ±5% to 15% (Winter, 1981). Measurement error for extreme events (very low or very high flow) may be significantly higher.

In addition to uncertainty in measurements used to generate a rating curve, changes in river channel geometry may alter the accuracy of the rating curve with time. Changes in river channel geometry may be over the long term (riverbed erosion), or the short term (aquatic plant growth or river ice conditions causing backwater). This uncertainty is more significant in watercourses with sand-based streambeds, due to the increased mobility of the channel morphology. Malfunctions in gauge station equipment may also lead to loss of, or distortion of, streamflow calculations.

Frequent inspections of gauge stations, manual measurements to verify rating curves, and extensive quality assurance/control carried out by Water Survey of Canada attempts to limit error in streamflow estimates.

4.7.4 Limitations of the GAWSER Model

Although GAWSER is a comprehensive hydrologic model, its development is subject to a number of assumptions and simplifications which will affect the certainty of the results. Some of these limitations are summarized below:

- Scale

  Scale is a critical limitation of any regional model, and is a key limitation of the Long Point Region, Catfish and Kettle Creeks GAWSER models. With an inability to represent every hydrologic process, the model is focussed on key processes that are significant at the subwatershed scale. At the local scale however, some regionally insignificant processes may become dominant (e.g., urban systems). When analyzing model output, it should be recognized that while results are likely representative of the subwatershed average, there may exist significant variability within that subwatershed, which may not be explicitly accounted for within the model. Caution should be taken when temporally or spatially downscaling results from any watershed hydrologic model.

- Seasonal adjustment factors

  The monthly adjustment factors that GAWSER applies to infiltration parameters to represent the freezing and thawing of soils are based on the calibration of numerous models over a long period of time. While these adjustments would be representative of hydrologic conditions over the long term, they may not accurately replicate changing soil conditions seen under extremes, such as a late winter, or an early spring. This limitation is critical when analyzing extreme events, particularly those events that may occur when winter, early spring, or late fall months deviate from normal. As an example, significant amounts of recharge may occur during years with warmer than normal late falls, when the onset of frozen ground conditions is delayed. The model may underestimate recharge in this case.

  It is noted that other comparable hydrologic models (i.e., HSPF) also represent monthly changes in hydrologic parameters using similar adjustment factors, and the current state of hydrologic modelling knowledge must be enhanced before these models are able to reflect actual conditions. Furthermore, a body of knowledge must be built, which will allow one to properly characterize this process, before implementing it in a modelling algorithm.

- Handling of interflow / groundwater discharge

  Precipitation that infiltrates into the soil column and percolates through both evaporative soil layers is defined as groundwater recharge. Groundwater recharge enters one of two linear reservoirs before release to the surface water system. The linear reservoirs have different time coefficients, and are used to represent a slow groundwater response (well buffered groundwater discharges), and a quick groundwater response (transient groundwater discharge, or interflow). A single HRU can direct water to either of the reservoirs, but not both. By not allowing a proportion of recharge from a specific HRU to be sent to both linear reservoirs, a geologic/land cover combination that provides recharge to both a slow responding groundwater system, as well as interflow, cannot be represented. It is important to note that this uncertainty is related to the introduction of groundwater recharge back to the watercourse, not with the partitioning of precipitation into evapotranspiration, runoff and recharge.

- Deep Groundwater Storage

  GAWSER has the ability to redirect a specified fraction of groundwater recharge from a particular catchment to a regional groundwater storage element. Water from this regional storage element can then be returned back into the surface water system at a downstream catchment, as a crude representation of a regional groundwater flow system. However, a critical limitation of this process is the fact that this storage element is not mass conservative within GAWSER. If the water contained within the storage element is not withdrawn within a set time interval (24 days), the water is lost from the model. This severely limits the ability of GAWSER to truly replicate a regional flow system, where deep groundwater recharge may remain in the system for months, to years, before discharging. This limitation is particularly noticeable during extreme low flow periods, where the surface water flow system may rely on a well buffered groundwater discharge for sustained flow.

- Evapotranspiration

  The evapotranspiration component of any hydrology study is inherently uncertain due to gaps in the understanding / quantification of local-scale evaporative processes. GAWSER is relying on a simplification of the Penman equation, the Linacre equation, to generate potential evapotranspiration rates, which in itself is a source of uncertainty.

  Literature suggests that areas dominated by silty-clayey soils should have a higher rate of evapotranspiration than pervious soils. GAWSER modelling indicates a very weak trend in the opposite direction, which may be indicating an over-estimation of evapotranspiration for pervious subwatersheds, of up to 50 mm/yr.

  While specific evaporative processes are poorly understood and may lead to uncertain subwatershed estimates, watershed/basin scale estimates can be reliably calculated by determining the difference between precipitation and streamflow over a closed basin. Such estimates are included in the Ministry of Natural Resources Water Resources of Ontario publication (MNR, 1984), and range from 550-600 mm/year for the Study Area. GAWSER is estimating the area average evapotranspiration to be 555 mm/year, which matches well with the MNR estimate. While this reduces the level of uncertainty with the mean evapotranspiration rate, there remains some uncertainty with evapotranspiration from predominately pervious subwatersheds.

5.0 FEFLOW

The steady-state groundwater flow model developed for the LPRCA / CCCA / KCCA Study Area was developed using FEFLOW. The model builds upon earlier work completed by WHI (2003, 2007). The original modelling effort was completed as part of the Norfolk County Groundwater Study (WHI, 2003), which was one of 34 Provincial Water Protection Fund (PWPF) studies. That model was developed for Norfolk County and the LPRCA. The Norfolk County model was extended by WHI (2007) to encompass the CCCA and KCCA watersheds; that version of the model provided the basis for the groundwater water budget model described herein. This section describes the modelling tools developed and how earlier versions were refined to better represent conditions within the Study Area. The FEFLOW model components are described in a logical sequence, as follows:

1. Reasons for selecting FEFLOW as the modelling code;
2. Model construction to represent hydrogeologic conditions and key hydraulic features, including the Structure of the numerical mesh, the Properties, and the Boundary Conditions (perimeter and internal sources and sinks) applied;
3. Calibration of the numerical model to develop a representative groundwater flow tool;
4. Application of the regional FEFLOW model for water budgeting; and
5. A discussion of groundwater modelling uncertainty.

5.1 MODELLING CODE SELECTION

All numerical modelling work on the LPRCA / CCCA / KCCA groundwater flow model was completed using FEFLOW (WASY, 2007). FEFLOW was selected for this area because of its advanced capabilities for the following:

- Ability for the mesh discretization to focus on areas of interest to more precisely simulate observed physical features (pumping wells, rivers, etc.) and follow naturally complex boundary conditions;
- Efficiency of localized mesh discretization, requiring far fewer calculation points to achieve the same level of precision as with finite difference grids which are forced to carry refinements to the model boundaries;
- Ability of the elements to conform to the pronounced vertical variation of aquifer / aquitard layers; and
- Stable water table simulation that facilitates more accurate simulation of the shallow subsurface and allows the modeler to focus on conceptual rather than numerical issues.

Given these considerations, FEFLOW was selected to complete the regional groundwater modelling for the Study area. Since river discharge and pumping are thought to have a dominant influence on groundwater flow within the Study Area, FEFLOW's enhanced capabilities to incorporate these features were considered beneficial.

5.2 MODEL CONSTRUCTION

5.2.1 Model Structure

The structure of the model refers to the distribution of nodal calculation points in both the horizontal and vertical dimensions; those distributions create the 3D elements that represent the hydrogeologic setting.

The location and horizontal extent of the LPRCA / CCCA / KCCA model mesh is presented in Map 5.1. The mesh encompasses the entire Study Area, extending approximately 135 km in width (East-West) and approximately 60 km in height (North-South), resulting in a model area of approximately 4,000 km^2. Map 5.2 conveys the level of discretization contained within the LPRCA / CCCA / KCCA mesh. As this map shows, the mesh is refined in areas where it is important to have enhanced definition of groundwater flow. These areas include the major creek and river features (and tributaries), and large pumping wells (as identified in the PTTW dataset). The mesh was also designed to conform to the subwatershed boundaries located throughout the Study Area (total of 31). It is important to note that these subwatershed boundaries are not physical groundwater flow boundaries, but are represented in the mesh for the purposes of calculating water budget results.

The mesh designed by WHI (2007) was redesigned as part of this study to enhance the ability to conform to key features. The horizontal distribution of node points (discretization) was re-designed to incorporate all major river features as well as permitted pumping locations and to conform to all subwatershed boundaries. Through this refinement, the level of discretization along rivers was reduced from ~ 300m (WHI, 2007) to 50-100m for this study. The mesh contains approximately 1.0 million nodes (~105,000/layer) and 1.7 million elements (~208,000/layer).

The number of vertical layers applied within the current version of the model was also modified from that developed by WHI (2007). The WHI version of the model contained four bedrock layers (1-weathered and 3 un-weathered) that extended more than 500m into the underlying bedrock (with ~100m overburden). However, a review of available borehole data and reflection from experienced hydrogeologists suggested that the active, fresh-water portion of the bedrock was limited to the upper 50m (Theo Beukeboom, pers. comm.). Hydraulic conductivity profiling at the Nanticoke Generating Station, using packer testing, supports this assumption, as evidenced in Figure 5.1 (taken from Jensen, 1995). This profile illustrates hydraulic conductivity moving to 10^{-9} m/s by 15 m below top of bedrock, with discrete features of higher conductivity occurring between 25-35 m below top of rock. The presence of these discrete flow zones have also been identified by Johnston (1964) and Yager (1996). It is possible that there are local flow zones in the bedrock deeper than 50 m; however it is likely that on a regional scale, the transmissivity of this bedrock portion is insignificant. As a result, flow through the bedrock layers was simulated using 2 layers (1 weathered and 1 un-weathered) with a thickness of 5m and 50m respectively.

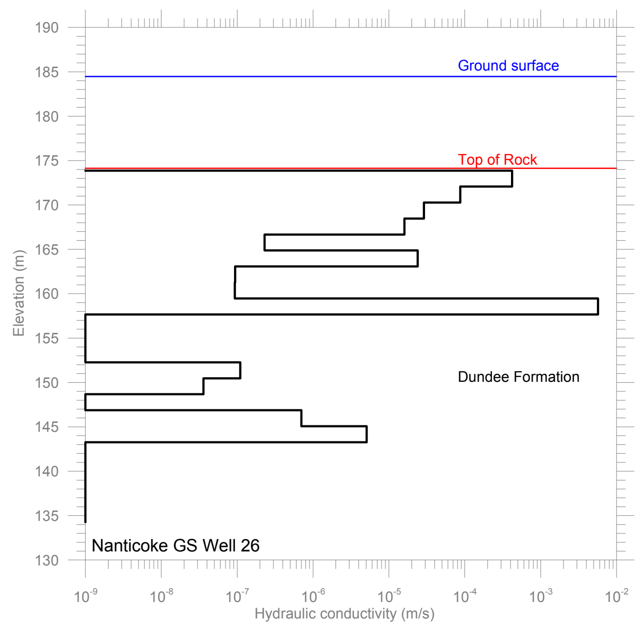


Figure 5.1 - Hydraulic Conductivity Profile for Nanticoke Generating Station (Jensen, 1995)

Overburden layers were not modified from the earlier version. The model was developed to have layers follow a series of hydrostratigraphic units (WHI, 2007). However, a review of this representation as well as the stratigraphic sequences in the area suggests that more work would be needed to explicitly delineate and represent physical hydrostratigraphic units. Consequently, the overburden layers are considered to represent a means of subdividing the unconsolidated sediments, without a direct link to specific stratigraphic units. To compensate for this, properties within each model layer are assigned based on the lithology of the surrounding boreholes.

The model currently contains 8 model layers, 6 applied to subdivide the overburden unconsolidated deposits and 2 applied within the bedrock, representing the weathered and un-weathered portions. Map 5.3 presents a three-dimensional oblique view of the model structure; the colour ramp and hill-shading applied highlight the topographic structure incorporated, while the layer elevations are evident along the sides of the image. Appendix A presents an overview of model structure, including the thickness of each layer and selected 3D views.

5.2.2 Model Properties

The primary hydrogeologic properties assigned within the FEFLOW model include the hydraulic conductivity and the porosity. Hydraulic conductivity is the primary variable that controls the calculated hydraulic head distribution throughout the model domain (based on boundary condition values). Porosity refers to the volume of void space per unit volume of geologic materials and is used in the velocity calculations. When conducting groundwater flow modelling, porosity is only used when analyzing particle path lines.

In developing a groundwater model, initial estimates of hydraulic conductivities are first specified and later modified through calibration. Where available, hydrogeologic properties can be derived from pumping and slug tests within geologic formations. Characterization reports for each of the Long Point Region, Kettle Creek and Catfish Creek Conservation Authorities denoted hydraulic conductivity estimates for each hydrostratigraphic unit. Where such tests are not available, conductivity values are estimated based on the typical value for a given lithology. Given the scale of the LPRCA/CCCA/KCCA model and the model layer structure described above, initial overburden hydraulic conductivity estimates were derived based on borehole lithology records within each model layer, while bedrock values were applied to be consistent with values from previous studies. For example, the Watershed Characterization Reports quote an estimate for the hydraulic conductivity of the Dundee formation at 5.7×10^{-5} m/s, whereas the value applied in the model is 6×10^{-5} m/s

Initial estimates of hydraulic conductivity were specified throughout the three-dimensional model as follows:

- To provide continuity between the groundwater and surface water models, the hydraulic conductivity for the surficial model layer (layer 1) was derived from the distribution applied within the GAWSER model. The values determined for the soil infiltration parameter through the GAWSER model calibration were multiplied by 100 (and translated into m/s) and applied in the FEFLOW model. The factor of 100 was found to be necessary to allow the FEFLOW model to accept the volume of recharge GAWSER predicts. The need for the multiplication factor is expected to result from a difference in the internal treatment of the recharge function in FEFLOW and GAWSER. Within GAWSER, the soil infiltration parameters are applicable for only the upper soil layers, whereas the hydraulic conductivities for the surficial model layer in FEFLOW refers to deeper overburden and is affected by the unsaturated soil conditions (effectively reducing the hydraulic conductivity in the shallow subsurface, based on the K-saturation relationship applied in

FEFLOW). This effect occurs because of the steady-state approach to the FEFLOW modelling. As a result of the steady-state approach the shallow sub-surface remains unsaturated in the simulation and recharge must pass through this unsaturated zone. In contrast, recharge in GAWSER is calculated on an hourly basis and a time-constant hydraulic conductivity is applied. Regardless, using the same distribution in both models provides another level of continuity between the surface and groundwater models.

- Hydraulic conductivity values applied to layer 2 in the FEFLOW model were assigned to be consistent with the quaternary geologic mapping available across the Study Area.
- Hydraulic conductivity values for overburden model layers 3-6 were estimated through an analysis of the lithologic logs within the MOE water well record database following the methodology outlined in Martin & Frind (1998). MOE water well databases from the OGS Groundwater Resource Inventory Projects for Long Point (WHI, 2004) and Catfish and Kettle Creeks (Strynatka, et. al, 2006) were used for this project. Approximately, 19 000 wells were available for Long Point, and 7 000 wells were available for Kettle and Catfish Creek. Only wells which were identified as having a MOE location reliability code of 5 or better were used, which resulted in approximately 14 000 wells for Long Point and 6 000 for Catfish and Kettle. Using the lithology reported in the borehole logs, and a generalization of the relationship between hydraulic conductivity and lithology, a preliminary estimate of hydraulic conductivity within each hydrostratigraphic layer was developed for every borehole. Those estimates were then interpolated and generalized to generate a realistic representation of hydraulic conductivity distribution within model layers 3-6. This process results in a highly heterogeneous distribution of hydraulic conductivity that reflects the areas of higher and lower hydraulic conductivity within model layers.
- All bedrock model layers were assigned uniform hydraulic properties representative of the bedrock materials. Where practical, hydraulic conductivities were taken from previously calibrated groundwater models, such as for the Norfolk County Groundwater Study (WHI, 2003) and the GRCA Integrated Water Budget Study (AquaResource, 2009b).

Initial estimates of hydraulic conductivity were subsequently modified through the model calibration process. Layer thicknesses however were not modified during model calibration. As a result, the calibration of the ability of the groundwater system to transmit flow was primarily accomplished by varying hydraulic conductivity.

Within the current model, it has been assumed that all model layers contain fresh water (low TDS and salinity) and that the hydraulic conductivity of the un-weathered bedrock is not diminished by the weight of the overlying sediments. These assumptions have been applied to simplify the development of the numerical model. However, this may be an area where future modelling refinements are required. Appendix A presents maps of the spatial distribution of hydraulic conductivity within each model layer.

5.2.3 Model Boundary Conditions

Beyond the hydrostratigraphic structure and the hydrogeologic properties, the other primary model parameters are the boundary conditions. Model boundary conditions provide the link between the hydrologic processes simulated within the model domain and the area surrounding it. Boundary conditions are inherently applied to all external faces of the 3D groundwater model, including the ground surface, the sides, and the bottom. Conditions applied along the top of the model include groundwater recharge (provided from the GAWSER model) and surface water bodies (streams, rivers, and lakes). Side boundary conditions define the interaction of the LPRCA / CCCA / KCCA groundwater flow system and the surrounding watersheds. For the bottom boundary of the model, the model is designed to extend vertically throughout the active portion of the flow field, allowing the bottom boundary to be specified as a no-flow boundary.

In general, specified head boundary conditions around the perimeter of the model were minimized to reduce the potential for re-circulating boundary effects. Re-circulation of water within a model can occur when boundary conditions are applied along a watershed divide for example, where large volumes of water may be artificially transferred between adjacent boundary nodes.

5.2.3.1 Recharge

As presented in Chapter 4, the GAWSER model was calibrated to estimate recharge rates for input to the FEFLOW groundwater model. GAWSER calibration efforts were focused on the low-flow regime (including the effects of irrigation pumping) to be able to better constrain the groundwater recharge estimates. Calibrated recharge estimates (see Map 4.9) ranged from a low value of <50 mm/yr (Haldimand Clay Plain) to a high of over 400 mm/yr (Norfolk Sand Plain). High recharge areas within the sand plain are due to permeable soils and relatively flat topography (lack of surface runoff). These recharge estimates are within the range of realistic values expected and are considered reasonable due to the methodology used to develop them. Since the GAWSER model is calibrated to available gauge data for low-flow conditions, additional confidence is placed on the estimated values and their distribution.

5.2.3.2 Streams, Rivers & Lakes

Specification of stream and river boundaries within the LPRCA/CCCA/KCCA model was achieved by applying specified head boundary conditions. All watercourses, with a Strahler Class 3 and above, are included as boundary conditions. Such boundary conditions were considered appropriate for this model as the majority of the streams lie within coarse-grained alluvium (sand plain or modern alluvium) such that the connection ("conductance") with the underlying groundwater system is assumed to be relatively high. The river / stream stage is taken from water levels represented in the available Digital Elevation Model (DEM). Further, the stream network was manually inspected to ensure that the stage specified at consecutive node locations was continuously falling in the downstream direction. As a result, the boundary conditions applied to the model are "hydraulically corrected". Stream boundary values range from a low of 174 masl near Lake Erie to a high of near 300 masl in the northern portion of the Study Area.

Boundary conditions for lakes and reservoirs within the LPRCA / CCCA / KCCA were also simulated using specified head values. Application of specified-head values assumes that there is a good hydraulic connection between the lake and the underlying groundwater system. As with the streams, lake stage was taken from DEM elevations. Map 5.4 shows all watercourse boundary conditions specified within the FEFLOW model.

5.2.3.3 Lateral Side Boundaries

To determine appropriate lateral boundary conditions for the model, water level trends around the perimeter of the model were carefully reviewed. Where water level trends suggested that natural flow boundaries exist (groundwater divides), a no-flow boundary was applied. In other areas where water level trends indicated cross-boundary flow, fixed water level boundary conditions equivalent to the equipotential heads in those layers were applied. The water levels used for this exercise were interpreted from interpolated surfaces of water levels reported in the MOE water well database. The review process also included evaluation of all cross-boundary flows to ensure that the direction and magnitude of cross-boundary flows was reasonable.

For the overburden groundwater system, boundaries where appreciable interchange is expected to occur include the headwaters of the Big Creek and Stoney Creek subwatersheds (interchange is expected with Whiteman's and Mackenzie Creek subwatersheds). The same condition was applied within the neighbouring GRCA model. An additional area where cross-boundary flow was simulated includes the headwaters of Kettle Creek, north of Belmont.

Within the bedrock, exchange is expected to occur along more locations of the northern boundary of the model, simulating more regional groundwater flow toward Lake Erie. Most notably, exchange is permitted between the Big Creek and Whiteman's Creek subwatersheds, and along the headwaters of Big Otter Creek and its tributaries (north of Tillsonburg). Maps 5.5 and 5.6 display the overburden and bedrock boundary conditions specified in the FEFLOW model, respectively.

5.2.3.4 Pumping Wells

As outlined in Chapter 3, considerable effort was undertaken to better estimate the amount of water use within the LPRCA / CCCA / KCCA watershed.

The approach described in Section 3 utilizes the best available data to determine the location, screened interval and pumping rate for wells. Reported "actual" pumping rates were used where available (municipal pumping wells and through surveys). For other permits to take water, the consumptive use estimate for the source was applied. Non-permitted water takings are not represented within the model. All pumping well information, including the rate, location, and screened interval, was assembled within a relational database. For some wells, and particularly for dugout ponds, the screened interval was not known. In that case, wells were assumed to be screened within the most common local aquifer unit while dugout ponds were assumed to extract water from a pond 3 m deep. That information was then used to import well boundary conditions into the FEFLOW model. All pumping well rates in FEFLOW are applied in the units of cubic metres per day.

FEFLOW treats the screened portion of all wells as an open borehole by superimposing a one-dimensional line element onto the existing 3-dimensional finite element mesh. In most cases, the well nodes along the one-dimensional line element span more than one layer of elements; however, in some cases only one node is selected.

A total of 1,971 wells are incorporated within the FEFLOW model with a total demand of 1.7 m^3/s. Municipal pumping within the groundwater system accounts for 0.2 m^3/s, the remainder is primarily from agricultural demand. Map 3.2 presents the location of the groundwater wells and their relative permitted volumes.

Appendix A presents maps of the boundary conditions applied within each model layer for further inspection.

5.3 MODEL CALIBRATION

5.3.1 Calibration Approach

The typical approach to calibration is to alter the hydraulic conductivity value specified for discrete hydrogeological units (i.e., aquifers, aquitards), where each unit would encompass many elements and one or more layers. However, since the hydraulic conductivity field applied within this model is heterogeneous, changing hydraulic conductivities manually for each unit is impractical. To overcome this challenge, the current calibration effort subdivided the watershed into subwatershed polygons which were used to modify elemental properties as a group. The calibration approach is to use a hydraulic conductivity multiplier for all elements within these subwatersheds on a layer-by-layer basis. Using multipliers within each zone and scaling (i.e., increasing or decreasing) the hydraulic conductivity helps control the flow conditions, increasing the accuracy of water level estimates, while maintaining the relative heterogeneity suggested by the variability of the borehole logs.

To support the calibration, a calibration database was developed to store input parameters, files and hydraulic conductivity multipliers as well as the qualitative and quantitative results of all calibration simulations. This database also provides a means of tracking parameter changes from one calibration simulation to the next.

The calibration targets were used in model calibration with these specific considerations:

- Agreement between modelled and observed water levels was desired to ensure that groundwater flow directions were generally consistent with those reflected by observed data.
- Traditional statistical measures of calibration are minimized including mean error of residuals, mean absolute error of residuals and normalized root mean square.
- The differences between simulated and observed water levels at monitoring wells were plotted as 'spatial residuals' across the watershed. A key calibration goal was to minimize spatial trends in these residuals, to validate the conceptual model. At the end of the calibration process, spatial trends in residuals suggest areas within the watershed where further local characterization and calibration is required.
- Baseflow estimates at WSC gauges were assumed to accurately reflect groundwater discharge, and they were treated as key calibration targets.

The following sections present the simulation results of the calibrated model and provide details on the quantitative and qualitative measures of calibration.

5.3.2 Water Level Calibration Targets and Results

Observed water levels (head) and groundwater discharge (portion of stream baseflow) were used as calibration targets for the groundwater model. To calibrate the LPRCA / CCCA / KCCA groundwater model, water level information was carefully selected from the MOE water well information system. Water levels selected for use in calibration included those with high location reliability and with static water levels observed in the period 1980-onward (2450 well water levels). Only wells with MOE reliability codes of 5 or better were used.

In addition to the water level calibration targets used, baseflow discharge estimates at 15 locations throughout the model domain for the 1980-2005 period were also used as calibration targets.

Because the observed water elevations are taken from the MOE water well database, individual observed water levels may not be representative of long term average conditions. This may be the case because the calibration targets span observations over a 25 y period (1980-2005) and reported water levels may be influenced by temporal variations, measurement error, well completion and installation techniques.

Figure 5.2 presents the scatter plot of observed and simulated hydraulic heads for the calibration target points. As this figure shows, good agreement between trends in simulated and observed water levels is achieved. This regional match of observed and simulated water levels (i.e., not all local areas match well) suggests that the numerical model represents the key hydrogeologic functions at the regional scale. This plot however also illustrates a degree of scatter persists in the model (dashed lines represent 10m intervals from the diagonal, perfect-fit line). This degree of scatter indicates that the local scale (approximately a scale of 1-5 kilometres) the hydrogeologic characterization is not sufficient to replicate observed conditions.

Calibration statistics for the hydraulic head calibration measures are illustrated on the figures and further explained below:

- Normalized root mean squared (NRMS) error = 5.3%. This percentage value allows the goodness-of-fit in one model to be compared to another, regardless of the scale of the model. Based on our experience this level of calibration is considered appropriate for a model and indicates that the key regional hydrologic functions are represented within the model;
- Root mean squared (RMS) error = 7.3 m. The RMS is similar to a standard deviation, providing a measure of the degree of scatter about the 1:1 best-fit line, assuming a normal distribution exists. The measure indicates that the majority of the statistical population (~68%) of predicted water levels would fall within 7.3 m of the observed value (95% would fall within 14.6 m). The RMS for the PGMN wells alone is of a similar magnitude at 6.5 m. The magnitude of the RMS achieved is consistent with that achieved in other regional model calibration studies, including the GRCA Integrated Water Budget. An error of ± 5m is generally accepted to be inherent in the use of water well record data, reflecting inaccuracies in well elevation and measurements;
- Mean Error = 2.1 m. The mean error is a measure of whether on average predicted water levels are higher or lower than those observed (ideally it should be close to 0). This statistic indicates that on average, the simulated water levels are high by 2.1 m; and
- Mean Absolute Error = 5.6 m. The mean absolute error is a measure of the average deviation between observed and simulated water levels. The mean absolute error of 5.6 m is less than the population statistic (RMS) and similar to the expected level of error when using water levels from well records (± 5 m).

The integrated manner in which the FEFLOW and GAWSER models have been calibrated to two independent data sets (1, total streamflow and baseflow; and 2, water well levels) provides enhanced confidence in the model-predicted flow volumes. When assessing model performance, the use of multiple, but separate datasets increases the confidence that the modelling system is accurately representing the hydrologic processes. Based on the overall performance of the modelling system in replicating these observed conditions, the modelling system is considered to be accurately replicating surface and groundwater flow volumes, and thus is able to provide realistic water budget estimates for the Study Area. We are confident that any water budget errors that result from calibration residuals would not change determinations of those subwatersheds that are potentially stressed in the accompanying Tier 2 Water Quantity Stress Assessment (AquaResource, 2009a); the sensitivity analysis discussed in the companion report is designed to cover the range of uncertainty in the flow modelling predictions.

Nonetheless, prior to any future application of the model, the model calibration should be reviewed to ensure it is appropriate for the desired application and in some cases, additional calibration may be required. .

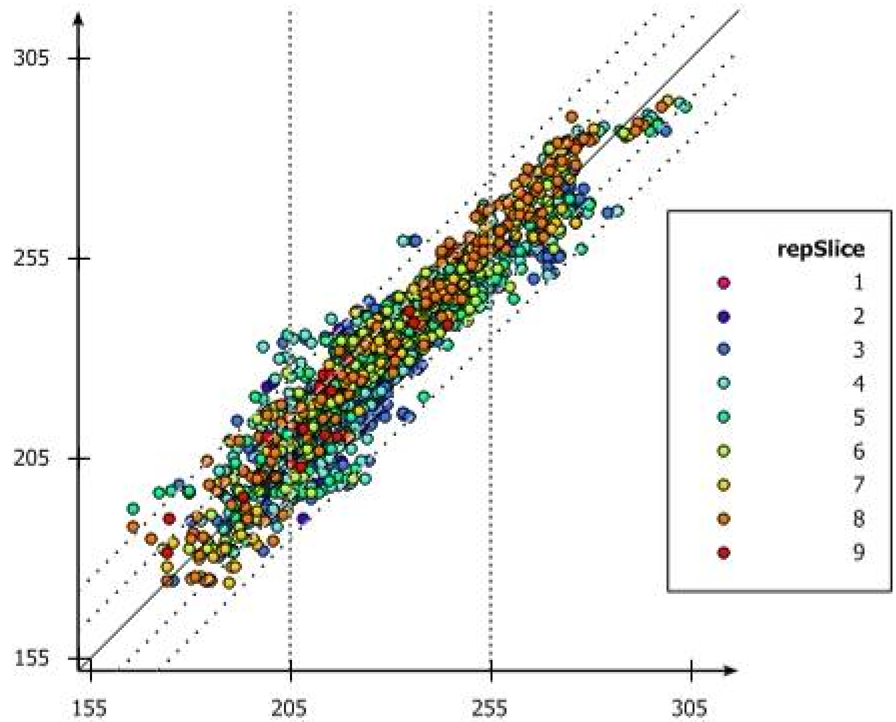


Figure 5.2 - Scatter Plot of Simulated vs. Observed Heads

Map 5.7 illustrates the spatial distribution of calibration residuals (simulated - observed hydraulic head) match between the observed and calculated hydraulic head measurements for all water level calibration targets. Major residual trends have been removed through calibration; however, as this map illustrates, some trends in the data remain. Further model layer refinement and calibration would be required to further reduce these trends.

5.3.3 Baseflow Calibration Targets and Results

In order to estimate groundwater discharge, streamflow records for the 1980-2005 period were separated into baseflow and runoff components using the 3^{rd} pass of the software program, BFLOW, as described in Bellamy et al. (2003). While baseflow is commonly associated with groundwater discharge, this assumption is not always valid. Baseflow can be sustained by the release of water from any large hydrologic or hydrogeologic feature within the upstream drainage area. Aquifers which are hydraulically connected to the watercourse can be such features, as can be significant wetland complexes or large lakes/reservoirs. Wastewater treatment plant discharges also contribute to baseflow. To be able to associate separated baseflow with groundwater discharges, wastewater treatment plant discharges were removed from observed streamflows, to create a naturalized estimate of baseflow.

Recognizing the uncertainty in estimated groundwater discharge rates, the calibration approach relied on an estimated range, as opposed to a single value. The range was bounded by the annual average groundwater discharge (upper limit), and the average groundwater discharge observed during the ice-free period of May – Nov. (lower limit). Estimating groundwater discharge for the ice-free period recognizes that measured winter streamflows may be overestimated due to backwater effects caused by river ice.

The match between observed and simulated baseflow is presented in Figure 5.3. As indicated in Figure 5.3, the range of observed groundwater discharge targets (light blue bars) are typically considered appropriate for comparison to discharge output from a steady-state model. This range is assumed because the method used to estimate baseflow rates is uncertain, and the range in groundwater discharge estimates is considered to encapsulate average annual values. The dark blue squares on the maps represent the simulated groundwater discharge conditions along the stream / river reach. The stations are listed from left to right in order of the relative groundwater discharge, with those on the left representing headwater streams and those on the right representing major river segments (note the log scale for the flows).

In general, the match to observed flows along large stream reaches is good; however, there is scatter associated with the match to medium and low flow reaches. Despite these limitations, the overall match to observed streamflow is considered reasonable. Future calibration efforts should focus on those reaches where the difference between the observed and simulated conditions is highest. For those areas, it is likely that model layer structure modifications as well as local hydraulic conductivity modifications can be used to improve the local calibration to baseflow. Inaccuracies in model layers and assigned hydraulic conductivity values are considered to affect simulated groundwater flow conditions on the scale of 1-5 km (considered a local-scale within this assessment). Additional characterization, including through the development and interpretation of cross-sections, would be required to improve the simulation capabilities at this scale.

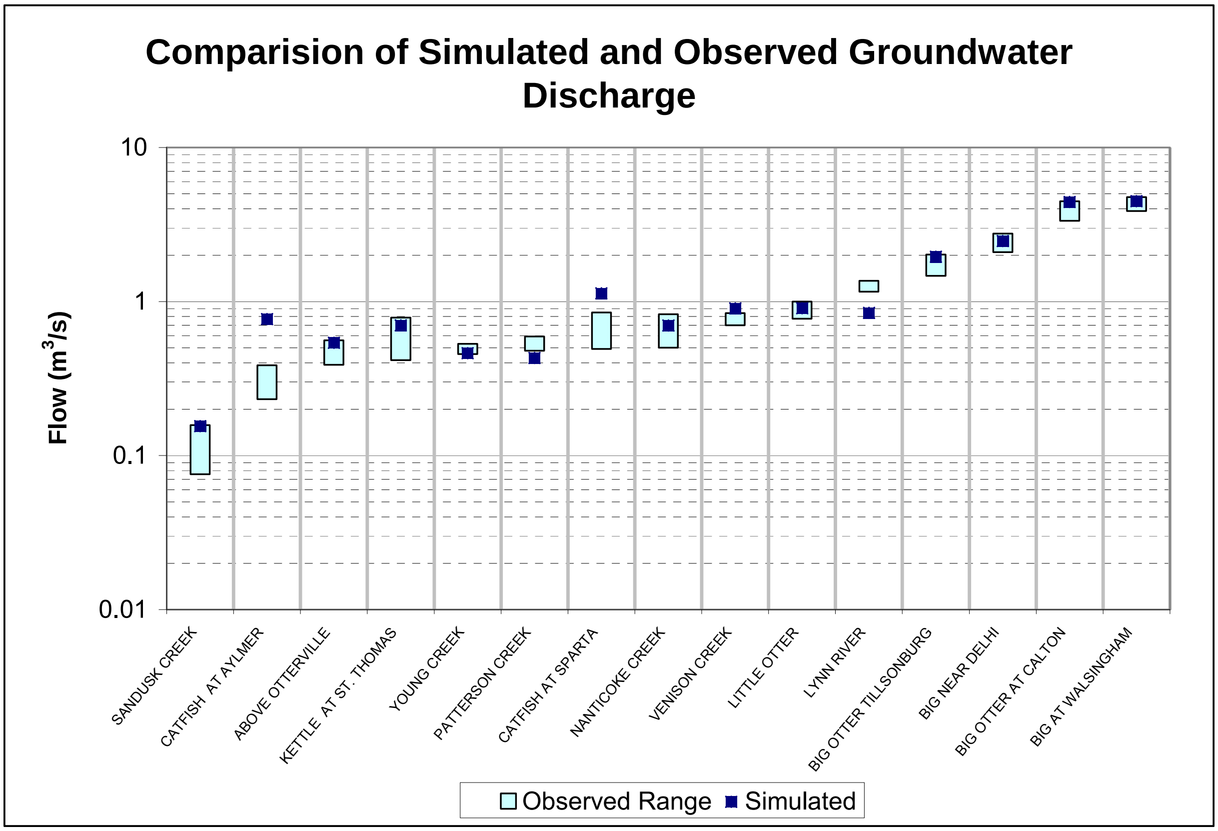


Figure 5.3 - Simulated and Observed Groundwater Discharge

5.4 GROUNDWATER MODELLING ANALYSIS

The calibrated groundwater model provides a synthesis of available information that can be used to increase the understanding about the groundwater flow system and its interaction with the surface water system. Typical tools for completing such an assessment include the following:

- Review of simulated hydraulic head patterns on 2D maps for a hydrostratigraphic layer. This type of review highlights areas of higher or lower hydraulic head and provides insight into the general flow system. Sequential maps for multiple layers indicate areas of potential interaction between hydrostratigraphic units, for example flow between shallow and deep aquifer units;
- Groundwater discharge distribution can be used to visualize the areas of greater interaction between the groundwater and surface water systems. This information in conjunction with the water level maps provides insight into the groundwater flow system; and
- Forward and backward particle tracking to better visualize the three-dimensional groundwater flow system. Backwards particle tracking from key areas of interest (such as areas of higher baseflow discharge) can also provide a great deal of insight into the interconnections between significant discharge zones and their recharge origin. No particle tracking calculations were done as part of this study.

Maps 5.8 and 5.9 present the calibrated hydraulic head distribution throughout the LPRCA / CCCA / KCCA watershed for the water table and contact zone (i.e., weathered bedrock) aquifers, respectively. Both maps illustrate the flow from the Northern reaches of the watershed (topographic high) toward Lake

Erie. The water table map (Map 5.8) also exhibits the influence of primary surface water features; the influence on deeper groundwater flow within the bedrock is minimized due to the thickness of lower conductivity overburden sediments within this area. The irregularity of the water table reflects the heterogeneity of the hydraulic conductivity field applied to the overburden layers in addition to strong local influences of surface water features. In contrast, the hydraulic conductivity within the contact zone aquifer is relatively uniform, resulting in a smoother contour distribution. Additionally, the direct influence of surface water features decreases for deeper hydrogeologic units.

Map 5.10 presents the difference in hydraulic head between the bedrock and the water table; derived from the two surfaces presented in Map 5.8 and 5.9. Those areas where the difference in hydraulic heads between the water table and the bedrock are less than 10 m are shown as white; these areas may not have a strong driving force for vertical flow and may be dominated by horizontal flow (unless the intervening material has a relatively high hydraulic conductivity). Areas in brown represent areas of downward hydraulic gradients. Conversely, green areas indicate regions where strong upward gradients exist and are potential locations of groundwater discharge. Where discharge boundaries exist in the model (such as along streams) those boundaries over-ride recharge conditions. As such, no recharge is applied directly to discharge boundary nodes in the model.

Map 5.11 presents the distribution of groundwater discharge flux to the streams and rivers throughout the Study Area. As is expected in an area of relatively low topographic relief, the majority of groundwater discharge occurs along major stream reaches, such as along the main branches of Big Creek and Big Otter Creek (darker, thicker, blue lines). Lighter blue lines indicate that the headwater regions primarily receive smaller discharge volumes. Similarly, light blue lines within the Haldimand Clay Plain and upper reaches of Catfish Creek indicate relatively low groundwater discharge along those reaches. These results provide an initial regional-scale visualization of groundwater / surface water interactions.

5.5 UNCERTAINTY

Any model developed to represent a natural system is inherently a simplification of that natural system. Part of the reason for this is that the complexities of the physical system can never be known well enough to incorporate all details into a numerical context. In reality, most of the scientific approach involves representing physical conditions observed using approximations of larger-scale functionality; hydraulic conductivity is an example of this. This approximation does not negate the ability of scientists and practitioners to utilize numerical models as tools to help understand and manage natural systems; however, there is a need to recognize the limitations of such tools when interpreting model results.

Many elements of the groundwater modelling process using any modelling code are subject to uncertainty. Although the calibration process is performed in an attempt to provide a realistic representation of physical conditions and reduce uncertainty, the model results and water budgets reflect the uncertainty in the model input parameters.

The following sections summarize some of the uncertainties associated with the FEFLOW modelling process and discuss some of the potential impacts of this uncertainty.

5.5.1 Watershed Characterization

The Study Area steady-state groundwater flow model is designed to incorporate the key hydrogeologic features of each subwatershed and their characteristics. Thus the model has been designed to evaluate the flows through the system at a subwatershed level by incorporating key identified features and characteristics as understood through the characterization process and through local experience. The implication is that features at a smaller scale may not be adequately represented to support more local assessments and additional refinement and characterization is required to examine those features.

In most cases the limiting factor that results in uncertainty is the lack of available subsurface data. For the LPRCA / CCCA / KCCA model, an attempt was made to utilize knowledge from all available data through the generation of hydraulic conductivity fields, based on the lithology recorded at individual boreholes.

Important watershed characterization elements subject to uncertainty are listed below:

- Hydrostratigraphic Interpretation: Uncertainty in the geologic conceptual model has led to the definition of numerical model layers that are neither representative of hydrostratigraphic conditions, nor are they uniformly distributed. The model layers developed by WHI (2007) contain thick regions that are not supported by the underlying borehole data. An example of this is one area in the Catfish Creek Conservation Authority, where the “Fossil Alluvium” layer (layer 6) has been assigned a thickness of 50m, whereas practically this layer is considered to be approximately 1m thick. A lack of borehole logs that penetrate to depth in this area exacerbate the uncertainty associated with this interpretation and the assigned hydraulic conductivity.

- Hydrogeologic Characteristics: The hydrogeologic characteristics were generated by interpolating point estimates of hydraulic conductivity based on borehole lithologies. As a result, there are numerous sources of uncertainty, including the following:

    - driller’s recorded lithology which is subject to the individuals’ subjective opinion of drill cuttings and the depth from which they originate;
    - hydraulic conductivity associated with a lithology (each lithology could have a range of potential values that spans at least one order of magnitude, whereas the approach used assigns a “representative” value). Further for some descriptors, such as till, the range of applicable hydraulic conductivity values could span 3 orders of magnitude;
    - lack of consideration for the stratigraphic unit (i.e., Port Stanley or Catfish Creek Till) which may constrain the practical conductivity range; and
    - linear interpolation between boreholes (assumes linear variation and ignores potential geologic controls on extrapolation of conductivity estimates).

- Rivers, Wetlands and Lakes: Surface water features are characterized as having a constant, specified water level that is representative of average conditions and is independent of conditions within the groundwater system. Further, this model assumes there is a direct hydraulic connection with the underlying aquifer system such that the flow to and from the surface water feature is controlled by the hydraulic conductivity of the finite elements in contact with the surface water feature. These simplifying assumptions overlook the natural seasonal variability in surface water levels as well as the spatial distribution of river / wetland and lake bottom materials (siltation) that may limit or resist interaction with the groundwater system. These assumptions result in uncertainty regarding local hydraulic controls on hydraulic heads and recharge / discharge to / from the groundwater system.

- Groundwater Recharge Estimates (GAWSER): Recharge estimates from the calibrated surface water model are considered more physical than the traditional method of ad-hoc recharge assignment based on surficial soils; however, there is considerable uncertainty associated with those estimates also. GAWSER calibration ensures that the volume of recharge within a basin is realistic (within the uncertainty in evapotranspiration). As such, the cumulative recharge sum is calibrated and the local variability in recharge is assumed, based on available surficial geology mapping. Ideally, recharge through individual soil types would be calibrated to field observations, but this is beyond the state of the practice at this point.

- Perimeter Boundary Conditions: Boundary conditions around the perimeter of the LPRCA / CCCA / KCCA FEFLOW model allow flow into and out of the model domain to occur. Boundary conditions are established based on mapping of interpolated potentiometric surfaces for the water table position and deep overburden / bedrock water levels. Application of boundary conditions was limited in this study to areas where interpolated potentiometric surfaces indicated potential for cross-boundary flows. As such, the perimeter boundary conditions are subject to the following uncertainty:
  - Water levels predicted in the relevant potentiometric surface and the assumptions inherent to the interpolation process;
  - Application of discrete potentiometric surface data to all aquifer units of the model; and
  - Level of interaction is based on the hydraulic conductivity specified for each aquifer unit and its uncertainty.

  To minimize the uncertainty in the boundary conditions, the flow computed across each boundary segment was reviewed to ensure that it was consistent with the conceptual model and the current hydrogeologic understanding.

5.5.2 Calibration Data

The scale of the calibration effort is consistent with the scale of the model. As such the focus of the design and calibration of the LPRCA / CCCA / KCCA model is on regional-scale features that control groundwater flow at the subwatershed level. Accordingly, the calibration procedure implemented for this study was to group parameters spatially and vary them in proportion to one another. During that procedure, calibration focused on spatial trends in observed water levels and discharge estimates; no attempt was made to match or explain individual outliers, as isolated outliers are expected to occur within the MOE water well record database. Calibration targets only included water levels reported in the MOE water well database.

- Water levels from MOE Water Well Records: The expected range of uncertainty associated with water well records is on the order of 5 m. This is due to many factors, including the clogging of the aquifer materials due to the drilling method, measurement timing (may not have recovered to static conditions), variability of the water level relative to the time of measurement, measurement error or recording errors, measurement point elevation errors, etc. As a result it is common to see scatter with this type of data, such that individual values cannot be trusted, but the trends illustrated by multiple data points are expected to be realistic. Since natural fluctuations in groundwater levels are generally minor (~2 m or less where stress conditions are consistent), carefully measured water levels are considered to be more certain than most other calibration targets.

- Groundwater Discharge Estimates: Groundwater discharge is expected to be a component of the baseflow in most stream / river courses; the remainder of the baseflow is contributed from upstream wetland or other storage mechanisms. Since the proportion of groundwater discharge to wetland discharge is rarely known, this is one source of uncertainty. Further, baseflow discharge is estimated using streamflow recession approaches which are empirical and interpretive. Further, baseflow estimates are generally determined from a limited time period of available streamflow record yet are assumed to be representative of an average “static” condition. The approximation from highly variable natural and seasonally fluctuating river conditions results in uncertainty such that calibration of groundwater discharge to baseflows is generally targeted to be within the range of observed baseflow estimates.

5.5.3 Limitations of the Modelling Approach

In addition to the characterization and calibration uncertainty, the numerical representation and simulation of groundwater flow systems also contains limitations. Model simulation uncertainty comes from both the approximate solution of the equations using the finite element method as well as the limitations surrounding finite discretization and assumptions of steady-state.

- Galerkin Finite Element Solution: The Galerkin finite element method employed by FEFLOW solves the system of equations using an iterative solver that attempts to minimize the residuals globally; it is expected that some numerical error can exist internally within the model domain, although this is generally minor.
- Finite Discretization: Practically, the solution of the equations is limited to calculation of groundwater head and flows at a finite number of points; the higher the number of points (smaller the elements) the more computer power and time is needed. More precision is achieved when using a higher number of calculation points, particularly in areas of larger water level changes. With regional models, there is a balance between the level discretization (distance between calculation points) and the required computer power to efficiently run and calibrate the model (also financial budget). The practical limitation of discretization therefore presents some uncertainty in the water budget results.
- Steady-State Solution: Similarly to the spatial discretization, the time discretization chosen for modelling affects the computer power and time (cost) required to calibrate and apply a numerical model. As a result, one simplifying assumption that is commonly made is that the groundwater flow system can be adequately represented using a steady-state simulation approach. In general, since groundwater systems respond at relatively slow rates (months, years, decades) particularly at the regional scale, a steady-state approximation is reasonable and provides general understanding. This assumption may however create differences between the simulated conditions and conditions observed in the field at any one particular time.

As noted above, there are a number of limitations in the numerical modelling process that lead to uncertainty in model predictions. The uncertainty due to the modelling process, however, is considered to be relatively minor compared to the uncertainty in the physical characterization and calibration process.

5.6 SUMMARY OF FEFLOW MODEL

In summary, there are many sources of uncertainty associated with numerical models and their application to regional settings. Any numerical model developed to represent a natural system will be inherently more simplified than nature and thus will involve numerous approximations.

Nonetheless, models are commonly used throughout the water resources planning and management industry and are found to be essential planning tools; they are often the only way to address complex questions that require the integration of multiple data sets.

The LPRCA / CCCA / KCCA FEFLOW model has been developed as a regional groundwater flow model in concert with the GAWSER model, resulting in a loosely coupled “modelling system”. This modelling system includes both a physical representation of the surface water system (streamflow-generation model) and the groundwater system (groundwater flow model). The modelling system provides the ability to simulate and quantify the relative volume of water moving through the subwatersheds, and is calibrated to two independent data sets; 1) total streamflow and baseflow; and 2) water well levels. When assessing model performance, the use of multiple, but separate datasets increases the confidence that the modelling system is accurately representing the hydrologic processes. As presented in Section 4, the streamflow generation model is reasonably replicating observed streamflow volumes, as well as seasonal and inter-annual variability in streamflow. Recharge rates estimated from the streamflow generation model are used to constrain recharge rates within the groundwater flow model, which has been shown to reasonably replicate both water levels and baseflow estimates. Based on the overall performance of the modelling system in replicating these observed conditions, the modelling system is considered to be accurately replicating surface and groundwater flow volumes, and thus is able to provide realistic water budget estimates for the Study Area.

As with any model however, their application beyond the purpose for which it is designed is cautioned due to the uncertainty associated with predictions at a smaller scale.

6.0 Integrated Water Budget

6.1 INTRODUCTION

This section presents the integrated water budget for the Long Point Region, Kettle Creek, and Catfish Creek Conservation Authorities. This integrated water budget considers average annual estimates of key hydrologic parameters relating to both surface water and groundwater resources, and the integration between the two.

As was discussed in Chapter 4, surface water budget components have significant temporal variability. Results presented within this section are based on average annual conditions for the 1980-2004 period and it is recognized that these results may vary significantly based on climate conditions. The analysis does not account for changes in water storage that would occur from one time period to the next.

The time period of 1980-2004 was selected to summarize the average integrated water budget information. This period is consistent with the observed water levels used for the FEFLOW calibration. A longer-term period was not used for averaging as it was felt that the current water demand estimates would not be representative of historical water use. It is recognized that the selected time period differs from the 1960-1999 period commonly used for metrological analysis, as well as the 1971-2001 climate normal period. The difference in precipitation between the 1980-2004 period and the 1960-1999 and 1970-2001 time periods for the Delhi area is included in Table 6.1, and is shown to be well within measurement error typically associated with rainfall measurement. This suggests that the analysis is fairly insensitive with regard to the time period selected, and the 1980-2004 time period is representative of long term average climate conditions.

Table 6.1 - Differences in Average Precipitation for Varying Time Periods

Time Period	Average Precipitation (mm/year)	1980-2004 Average Precipitation (mm/year)	Percent Difference (%)
1960-1999	959	973	-1.4%
1971-2001	987	973	1.5%

The following sections quantify, and present the water balance components at a variety of spatial scales. The components presented have been calculated assuming no net change in stored water over the time period. Inputs to a subwatershed (precipitation, groundwater inflows) are balanced by subwatershed outflows (streamflow, evapotranspiration, groundwater outflows).

6.2 STUDY AREA SUMMARY

As shown on Table 6.2 the average annual precipitation over the 1980-2000 period is approximately 955 mm/year. GAWSER has estimated average annual evapotranspiration to be 555 mm/year, which compares favourably with the evapotranspiration estimates included within the Water Resources of Ontario (MNR, 1984) estimate of 550-600 mm/year. When storage is assumed to be zero, water that does not evaporate or transpire will be observed as runoff or groundwater recharge. The average runoff rate across the Study Area is 194 mm/year, with an average groundwater recharge rate of 204 mm/year. Water taken from watercourses, that is not immediately returned to the surface water system, is approximately 0.90 m^3/s, or 7 mm/year. While precipitation and evapotranspiration rates have some degree of spatial variability, runoff and recharge rates have the most significant spatial variability due to changing soils, surficial geology, and land cover.

Table 6.2 – Average Annual Water Budget (Surface Water)

Water Budget Parameter	Value (m^3/s)	Value (mm/year)
Precipitation	115.6	953
Evapotranspiration	67.3	555
Runoff	23.5	194
Recharge	24.8	204
SW Taking	0.87	7

Table 6.3 summarizes the average annual groundwater budget for the Study Area. It is linked to the surface water budget by the recharge rate. Water taken from aquifers, that is not immediately returned to the groundwater system, is approximately 1.7 m^3/s, or 14 mm/year. The FEFLOW groundwater model estimates average annual groundwater discharge to surface water features to be 20 m^3/s. Additionally, approximately a net flow of 0.6 m^3/s flows into the Study Area from adjacent watersheds, and 3.9 m^3/s flows out of the area to Lake Erie. The sign associated with the values indicates whether it is an inflow to the groundwater system (positive) or an outflow from the groundwater system (negative).

Table 6.3 – Average Annual Water Budget Summary (Groundwater)

Water Budget Parameter	Value (m^3/s)	Value (mm/year)
Recharge	+24.8	+204
Net Flow In Across Watershed Boundaries	+0.6	+5
Net Flow into Lake Erie	-3.9	-32
Net Discharge to Surface Water Features	-20.0	-164
GW Taking	-1.7	-14

6.3 SUBWATERSHED WATER BUDGET RESULTS

This section summarizes the water budget results for each of the 31 subwatersheds included in Tables 2.1, 2.2, and 2.3. The detailed water budget parameters extracted from the GAWSER and FEFLOW analysis are described on Table 6.4.

Table 6.5 and 6.6 summarize the water budget components for each of the subwatersheds in mm and m^3/s, respectively. Maps 6.1, 6.2, 6.3, and 6.4 illustrate precipitation, evapotranspiration, runoff and recharge, respectively, on a subwatershed basis. Map 6.5 illustrates the estimated inter-basin groundwater transfer, as a percentage of recharge. This map shows those subwatersheds that have either net outflow or inflow of groundwater, normalized to the subwatershed's estimated recharge volume.

Table 6.4 - Summary of Water Budget Components

Parameter	Source	Description
Precipitation	Data Analysis / GAWSER	Climate data used to represent the precipitation over each of the subwatersheds is summarized by GAWSER and is presented here.
Evapotranspiration	GAWSER	GAWSER estimates estimated actual evapotranspiration for each hydrologic response unit (HRU).
Runoff	GAWSER	When the precipitation exceeds the infiltration capacity of a soil, overland runoff is created. Subwatersheds with tighter surficial materials tend to have a higher proportion of runoff.
Recharge	GAWSER	GAWSER estimates the amount of groundwater recharge for each HRU. This column summarizes groundwater recharge for the subwatersheds. Subwatersheds with more pervious materials have a higher proportion of recharge.
Average Inflow	GAWSER	The total streamflow entering the subwatershed from upstream subwatersheds.
Average Outflow	GAWSER	The total average annual streamflow leaving the subwatershed. This includes any upstream inflows to the subwatershed as well as flow generated by the specific subwatershed in question.
Flow Yield	GAWSER	This component quantifies the amount of streamflow increase seen in the particular subwatershed, on an average annual basis. The value is the difference between the average inflow and the average outflow.
Surface Water Taking	Water Use Estimates	The amount of water taken from a surface water source and not immediately returned to that source. Includes estimates from PTTW as well as rural domestic and non-permitted agricultural use.
Groundwater Taking	Water Use Estimates	The amount of water taken from an aquifer and not immediately returned to that source. Includes estimates from PTTW as well as rural domestic and non-permitted agricultural use.
External Boundary	FEFLOW	This component identifies groundwater flow through the boundaries of the groundwater flow model. This is representative of groundwater flow out of, or into, the Study Area. Negative flows indicate water leaving the basin, positive flows indication water entering the basin.

Parameter	Source	Description
Surface Water Discharge	FEFLOW	This parameter quantifies the groundwater flux to rivers and streams in the particular subwatershed. Negative values indicate that flow is leaving the groundwater system to the surface water system
Inter-Basin Transfer	FEFLOW	The amount of groundwater flow to another subwatershed within the Study Area. Positive values indicate where the subwatershed is experiencing a net increase of groundwater flow from adjacent subwatersheds. Negative values indicate where the subwatershed is experiencing a net loss of groundwater flow to adjacent subwatersheds.
Flow In Ratio	FEFLOW	$= \frac{(RiverDischarge + WellExtractions)}{Recharge} - 1$ This parameter is the ratio of groundwater discharge (river discharge + extractions) to the amount of recharge in a particular subwatershed. Where the value is negative, it indicates a percentage of recharge that is leaving the basin. Where the value is positive, it indicates how much water, with respect to existing recharge, is entering the subwatershed.

Table 6.5 - Integrated Water Budget (Depth)

Subwatershed		Area (km^2)	Surface Water System (mm/year)								Groundwater System (mm/year)				
			Precip	ET	Runoff	Recharge	SW Taking	Inflow	Outflow	Flow Yield	GW Taking	External Boundary	River Discharge	Inter-Basin Transfer	Flow In Ratio
Kettle Creek	Upper Kettle	199	970	608	237	125	-1	-	339	339	-4	21	-74	-70	-38%
	Dodd Creek	131	966	602	239	125	0	-	345	345	-1	0	-57	-68	-53%
	Lower Kettle	190	970	615	181	174	-2	593	1045	452	-5	-178	-94	100	-43%
Catfish Creek	West Catfish	149	904	560	235	109	-1	-	246	246	-3	26	-77	-58	-27%
	Catfish Above Aylmer	143	905	568	202	135	-2	-	345	345	-4	0	-169	35	28%
	Lower Catfish	103	931	586	142	203	-9	837	1314	477	-13	-2	-344	154	76%
	Silver Creek	93	924	585	124	215	-9	-	343	343	-10	-52	-149	-7	-26%
Big Otter	Otter Above Maple Dell Road	99	992	542	223	226	-6	-	439	439	-10	34	-174	-79	-19%
	Otter at Otterville	75	973	541	223	209	-9	582	997	415	-12	0	-176	-23	-10%
	Otter at Tillsonberg	153	971	498	264	208	-12	825	1305	480	-28	52	-269	53	43%
	Spittler Creek	116	973	529	274	170	-2	-	447	447	-3	43	-130	-82	-22%
	Lower Otter	168	968	535	227	206	-9	1487	1942	455	-5	-17	-203	17	1%
	Little Otter	118	969	552	123	294	-6	-	426	426	-17	0	-266	-6	-4%
Lake Erie Tribs	South Otter	120	974	564	96	314	-18	-	384	384	-10	-68	-222	-16	-26%
	Clear Creek	87	952	562	88	302	-6	-	284	284	-16	-108	-185	7	-33%
Big Creek	Big Above Cement Road	89	914	534	191	189	-2	-	322	322	-4	55	-181	-60	-1%
	Big Above Kelvin Gauge	64	914	545	101	269	-2	449	731	283	-55	-84	-136	15	-29%
	Big Above Delhi	154	951	549	114	288	-17	304	840	536	-33	-25	-264	31	3%
	North Creek	58	970	565	83	322	-20	-	252	252	-52	0	-203	-79	-21%
	Big Above Minnow Creek	72	993	564	81	348	-15	1996	2367	371	-50	0	-342	40	12%
	Big Above Walsingham	123	993	563	135	295	-26	1395	1880	485	-13	0	-322	37	13%
	Venison Creek	98	980	563	102	315	-16	-	422	422	-16	0	-365	64	21%
	Lower Big	96	984	490	281	213	-7	2830	3282	452	-7	-28	-126	-54	-38%
Lake Erie Tribs	Dedrick Creek	138	1006	551	180	274	-15	-	270	270	-9	-166	-158	56	-39%
	Young/Hay Creeks	120	1004	563	136	305	-13	-	243	243	-22	-112	-130	-50	-50%
Lynn River	Lynn River	172	983	584	116	283	-8	-	422	422	-38	-24	-206	-10	-14%
	Black Creek	134	979	566	250	163	-1	-	381	381	-10	-35	-117	-3	-22%
Nanticoke Creek	Nanticoke Upper	114	915	553	178	185	-5	-	344	344	-40	-13	-145	11	0%
	Nanticoke Lower	85	897	514	299	84	-1	463	790	327	-2	-33	-73	23	-11%
Eastern Tribs	Sandusk Creek	182	874	505	301	68	-1	-	338	338	-2	-28	-36	-3	-43%
	Stoney Creek	186	874	506	302	66	-1	-	313	313	-2	-44	-15	-6	-74%
Total Area		**3828**	**953**	**555**	**194**	**204**	**-7**			**380**	**-14**	**-27**	**-164**		

Table 6.6 - Integrated Water Budget (m3/s)

Subwatershed		Area (km^2)	Surface Water System (m^3/s)								Groundwater System (m^3/s)				
			Precip	ET	Runoff	Recharge	SW Taking	Avg Inflow	Avg Outflow	Flow Yield	GW Taking	External Boundary	River Discharge	Inter-Basin Transfer	Flow In Ratio
Kettle Creek	Upper Kettle	199	6.12	3.84	1.50	0.79	0.00	-	2.14	2.14	-0.02	0.13	-0.46	-0.44	-38%
	Dodd Creek	131	4.02	2.51	1.00	0.52	0.00	-	1.44	1.44	-0.01	0.00	-0.24	-0.28	-53%
	Lower Kettle	190	5.84	3.70	1.09	1.05	-0.01	3.57	6.30	2.72	-0.03	-1.07	-0.57	0.60	-43%
Catfish Creek	West Catfish	149	4.26	2.64	1.11	0.51	0.00	-	1.16	1.16	-0.01	0.12	-0.36	-0.27	-27%
	Catfish Above Aylmer	143	4.11	2.58	0.91	0.61	-0.01	-	1.56	1.56	-0.02	0.00	-0.77	0.16	28%
	Lower Catfish	103	3.03	1.90	0.46	0.66	-0.03	2.72	4.27	1.55	-0.04	-0.01	-1.12	0.50	76%
	Silver Creek	93	2.74	1.73	0.37	0.64	-0.03	-	1.02	1.02	-0.03	-0.15	-0.44	-0.02	-26%
Big Otter	Otter Above Maple Dell Road	99	3.12	1.71	0.70	0.71	-0.02	-	1.38	1.38	-0.03	0.11	-0.55	-0.25	-19%
	Otter at Otterville	75	2.31	1.28	0.53	0.50	-0.02	1.38	2.36	0.98	-0.03	0.00	-0.42	-0.05	-10%
	Otter at Tillsonberg	153	4.71	2.42	1.28	1.01	-0.06	4.01	6.34	2.33	-0.14	0.25	-1.31	0.25	43%
	Spittler Creek	116	3.57	1.94	1.01	0.62	-0.01	-	1.64	1.64	-0.01	0.16	-0.48	-0.30	-22%
	Lower Otter	168	5.16	2.85	1.21	1.10	-0.05	7.93	10.35	2.42	-0.03	-0.09	-1.08	0.09	1%
	Little Otter	118	3.61	2.06	0.46	1.10	-0.02	-	1.59	1.59	-0.06	0.00	-0.99	-0.02	-4%
Lake Erie Tribs	South Otter	120	3.70	2.14	0.36	1.19	-0.07	-	1.46	1.46	-0.04	-0.26	-0.84	-0.06	-26%
	Clear Creek	87	2.63	1.55	0.24	0.83	-0.02	-	0.78	0.78	-0.04	-0.30	-0.51	0.02	-33%
Big Creek	Big Above Cement Road	89	2.59	1.52	0.54	0.54	-0.01	-	0.91	0.91	-0.01	0.16	-0.52	-0.17	-1%
	Big Above Kelvin Gauge	64	1.86	1.11	0.21	0.55	0.00	0.91	1.49	0.58	-0.11	-0.17	-0.28	0.03	-29%
	Big Above Delhi	154	4.66	2.69	0.56	1.41	-0.08	1.49	4.11	2.62	-0.16	-0.12	-1.29	0.15	3%
	North Creek	58	1.78	1.04	0.15	0.59	-0.04	-	0.46	0.46	-0.10	0.00	-0.37	-0.15	-21%
	Big Above Minnow Creek	72	2.28	1.29	0.18	0.80	-0.04	4.58	5.43	0.85	-0.11	0.00	-0.78	0.09	12%
	Big Above Walsingham	123	3.86	2.19	0.52	1.15	-0.10	5.43	7.31	1.89	-0.05	0.00	-1.25	0.14	13%
	Venison Creek	98	3.03	1.74	0.31	0.97	-0.05	-	1.31	1.31	-0.05	0.00	-1.13	0.20	21%
	Lower Big	96	3.00	1.49	0.86	0.65	-0.02	8.62	10.00	1.38	-0.02	-0.08	-0.38	-0.16	-38%
Lake Erie Tribs	Dedrick Creek	138	4.39	2.41	0.79	1.20	-0.07	-	1.18	1.18	-0.04	-0.72	-0.69	0.24	-39%
	Young/Hay Creeks	120	3.83	2.15	0.52	1.16	-0.05	-	0.93	0.93	-0.08	-0.43	-0.49	-0.19	-50%
Lynn River	Lynn River	172	5.35	3.18	0.63	1.54	-0.04	-	2.30	2.30	-0.21	-0.13	-1.12	-0.05	-14%
	Black Creek	134	4.15	2.40	1.06	0.69	0.00	-	1.61	1.61	-0.04	-0.15	-0.50	-0.01	-22%
Nanticoke Creek	Nanticoke Upper	114	3.32	2.00	0.64	0.67	-0.02	-	1.25	1.25	-0.14	-0.05	-0.53	0.04	0%
	Nanticoke Lower	85	2.42	1.39	0.81	0.23	0.00	1.25	2.13	0.88	0.00	-0.09	-0.20	0.06	-11%
Eastern Tribs	Sandusk Creek	182	5.03	2.91	1.73	0.39	0.00	-	1.95	1.95	-0.01	-0.16	-0.21	-0.02	-43%
	Stoney Creek	186	5.15	2.98	1.78	0.39	0.00	-	1.84	1.84	-0.01	-0.26	-0.09	-0.03	-74%
Total Area		**3828**	**115.62**	**67.33**	**23.53**	**24.77**	**-0.87**			**46.10**	**-1.70**	**-3.31**	**-19.96**		

The following sections summarize Water Budget results for each subwatershed. Values reported are based on annual averages, and may exhibit significant seasonal variation. Due to the regional perspective of this analysis, the subwatershed descriptions may lack local details that may have local hydrologic significance. Local scale interpretation and/or models may provide differing results than those presented here averaged spatially and temporally.

6.3.1 Upper Kettle Creek Subwatershed

The Upper Kettle Subwatershed is located in the northeast portion of the Kettle Creek Conservation Authority, and is characterized by having predominantly low permeability surficial materials. Port Stanley Till dominates the subwatershed, with few isolated pockets of surficial sand and gravels. The topography is relatively flat. Average annual precipitation for this subwatershed is 970 mm which is slightly higher than the average for the Long Point/Catfish/Kettle region (950 mm). Evapotranspiration for this subwatershed is estimated to be approximately 610 mm, compared to the Study Area average of 555 mm. Due to the low permeability surficial materials, the subwatershed generates more surface runoff (240 mm) than the area average (195 mm), and less groundwater recharge (125 mm) than the area average (205 mm).

Most overburden aquifers within this subwatershed are confined to pockets of pervious deposits found within the Port Stanley and Tavistock Tills. Singer et al. (2003) also named a “South London Aquifer” that is located within Upper Kettle. This South London Aquifer consists of sand and gravel deposits ranging in thickness from several metres up to 50 m. The aquifer is confined under till deposits up to 60 m in thickness. Groundwater discharge, as predicted by the groundwater flow model, is minimal throughout most of this subwatershed. There is a net groundwater loss of approximately 0.44 m^3/s to the West Catfish and Lower Kettle Subwatersheds.

There is minimal water demand in this subwatershed, with only 0.12 m^3/s of groundwater permitted and 0.02 m^3/s of surface water permitted. Including non-permitted agricultural and rural domestic demand, it is estimated that 0.03 m^3/s is pumped on an average annual basis. Of the pumped water, 0.02 m^3/s is not returned to the original source. This subwatershed contains the Belmont municipal system.

6.3.2 Dodd Creek Subwatershed

Dodd Creek is the main tributary to Kettle Creek, and is located in the western portion of the Kettle Creek Conservation Authority. The surficial materials of the subwatershed are predominately Port Stanley Till, but do have a slightly higher proportion of granular deposits than the Upper Kettle Subwatershed. The average annual precipitation for Dodd Creek is 965 mm, which is slightly higher than the area average precipitation (955 mm). Evapotranspiration is estimated to be approximately 600 mm, which is higher than the area average of 555 mm. Similar to the Upper Kettle subwatershed, the low permeability surficial materials cause higher than average surface runoff (240 mm), and lower than average groundwater recharge (125 mm).

Aquifers within Dodd Creek are limited to isolated pockets of granular deposits found within the tills. The South London Aquifer, as described for the Upper Kettle Subwatershed, may also extend into the Dodd Creek Subwatershed. Groundwater discharge is minimal throughout most of the Subwatershed; however, pockets of groundwater discharge may occur where watercourses intersect surficial granular deposits. Approximately 0.30 m^3/s of groundwater flows from the Subwatershed to the lake.

There is very low water demand within this subwatershed, with 0.02 m^3/s of groundwater permitted, and no surface water permitted. Including the non-permitted takings, the total amount of pumping within the Dodd Creek Subwatershed is estimated to be 0.01 m^3/s; very little pumped water is returned to its original source.

6.3.3 Lower Kettle Creek Subwatershed

The Lower Kettle Subwatershed is the last subwatershed to discharge into Kettle Creek before the creek empties into Lake Erie. The delineated subwatershed area also includes numerous gullies and small tributaries that discharge directly into Lake Erie. The surficial materials within this Subwatershed include a mixture of Port Stanley Till in the northeast, glaciolacustrine deposits in the west, and granular material in the south and southeastern portion. The precipitation for the Lower Kettle Subwatershed is 970 mm, which is slightly higher than the area average of 955 mm. Evapotranspiration is estimated to be approximately 615 mm, which is also higher than the area average of 555 mm. Due to a higher variability in surficial materials than in the upstream subwatersheds, the Lower Kettle Subwatershed produces less surface runoff (180 mm) than upstream areas, and more groundwater recharge (175 mm).

Singer et al. (2003) described a significant overburden aquifer located within the Lower Kettle Creek Subwatershed, the South Central Elgin Aquifer, which is located between St. Thomas and Lake Erie. The aquifer is generally less than 10 m in thickness, but in locations may be more than 25 m. The aquifer is confined in the northern portions, but becomes unconfined towards the south. This Subwatershed receives a large groundwater inflow from upstream subwatersheds (0.60 m^3/s) and the most significant groundwater outflow from the Subwatershed is predicted to occur via Lake Erie. A moderate groundwater discharge (0.60 m^3/s) is estimated to occur in the lower reaches of Kettle Creek as well as into some of the Lake Erie gullies.

Water demand for the Lower Kettle Creek Subwatershed is higher than the Upper Kettle Creek Subwatershed, but still low in comparison to other area subwatersheds. Approximately 0.12 m^3/s of groundwater is permitted and 0.02 m^3/s of surface water is permitted. Including all water uses, it is estimated that 0.05 m^3/s is pumped, of which 0.03 m^3/s is not returned to its original source.

6.3.4 West Catfish Creek Subwatershed

The West Catfish Creek Subwatershed is located in the northwest portion of the Catfish Creek Conservation Authority, and the surficial materials almost exclusively comprise Port Stanley Till. A small pocket of sand & gravel is mapped in the southeast portion of the Subwatershed. The precipitation for this subwatershed (905 mm) is below the average for the Study Area (955mm), and the estimated evapotranspiration (560 mm) is similar to the Study Area average (555 mm). Due to the low permeability surficial materials, surface runoff (235 mm) is higher than the Study Area average (194 mm), and groundwater recharge is predicted to be lower (110 mm) than average (205 mm).

Overburden aquifers are generally limited to pockets of granular material located within the Port Stanley and Tavistock Tills. Initially, it was thought these pockets were relatively isolated and disconnected, but modelling results indicate that some degree of connectivity may exist. Simulated groundwater discharge is generally minimal, with some reaches of locally significant discharge predicted to occur in the southwestern portion of the Subwatershed, where granular materials are present at surface. The modelling predicts a net groundwater outflow of approximately 0.27 m^3/s, which may be providing flow into the Lower Kettle Creek, Lower Catfish Creek or Catfish Creek Above Aylmer Subwatersheds.

Water demand within West Catfish is very low, with only 0.01 m^3/s of groundwater permitted and ~0 m^3/s of surface water permitted. Of total takings, including non-permitted uses, it is estimated that 0.01 m^3/s is pumped, and all of this is considered to be a consumptive demand.

6.3.5 Catfish Creek Above Aylmer

The Catfish Creek Above Aylmer Subwatershed drains the eastern portion of Catfish Creek, and predominantly comprises Port Stanley Till. Granular surficial deposits are mapped along the southeastern boundary of the subwatershed which is shared with the Big Otter Creek Watershed Area. Precipitation is estimated to be 905 mm, which is less than the area average of 955 mm. Evapotranspiration is estimated to be slightly higher (570 mm) than the average (555 mm). The predominance of low permeability materials within the subwatershed results in a surface runoff estimate (200 mm) slightly higher than the area average (195 mm), and estimated groundwater recharge (135 mm) that is significantly lower than the area average (205 mm).

Singer et al. (2003) have described an extensive aquifer located within the central portion of the Catfish Creek Conservation Authority. The Central Catfish Creek Aquifer has been identified in the Springfield area, as well as near Aylmer and to the east of Aylmer. Wells completed in this aquifer typically penetrate less than 10 m; however, some deeper wells have been found that log more than 20 m of continuous sand and gravel. This aquifer is mostly confined, except where it enters Malahide Township, and crosses several subwatershed boundaries. Singer et al. (2003) also described a local overburden aquifer in the Brownsville area, which is mostly confined, but not laterally extensive. Groundwater discharge is predicted to be moderate in the easterly portion of the Subwatershed. However, it should be noted that in this area, due to uncertainties with the conceptual hydrogeologic model, simulated groundwater levels are higher than observed. Due to this, the predicted groundwater discharge may be overestimated. There is an overall net groundwater inflow to this subwatershed, likely from the West Catfish Creek Subwatershed, approximately equal to 0.3 m^3/s.

Water demand within Catfish Creek Above Aylmer Subwatershed is moderate, with 0.23 m^3/s of groundwater permitted and 0.15 m^3/s of surface water permitted. It is estimated that all water uses, including non-permitted uses, pump an annual average rate equal to 0.03 m^3/s. Roughly 0.02 m^3/s is not returned to the source from which it was drawn and is considered consumed. This subwatershed contains the Brownsville municipal system.

6.3.6 Lower Catfish Creek Subwatershed

The Lower Catfish Creek Subwatershed consists predominantly of granular deposits, with isolated deposits of Port Stanley till. The average precipitation is 930 mm which is slightly less than the area average precipitation (955 mm). Average evapotranspiration is 586 mm which is slightly higher than the area average. Due to the prevalence of permeable surficial materials, surface runoff (140 mm) is lower than in the upper subwatersheds, and is also lower than the area average (195 mm). Groundwater recharge for the subwatershed is estimated to be 205 mm, which is the same as the area average (205 mm).

The primary groundwater aquifer is the Central Catfish Creek Aquifer, described in the Catfish Creek Above Aylmer subwatershed description. Extensive surficial granular deposits are also associated with numerous local unconfined aquifers. Simulated groundwater discharge is predicted to be very significant through the incised lower reaches of Catfish Creek. Approximately 1.1 m^3/s of discharge is predicted within Lower Catfish; however, due to uncertainties with the conceptual geologic model in the area, this value is uncertain. In contrast to the Lower Kettle Creek Subwatershed, where the major groundwater outflow is to Lake Erie, Lower Catfish has a smaller amount of outflow (0.1 m^3/s) to the lake.

Water demand within the Lower Catfish Creek Subwatershed is relatively high, with approximately 1.3 m^3/s of groundwater permitted and 0.72 m^3/s of surface water permitted. Of the total amount pumped, including non-permitted uses, it is estimated that 0.09 m^3/s is pumped on an annual average basis. Approximately 0.07 m^3/s of the pumped water is not returned to the source from which it came.

6.3.7 Silver Creek Subwatershed

The Silver Creek Subwatershed includes a number of tributaries and gullies that flow directly into Lake Erie. The granular deposits that exist in Lower Catfish Creek Subwatershed extend into this Subwatershed, and continue northeast, merging with the Norfolk Sand Plain. There are a few isolated deposits of Port Stanley Till. Precipitation for the Silver Creek Subwatershed is 924 mm, which is slightly less then the area average of 955 mm. Evapotranspiration is estimated to be 585 mm, which is higher than the area average of 555 mm. The predominance of permeable surficial materials causes surface runoff (125 mm) to be significantly lower than the average (195 mm), and recharge is estimated to be approximately 215 mm, which is slightly higher than the average of 205 mm.

The Central Catfish Creek Aquifer, as described above, also extends into Silver Creek. The pervious surficial materials are reflected by local unconfined aquifers. Approximately 0.4 m^3/s of discharge is predicted into Silver Creek, with the Silver Creek tributary receiving the majority of this discharge. The Silver Creek Subwatershed discharges a fairly minimal amount of flow to Lake Erie, 0.15 m^3/s.

Due to a high number of irrigation operations, water demand is significant within the Silver Creek Subwatershed. Approximately 0.96 m^3/s of groundwater is permitted, and 0.71 m^3/s of surface water is permitted. In total, it is estimated that approximately 0.10 m^3/s of water is pumped for anthropogenic purposes on an annual average basis, and 0.05 m^3/s is not returned to the original source.

6.3.8 Big Otter Creek Above Maple Dell Road Subwatershed

The surficial materials in Big Otter Creek Above Maple Dell Road Subwatershed are characterized as a mixture of Port Stanley Till and pervious deposits associated with the Norfolk Sand Plain. Port Stanley Till dominates in the westerly portion of the subwatershed, with the majority of the pervious deposits in the easterly portion. Precipitation for this area is 990 mm, which is higher than average, with evapotranspiration being estimated to be 540 mm, which is lower than average. Runoff and recharge estimates are the same, with the Subwatershed producing 225 mm of each.

There are a number of groundwater aquifers located in this subwatershed, as well as the Spittler Creek and Otter Creek at Otterville Subwatersheds. Singer et al. (2003), identified a number of local aquifers located within the St. Thomas Moraine, near the northwest boundary of LPRCA. These aquifers are typically confined, approximately 10 m thick, and consist of sand and gravel. The aquifers are located nearby Culloden, Mount Elgin, Holbrook and Burgessville. Numerous wells are also completed in the bedrock (Dundee Formation) in this region of the Study Area. Groundwater discharge is moderate, with a total of 0.50 m^3/s being discharged within the subwatershed. The majority of the discharge occurs in the easterly portion of the subwatershed, within the pervious deposits.

Water demand within the subwatershed is moderate, with 0.57 m^3/s of groundwater takings permitted and 0.50 m^3/s of surface water takings permitted. Including non-permitted takings, it is estimated that 0.11 m^3/s is pumped, with 0.05 m^3/s consumed. The municipal system for the town of Norwich is located within this subwatershed.

6.3.9 Otter Creek at Otterville Subwatershed

The surficial materials found in the Otter at Otterville Subwatershed are similar to the Otter Above Maple Dell Road Subwatershed. The western portion is dominated by Port Stanley Till, with the easterly portion mainly comprising pervious deposits. Precipitation for the Otter at Otterville Subwatershed is 973 mm, which is higher then the area average of 955 mm. Evapotranspiration is estimated to be approximately 540 mm, which is close to the area average of 555 mm. Much like Otter Above Maple Road Subwatershed, this Subwatershed is estimated to generate similar amounts of runoff (225 mm) and recharge (210 mm).

Significant aquifers within the Subwatershed are limited to local aquifers found within the St. Thomas Moraine, as described above, as well as the Dundee bedrock aquifer. A moderate amount of groundwater discharge, 0.40 m^3/s is predicted to occur almost exclusively within the main channel of Big Otter Creek, with no significant discharge occurring in the westerly portions of the Subwatershed. There is a negligible net groundwater outflow of 0.05 m^3/s to adjacent subwatersheds.

Water demand is moderate within the subwatershed, and is driven primarily by agricultural uses in the easterly portions of the Otter at Otterville Subwatershed. In total, 0.69 m^3/s of groundwater takings are permitted, with 0.50 m^3/s of surface water takings permitted. It is estimated, that including non-permitted uses, on an annual average basis, approximately 0.05 m^3/s is pumped and not returned to its original source. The Otterville municipal supply wells are located within this Subwatershed.

6.3.10 Spittler Creek Subwatershed

The predominant quaternary material throughout the Subwatershed is Port Stanley Till. Sand and gravel deposits are present, on the eastern portion of the Subwatershed grouping, and are also interspersed throughout the Port Stanley Till. Precipitation for this area is 975 mm, which is higher than the area average of 955 mm. Evapotranspiration is estimated to be slightly below the area average of 555 mm, with a subwatershed estimate of 530 mm. In comparison to the first two Big Otter subwatersheds, Spittler Creek Subwatershed has a smaller proportion of granular deposits. As a result, the Subwatershed is predicted to have a higher runoff depth, of 275 mm, and lower rate of groundwater recharge (170 mm).

The groundwater aquifers located within the Spittler Creek Subwatershed are similar to those of the Otter at Otterville and Otter Above Maple Road Subwatersheds, and are generally limited to the local St. Thomas Moraines and the Dundee bedrock aquifer. Spittler Creek generates a moderate amount of groundwater discharge, with 0.48 m^3/s predicted to discharge, mostly in the easterly portion of the subwatershed. There is a net groundwater outflow of approximately 0.30 m^3/s into the Otter Creek at Otterville Subwatershed.

Water demand is low in the Spittler Creek Subwatershed, with permitted rates being 0.07 m^3/s for groundwater and 0.07 m^3/s for surface water. The total estimated permitted and non-permitted pumping rate is 0.02 m^3/s and considered as entirely consumptive. The municipal systems for Springford and Dereham Center are located within the Spittler Creek Subwatershed.

6.3.11 Otter Creek at Tillsonburg Subwatershed

The surficial materials of the Otter Creek at Tillsonburg Subwatershed are characterized as a mixture of pervious materials associated with the Norfolk Sand Plain on the east, and Port Stanley deposits to the west. The Subwatershed also includes the urban area of Tillsonburg. The average precipitation for the subwatershed is 970 mm, which is more than the area average of 955 mm. Evapotranspiration is estimated to be approximately 500 mm per year, which is less than the area average of 555 mm. Runoff is estimated to be 265 mm per year, which is higher than the watershed average (195 mm). Average annual recharge is estimated to be 210 mm per year.

Singer et al. (2003) described a significant confined aquifer in the Tillsonburg area. This aquifer is described as consisting of sand and gravel deposits up to 20 m in thickness. The confined aquifer is overlain by tills and clays that range from 2-56 m in thickness. There is also extensive groundwater discharge predicted throughout the subwatershed, but is focused on the main channel of Big Otter Creek. It is estimated that 1.31 m^3/s of groundwater discharges into surface water in this Subwatershed. This Subwatershed also receives 0.25 m^3/s of net groundwater inflow from adjacent subwatersheds.

Water demand is significant in this subwatershed, with permitted groundwater takings totaling 1.39 m^3/s and permitted surface water takings totaling 1.41 m^3/s. Including non-permitted uses, it is estimated that 0.21 m^3/s of water is pumped, of which 0.19 m^3/s is not returned to the source from which it was taken. The town of Tillsonburg's municipal wellfields for the town of Tillsonburg are located within this subwatershed.

6.3.12 Little Otter Creek Subwatershed

The Little Otter Creek Subwatershed is characterized as having a mixture of pervious deposits associated with the Norfolk Sand Plain, as well as finer-grained deposits associated with Port Stanley Till. Precipitation for Little Otter is 970 mm, which is slightly higher then the area average of 955 mm. Evapotranspiration is estimated to be approximately 535 mm, which is lower than the area average of 555 mm. Estimated runoff for the Subwatershed is 125 mm, which is lower than the area average (195 mm). Average annual recharge is estimated to be 295 mm, which is significantly higher than the area average (205 mm).

Groundwater discharge is significant throughout Little Otter Creek Subwatershed. The groundwater model estimates that approximately 1.00 m^3/s of discharge occurs within the Subwatershed, and is fairly evenly distributed along the creek. There is low net groundwater outflow from Little Otter to adjacent subwatersheds equal to 0.02 m^3/s.

Water demand within the Little Otter Subwatershed is high and primarily driven by agriculture. In total, 1.15 m^3/s of groundwater extractions are permitted and 0.89 m^3/s of surface water is permitted. Including non-permitted takings, it is estimated that 0.10 m^3/s of water is pumped, with 0.08 m^3/s of pumped water being classified as consumptive.

6.3.13 Lower Otter Creek Subwatershed

Lower Otter Creek Subwatershed, the last subwatershed before Big Otter Creek discharges into Lake Erie, consists of a mixture of pervious deposits, Port Stanley Till and glaciolacustrine deposits. The average annual precipitation is 970 mm and average annual evapotranspiration is estimated to be 535 mm per year. Surface runoff and recharge are estimated to be 230 mm and 205 mm, respectively.

The estimated groundwater discharge for Lower Otter Creek Subwatershed is 1.08 m^3/s and is estimated to be focused in the upper reaches of this Subwatershed. A significant discharge flux is predicted at the confluence of the Little Otter and Big Otter Creeks, where the main channel of Big Otter has incised into the surficial deposits. Little Otter has a low groundwater outflow to Lake Erie, totaling 0.09 m^3/s.

The total permitted groundwater taking from the Lower Otter Subwatershed is 0.57 m^3/s. The total permitted surface water taking from the Subwatershed is 1.52 m^3/s. Including non-permitted water takings, it is estimated that on an annual average basis, 0.08 m^3/s of water is pumped and that 0.07 m^3/s of pumped water is not returned to the original source.

6.3.14 South Otter and Clear Creek Subwatersheds

The South Otter and Clear Creek Subwatersheds discharge directly to Lake Erie and almost exclusively comprise permeable surficial materials. They have been grouped together here, only for descriptive purposes. Precipitation for South Otter and Clear Creek is 975 mm and 950 mm, respectively, which is close to the area average of 955 mm. Evapotranspiration is estimated to be in the 560-565 mm range for both Subwatersheds, which is roughly equal to the area average (555 mm). Due to the South Otter and Clear Creek Subwatersheds primarily consisting of granular material, runoff depths (95 mm, 90 mm) are much lower than the area average (195 mm). Recharge rates for South Otter and Clear Creek Subwatersheds are estimated to be 315 mm, and 300 mm respectively, which is significantly higher than the area average (205 mm).

The primary aquifer in both Subwatersheds is a very large unconfined aquifer created by the Norfolk Sand Plain. Underlying aquifers likely exist; however, the availability of sufficient amounts of available water near the surface has resulted in minimal drilling into deeper deposits. Groundwater discharge in the South Otter and Clear Creek Subwatersheds is moderate, with 0.84 m^3/s and 0.51 m^3/s, respectively, predicted to occur in each Subwatershed. Approximately 0.50 m^3/s of groundwater flow is predicted to discharge to Lake Erie from both Subwatersheds.

Water demand in both Subwatersheds is high. For the South Otter Subwatershed, permitted groundwater takings total 1.23 m^3/s and permitted surface water takings total 1.88 m^3/s. Of this, approximately 0.12 m^3/s, on an annual average basis, is estimated to be actually pumped, and 0.10 m^3/s is not returned to the source from which it came. In total, 0.08 m^3/s is not returned to any location within the Subwatershed. For the Clear Creek Subwatershed, approximately 1.41 m^3/s of groundwater is permitted and 0.61 m^3/s of surface water is permitted. For permitted and non-permitted uses, it is estimated that 0.08 m^3/s is pumped, with 0.06 m^3/s not being returned to its original source.

6.3.15 Big Creek Above Cement Road Subwatershed

The Big Creek Above Cement Road Subwatershed is located in the headwaters of the Big Creek Watershed Area and is characterized by having a mixture of low permeability surficial materials and granular, high permeability materials. The high permeability materials are predominately located in the eastern portions, but are also scattered throughout the remainder of the subwatershed. The average precipitation for the subwatershed is 915 mm, which is less than the area average of 955 mm. Evapotranspiration is estimated to be approximately 535 mm per year, which is also less than the area average of 555 mm. Due to the mixture of surficial materials, surface runoff (190 mm) and recharge (190 mm) are close the area averages, 195 mm and 205 mm, respectively.

Groundwater aquifers are generally limited to unconfined aquifers present in areas with granular deposits, and the deeper bedrock aquifer. Simulated groundwater discharge is minimal throughout the Subwatershed, with most of the discharge predicted to occur where pervious materials are present at surface. Approximately 0.25 m^3/s of groundwater outflow is predicted to leave the subwatershed, likely to the headwaters of Big Otter Creek. There is also an estimated groundwater inflow of 0.11 m^3/s through the model boundary from adjacent watersheds.

Water demand is low in this subwatershed, with 0.28 m^3/s of groundwater extractions being permitted, and 0.12 m^3/s of surface water takings being permitted, and is predominantly agricultural in nature. It is estimated that 0.03 m^3/s is actually pumped on an annual average basis, and that 0.02 m^3/s is not returned to its original source.

6.3.16 Big Creek Above Kelvin Subwatershed

The Big Creek Above Kelvin Subwatershed consists predominantly of materials associated with the Norfolk Sand Plan; however, isolated deposits of Port Stanley Till are present. The average precipitation for the Subwatershed is 915 mm, which is lower than the area average of 955 mm. The estimated evapotranspiration is approximately 545 mm, which is close to the average value (555 mm) for the Study Area. The predominance of granular material within this Subwatershed produces significantly less runoff (100 mm) than the area average (195 mm) and more groundwater recharge (270 mm) than average (205 mm).

As with most areas within the Norfolk Sand Plain, the most significant aquifer and source of water is the unconfined aquifer created by the Sand Plain. A number of wells within this Subwatershed are completed at depth into the Dundee formation. Groundwater discharge within this Subwatershed is relatively low, with 0.28 m^3/s of discharge predicted, largely focused on the main channel of Big Creek. Approximately 0.17 m^3/s of groundwater flow is predicted by the groundwater model to exit the LPRCA area and enter the GRCA along the easterly boundary.

Permitted water takings are predominately groundwater based with 1.91 m^3/s of groundwater takings permitted and 0.08 m^3/s of surface water takings permitted. It is estimated that 0.14 m^3/s is pumped on an annual average basis, of which 0.11 m^3/s is not returned to its original source.

6.3.17 Big Creek Above Delhi Subwatershed

The Big Above Delhi Subwatershed reaches from Delhi to the Big Creek at Kelvin gauge. Like many subwatersheds in the Norfolk Sand Plain, it almost exclusively comprises permeable surficial materials, interspersed with some deposits of Port Stanley Till. Average precipitation for the Subwatershed is 950 mm, which is close to the area average of 955 mm. Evapotranspiration for the area is predicted to be 550 mm, which is similar to the area average (555 mm). Due to the high percentage of permeable materials, surface runoff (115 mm) is lower than average (195 mm), and groundwater recharge (290 mm) is higher than average.

The model predicts groundwater discharge to be 1.30 m^3/s, and this discharge is focused on the main Big Creek channel. As with the Big Creek Above Kelvin Subwatershed, the Big Creek Above Delhi Subwatershed also discharges groundwater flow to the east (0.12 m^3/s), into the Grand River Watershed. The Big Creek Above Delhi Subwatershed is also estimated to receive a net inflow of groundwater, of 0.15 m^3/s, from upstream subwatersheds including the Big Creek Above Kelvin Subwatershed and the headwaters of Big Otter Creek.

Permitted water demand within this Subwatershed is high, with 4.9 m^3/s of groundwater extractions permitted, and 2.1 m^3/s of surface water takings permitted. Including non-permitted takings, it is estimated that 0.33 m^3/s on an annual average basis is pumped. The annual average amount of water taken and not returned to its original source is 0.24 m^3/s; however, the monthly maximum consumptive demand is 0.93 m^3/s.

6.3.18 North Creek Subwatershed

North Creek is a small tributary that joins Big Creek in the town of Delhi. The North Creek Subwatershed is characterized as being dominated by pervious surficial materials, with a small proportion being Port Stanley Till. The average annual precipitation is 970 mm for the Subwatershed, which is slightly above the area average of 955 mm. Evapotranspiration is 565 mm which is similar to the average of 555 mm. The predominance of the Norfolk Sand Plain results in runoff being very low (85 mm) and recharge very high (320 mm) as compared to area average values.

Simulated groundwater discharge is moderate, with a predicted discharge volume of 0.37 m^3/s, or 205 mm of equivalent depth. The majority of the discharge is predicted to occur along the North Branch of North Creek, with minimal discharge along the South Branch. The North Creek Subwatershed also exhibits a net outflow of approximately 0.15 m^3/s to adjacent subwatersheds.

Water demand is substantial with permitted groundwater takings equal to 1.00 m^3/s and permitted surface water takings equal to 1.04 m^3/s. Including non-permitted takings, it is estimated that 0.20 m^3/s is pumped, and that 0.13 m^3/s is pumped and not returned to the source from which it came. The North Creek Subwatershed contains the Delhi surface water intake located at Lehman Reservoir.

6.3.19 Big Creek Above Minnow Creek Subwatershed

The Big Creek Above Minnow Creek Subwatershed is located in the middle of the Norfolk Sand Plain, and is characterized by its permeable surficial materials. The buried Galt Moraine is also present in some locations, which is indicated by Wentworth Till at the surface. The average precipitation for the Subwatershed is 993 mm which is above the area average of 955 mm. Evapotranspiration is estimated to be 565 mm which is slightly higher than the area average (555 mm). The surface runoff is estimated to be 80 mm and groundwater recharge to be 350 mm, which reflects the nature of the pervious surficial materials.

Groundwater discharge is predicted to be high, with approximately 0.78 m^3/s of groundwater entering the surface water system. This discharge is highest along the main channel of Big Creek. There is a small net groundwater inflow, equal to 0.09 m^3/s, entering the Subwatershed from adjacent subwatersheds.

As with other subwatersheds located within the Norfolk Sand Plain, water demand is high due to agricultural use. Permitted groundwater takings total 2.65 m^3/s and permitted surface water takings total 1.02 m^3/s. It is estimated that including non-permitted takings, a total of 0.18 m^3/s is pumped, and that 0.15 m^3/s of that total is not returned to its original source. The municipal supply wells for the town of Delhi are located in this Subwatershed.

6.3.20 Big Creek Above Walsingham Subwatershed

The Big Creek Above Walsingham Subwatershed is characterized by the pervious surficial deposits of the Norfolk Sand Plain. Isolated deposits of silt and clay are also present in the central portion of the Subwatershed. On average, the Subwatershed receives approximately 995 mm of precipitation, which is higher than the area average. Estimated evapotranspiration is approximately 565 mm, which is close to the area average. Runoff and recharge rates are reflective of the pervious surficial materials, and estimated to be 135 mm and 295 mm, respectively.

Whereas the Big Above Minnow Creek Subwatershed had the majority of its groundwater discharge predicted to occur along the main channel, the majority of discharge in the Big Above Walsingham Subwatershed is estimated to occur in the tributaries of Big Creek. Approximately 1.25 m^3/s of discharge is estimated to occur largely in the tributaries of Trout Creek, Mosquito Creek, Cattle Creek, Silverthorn's Creek, and Deer Creek. The Subwatershed also receives a net groundwater inflow of approximately 0.14 m^3/s from adjacent subwatersheds.

Water demand is high and dominated by the agricultural sector. There is approximately 1.89 m^3/s of groundwater takings permitted, and 2.32 m^3/s of surface water takings permitted. It is estimated that on an annual basis, 0.37 m^3/s of water is pumped, and that 0.15 m^3/s is taken that is not returned to its original source.

6.3.21 Venison Creek Subwatershed

Venison Creek is a tributary that joins Big Creek just below the Walsingham gauge. The Subwatershed is characterized by predominantly pervious surficial materials, with some isolated deposits of Port Stanley Till in the headwaters. The average precipitation received by the Subwatershed is 980 mm, and the estimated evapotranspiration is 565 mm. As with all subwatersheds in the Norfolk Sand Plain, runoff (100 mm) is lower than the area average (195 mm) and recharge is higher (195 mm) than average (205 mm).

There is a significant amount of groundwater discharge predicted to occur within the Venison Creek Subwatershed. On an annual basis, 1.13 m^3/s of groundwater is estimated to discharge, and this is estimated by the model to be evenly distributed over the watercourses within the Venison Creek Subwatershed. Adjacent subwatersheds also provide the Venison Creek Subwatershed with a net groundwater inflow of 0.20 m^3/s.

There is a high water demand within the Venison Creek Subwatershed, driven predominantly by agricultural requirements. Approximately 1.76 m^3/s of groundwater takings is permitted, and 1.84 m^3/s of surface water takings is permitted. Including non-permitted takings, on an annual basis, it is estimated that 0.14 m^3/s is pumped, and 0.10 m^3/s is not returned to its original source.

6.3.22 Lower Big Creek Subwatershed

The Lower Big Creek Subwatershed is the last subwatershed before Big Creek enters into Lake Erie. The surficial materials of the Subwatershed contain the pervious materials of the Norfolk Sand Plain, Wentworth Till associated with the buried Paris Moraine, as well as glaciolacustrine deposits close to Lake Erie. A large portion of the Subwatershed has wetlands as the dominant land cover. The Subwatershed receives, on average, 984 mm of precipitation a year. Evapotranspiration is estimated to be approximately 490 mm per year, which is lower than the area average (555 mm). With the presence of glaciolacustrine deposits as well as wetlands, the runoff component of the water budget is estimated to be higher (280 mm) than average (195mm), with recharge (215 mm) being close to average (205 mm). Due to the high proportions of wetlands in this Subwatershed, there is more uncertainty surrounding these water balance estimates, as GAWSER's representation of wetland features may not fully represent groundwater/surface water interactions and evapotranspiration.

Approximately 0.38 m^3/s of groundwater discharge is estimated to occur within the Lower Big Subwatershed. Most of this discharge is estimated to occur in the upper reaches of Big Creek, near the Venison Creek/Big Creek confluence. Groundwater discharge downstream of the confluence to Lake Erie is lower. The Subwatershed has a net groundwater outflow of approximately 0.16 m^3/s, to the Dedrick Creek Subwatershed to the east, and a groundwater outflow to the Lake Erie of 0.08 m^3/s.

Water demand is moderate within the Lower Big Subwatershed, with 0.68 m^3/s of groundwater takings permitted and 0.64 m^3/s of surface water takings permitted. It is estimated that, on an annual average basis, 0.06 m^3/s of water is pumped, and 0.04 m^3/s is withdrawn and not returned to the source from where it was drawn.

6.3.23 Dedrick Creek and Young/Hay Creeks Subwatersheds

The Dedrick Creek and Young/Hay Creek Subwatersheds drain directly to Lake Erie and have been grouped here for description purposes. Both Subwatersheds are predominantly comprised of pervious surficial materials commonly associated with the Norfolk Sand Plain. The Dedrick Creek Subwatershed has a significant portion consisting of Wentworth Till associated with the buried Paris Moraine, and the Young/Hay Creeks Subwatershed has minimal isolated pockets of glaciolacustrine deposits. The average annual precipitation received by the Subwatersheds is 1005 mm, which is the highest in the Study Area. Evapotranspiration is estimated to range between 550-565 mm, which is close to the area average of 555 mm. Due to the presence of Wentworth Till, Dedrick Creek produces slightly more runoff (180 mm) then Young/Hay Creeks (135 mm), and less recharge (275 mm) than Young/Hay Creeks (305 mm).

Groundwater discharge is estimated to be 1.28 m^3/s, or 150 mm/year of equivalent depth within the Subwatersheds. This discharge is estimated to be evenly distributed throughout the stream reaches. A large amount of groundwater flow, 1.2 m^3/s leaves the Subwatersheds into Lake Erie.

Water demand is high in both Subwatersheds and is predominately agricultural based. Permitted takings in the Dedrick Creek Subwatershed total 1.27 m^3/s for groundwater sources and 1.2 m^3/s for surface water sources. Permitted takings in the Young/Hay Creeks Subwatershed total 1.48 m^3/s for groundwater takings and 0.94 m^3/s for surface water takings. Including non-permitted takings, total pumping from the Dedrick Creek Subwatershed equals 0.52 m^3/s and 0.10 m^3/s is not returned to its original source. For the Young/Hay Creeks Subwatershed, total pumping equals 0.28 m^3/s, and 0.13 m^3/s is not returned to the source from where it was drawn.

6.3.24 Lynn River Subwatershed

The surficial materials of the Lynn River Subwatershed are predominately previous materials associated with the Norfolk Sand Plain, with some pockets of Wentworth Till associated with the buried Galt Moraine. Glaciolacustrine deposits are present near the outlet of the Lynn River. The Subwatershed, on average, receives about 985 mm of precipitation and it is estimated that evapotranspiration removes 585 mm of that precipitation. Surface runoff depths are typical of a pervious subwatershed, and are estimated to be 115 mm, compared to the area average of 194 mm. Recharge is estimated to be 285 mm, compared to the area average of 205 mm.

As with most subwatersheds located within the Norfolk Sand Plain, the predominant groundwater source is the unconfined aquifer that comprises the Norfolk Sand Plain. There is 1.12 m^3/s of groundwater discharge predicted to occur within the Lynn River and its tributaries, with the majority of it occurring within Patterson Creek and in the main channel of the Lynn River, just downstream of Simcoe. The groundwater model predicts a small net groundwater outflow from the Lynn River to adjacent subwatersheds equal to approximately 0.05 m^3/s.

Water demand within the Lynn River Subwatershed is high and predominantly driven by agricultural uses. Groundwater takings for the Subwatershed total 3.7 m^3/s, and surface water takings total 0.92 m^3/s. It is estimated that actual pumping, on an annual average basis, totals 0.28 m^3/s, of which, 0.24 m^3/s is not returned to the source from which it was taken. Municipal supply wells which service the town of Simcoe are located in this Subwatershed.

6.3.25 Black Creek Subwatershed

The Black Creek Subwatershed is situated on the interface between the Norfolk Sand Plain and the Haldimand Clay Plain. The extreme westerly portion of the Subwatershed contains pervious materials associated with the Norfolk Sand Plain, with the eastern portion comprising glaciolacustrine deposits. On average, the Subwatershed receives 980 mm of precipitation per year, and 566 mm of that becomes evapotranspiration. Due to the higher proportion of glaciolacustrine deposits, runoff is higher (250 mm) than the area average (195 mm), and recharge is lower (165 mm) than the area average (205 mm).

In the western areas of the Subwatershed, the main aquifer is the Norfolk Sand Plain aquifer; however, the only viable aquifer towards the east is the Dundee bedrock aquifer, which tends to have poor water quality issues. Groundwater discharge is moderate along most of Black Creek, with 0.50 m^3/s predicted to discharge (120 mm equivalent). Areas of higher discharge are located in the westerly portions of the Subwatershed, near the pervious deposits of the Sand Plain. Approximately 0.15 m^3/s of groundwater flow exits the Subwatershed to Lake Erie to the south.

Water demand is moderate within the Black Creek Subwatershed, and similar to other subwatersheds, is primarily driven by agriculture. Permitted water demands total 0.61 m^3/s from groundwater sources and 0.03 m^3/s from surface water sources. It is estimated that for all demands, including non-permitted uses, approximately 0.05 m^3/s of water is pumped, of which 0.04 m^3/s is not returned to its original source.

6.3.26 Upper Nanticoke Creek Subwatershed

The Upper Nanticoke Creek Subwatershed is almost completely within the Norfolk Sand Plain, and therefore predominately consists of permeable surficial materials, but also includes deposits of Wentworth Till associated with the buried Galt/Paris Moraines, and glaciolacustrine deposits of the Haldimand Clay Plain in the extreme eastern portions of the Subwatershed. The Subwatershed receives, on average, 915 mm of precipitation per year, which is lower than the area average of 955 mm. Evapotranspiration is estimated to be approximately 555 mm, which is equal to the area average. Simulated runoff, 180 mm, is slightly lower than the simulated recharge, 185 mm. Due to the lower precipitation, both values are less than the area average of runoff (195 mm) and recharge (205 mm).

Groundwater discharge in Upper Nanticoke is estimated to be 0.53 m^3/s, and is focused on the western reaches in Subwatershed. Little to no discharge occurs in the eastern reaches in the Subwatershed, where the Clay Plain is predominant. There is minimal net groundwater inflow from adjacent subwatersheds and minimal groundwater outflow to the north to the Grand River Watershed.

There are substantial water demands within the Upper Nanticoke Subwatershed, driven primarily by agricultural requirements. In total, there are 4.2 m^3/s of groundwater takings permitted and 0.61 m^3/s of surface water takings permitted. It is estimated that, including non-permitted takings, the total amount of water pumped is 0.20 m^3/s, of which 0.16 m^3/s is not returned to the source from which it was taken. The Upper Nanticoke Creek Subwatershed includes the Waterford municipal supply wells.

6.3.27 Lower Nanticoke Creek, Sandusk Creek and Stoney Creek Subwatersheds

Lower Nanticoke Creek, Sandusk Creek, and Stoney Creek Subwatersheds are all located within the Haldimand Clay Plain, and share similar characteristics. Each has been grouped together here for discussion purposes only. The three Subwatersheds in the eastern portion of LPRCA overwhelmingly comprise glaciolacustrine deposits associated with the Haldimand Clay Plain. The Lower Nanticoke Creek Subwatershed does have some small portions of its area containing pervious deposits. The precipitation over the eastern Subwatersheds ranges from 875-900 mm, which is less than the area average of 955 mm. Evapotranspiration is estimated to range between 505-515 mm for these Subwatersheds, which is also lower than the area average. Surface runoff is typical of an area dominated by fine-grained materials, and is estimated to be 300 mm, which is the highest of all the subwatersheds investigated. Recharge is much lower than average, at 65-85 mm per year. Lower Nanticoke has the highest recharge of the three, at 85 mm, due to the localized pervious deposits.

The main groundwater source within the three Subwatersheds is the Dundee bedrock aquifer. As is the case in Black Creek Subwatershed, quality issues are common with such wells, which indicate a very slow-moving groundwater flow system. Groundwater discharge is minimal, with

0.50 m^3/s (~50 mm/year equivalent) of discharge predicted. The majority of this discharge occurs along the Lower Nanticoke reaches. Discharge to Lake Erie from all three Subwatersheds totals 0.50 m^3/s.

Water demand is low for all three Subwatersheds. For all Subwatersheds, the total permitted groundwater takings is 0.20 m^3/s and 0.02 m^3/s for surface water takings. Including the non-permitted water takings, it is estimated that 0.03 m^3/s is pumped, and 0.01 m^3/s is not returned to its original source.

6.4 GROUNDWATER FLOW DEPICTION

Utilizing forward particle tracking within the groundwater flow model, additional insight into the groundwater flow system that is linked to key surface water features can be obtained. Forward particle tracking is used to track the pathway that an imaginary water particle follows. For this application, particles are released at the water table to track recharging groundwater to its discharge zone. Using this approach, the linkage between recharge and discharge areas can be delineated, which assists in:

- Visualizing where differences exist between surface water subwatershed divides and groundwater flow divides;
- Identifying the recharge areas that supply key discharge features within critical stream reaches; and
- Understanding the pathway that recharging water is predicted to follow as it travels toward a discharge zone.

As with all results generated from the numeric tools developed for this Study, it should be recognized that the tools are regional in nature. As regional tools, they may not contain features that are significant at the local scale, and results should only be viewed from a regional perspective.

Forward particle tracking was completed by releasing particles at a 200 m grid spacing throughout the entire model domain. This results in a total of 25 particles for every square kilometre. Such a grid spacing was deemed appropriate for the regional nature of the analysis.

After release, the pathline (i.e. path through the subsurface) for each particle is recorded, as is the discharge point of the particle. Particles were allowed to travel through the groundwater system until they reached their discharge destination, which may represent a travel time of up to 1000 years for areas dominated by materials with low hydraulic conductivities (i.e. Haldimand Clay Plain).

For the presentation of results, four classes of particles are included. They are as follows:

1. Recharging particles that leave the model borders and enter adjacent Conservation Authorities;
2. Recharging particles that discharge to Lake Erie;
3. Recharging particles that discharge to individual streams within the model extent; and
4. Recharging particles that are captured by pumping wells.

White areas in the presented results reflect regions where particle traces did not reach a discharge destination within 1000 years.

Recharging particles which discharge to internal streams were further classified based on which one of the 31 subwatersheds they discharged within. This allows one to determine if particles are recharging in one subwatershed, and discharging in an adjacent subwatershed. Such an occurrence would suggest that the groundwater and surface water divides are not coincident and groundwater flow across the surface water divide occurs.

The results of the forward particle tracking are included in Maps 6.6 – 6.8. The results have been separated onto three different maps to present the information at an appropriate scale. All particles are coloured based on their classification into the four categories presented above. Particles which discharge directly to Lake Erie are coloured blue; particles leaving the model domain to adjacent Conservation Authorities are coloured buff; and particles that are captured by pumping wells are coloured grey. The remaining particles are coloured based on the subwatershed in which they discharge to. Watercourses are also included in Maps 6.6-6.8, and the width of each stream segment varies based on the estimated rate of groundwater discharge to that reach. Thicker streams indicate that higher rates of discharge are occurring at that location.

When viewing these maps, the reader should keep in mind that particle tracking results do not consider recharge volume, and are only a representation of the likely discharge point for a single water particle. As such, the results of the forward particle tracking analysis should be viewed with Map 4.9, which displays the rate of recharge modelled by GAWSER. Viewing both maps together will give a more complete understanding of both the volume and spatial distribution of groundwater recharge that sustains stream baseflow.

The results of the particle tracking indicate that for the majority of the Study Area surface water divides and groundwater divides are similar. This is particularly true within the relatively flat, high recharging, Norfolk Sand Plain. Recharge areas which ultimately discharge directly to Lake Erie are typically found in close proximity to the Lake Erie shoreline, or along subwatershed divides. Large portions of the Upper Kettle Creek also discharge directly to Lake Erie.

The particle tracking results indicate that there are at least two locations where groundwater divides significantly differ from the surface water divides: Upper Kettle, and between the Spittler Creek and Big Otter at Tillsonburg subwatersheds (see Map 2.1 for locations). In the upper reaches of the Upper Kettle Creek Subwatershed (Map 6.6), it is clear that the groundwater divides do not follow the topographical surface water divides. Most of the particles recharging in the northern Kettle Creek Conservation Authority enter a deep groundwater flow system and discharge to the lower reaches of Catfish Creek. Similarly, on Map 6.7, the Big Otter at Tillsonburg Subwatershed shows a significant inflow of particles that were originally recharged in Spittler Creek Subwatershed to the north. Tables 6.5 and 6.6 indicated a large volume of groundwater flow entering the Big Otter at Tillsonburg Subwatershed and the forward particle tracking has identified Spittler Creek as the source of this inflow.

This analysis has provided a means to better understand the groundwater system, and to identify where groundwater flow boundaries may differ from surface water boundaries. With this knowledge, water managers are provided a more complete representation of the watershed's hydrology and are thus better able to manage the system appropriately.

7.0 Conclusions & Recommendations

7.1 GENERAL

The detailed assessment of surface and groundwater flow volumes (supply), as well as the refined assessment of pumping (demand) has resulted in a more robust understanding of the water budget for the Study Area. This enhanced understanding was developed through a solid evaluation of key hydraulic / hydrogeologic functions and characteristics as well as through a refined assessment of consumptive water demands. This water budget work builds upon and supersedes the previous work used to develop the "High Use Watershed" designation (AquaResource, 2005).

7.2 MONITORING

Monitoring data for climate and streamflow conditions is critical to validating Water Budget results and Stress Assessment identifications. Since the mid 1990's, there has been a significant reduction in climate stations throughout Southern Ontario. This reduction in climate stations has compromised the ability to accurately characterize climate variability, both spatially and temporally. To better characterize climate variability, and increase certainty of Water Budget calculations, it is recommended that the climate station network be augmented. For maximum benefit, any additional stations should be operated and maintained to the Environment Canada standards.

Similarly, a lack of streamgauge information limits the ability to validate the Water Budget results. Of particular note are those subwatersheds that include drinking water intakes (e.g. North Creek). To better understand hydrological processes and the impacts of water takings within the subwatershed, a streamgauge on the outlet of North Creek would be invaluable. As with climate stations the operation of additional streamgauges to the Water Survey of Canada standard would greatly increase the reliability of observed data.

7.3 WATER USE

Initial water use assessments developed for the Study Area were built upon to incorporate consumption into the water use estimates. Recognizing the spatial scale dependence of water consumption facilitates distinguishing water takings that are moving water between sources and water takings that are removing water from the subwatershed. This understanding is required to more accurately characterize the effects a water taking may be having on a local water source.

Additional work was carried out to better characterize water demand. This included efforts to verify permit-to-take-water information, gathering reported rates of "actual" pumping, estimating agricultural demand based on discussions with the farming community, checking actual use information through calibration of the surface water model, and gathering relevant information contained within MOE's PTTW paper files. This characterization work has led to agricultural water use estimates being significantly lower than those assumed in previous studies.

While still imperfect, the current estimates of water use are considered more appropriate to quantify water takings on a subwatershed level. Maintaining the actual water use estimates will be part of a continual improvement process. As the MOE begins to collect actual water use data from permit holders, refinements can be made.

7.4 WATER SUPPLY AND RESERVE CALCULATION TOOLS

The integrated calibration of the groundwater and surface water modelling tools applied in this study, as well as their ability to represent the primary physical processes, provides confidence in the Water Budget values predicted throughout the Study Area.

Significant revisions have been made to the Long Point Region, Catfish Creek and Kettle Creek models. An updated methodology for incorporating water takings into GAWSER has been utilized, and has served to validate the assumptions governing the estimates of agricultural water use. Pervious soil response units within the Long Point Region model, overlying glaciolacustrine quaternary deposits, were modified to better represent the underlying materials being the limiting factor with respect to groundwater recharge. A successful calibration exercise was carried out specifically targeting monthly median flows. The results of this exercise indicate that the streamflow-generation models are effective tools for understanding major hydrologic processes at a subwatershed scale.

The FEFLOW model underwent significant revisions from the original Catfish/Kettle Creek expansion of the Norfolk County model. Recharge estimates have been updated to those consistent with GAWSER, water takings have been incorporated, all Strahler class 3 and above watercourses have been included, hydraulic conductivities have been determined by water well lithologies, and overburden and bedrock boundary conditions have been updated, as supported by recorded water level data. The updated model underwent a regional calibration and the results indicate that the groundwater modelling tool developed provides a realistic representation of the groundwater flow system at a regional scale. As such the groundwater model provides an effective water budget tool for subwatershed assessment.

The surface and groundwater modelling results are consistent with the understanding of the key hydrologic and hydrogeologic processes at the subwatershed scale. These models provide the quantitative calculation capability to perform subwatershed water budget calculations in support of the companion Tier 2 Water Quantity Stress Assessment (AquaResource, 2009a).

The modelling tools used for this study have been developed from regional datasets and calibrated to observations at the subwatershed scale and correspondingly the focus of the calibration was on large-scale features. Consequently, the models may not be equivalently valid at smaller scales where local features and processes have not been equally-well represented.

7.5 INTEGRATED WATER BUDGET

The modelling combination of GAWSER/FEFLOW utilized for the LPRCA/CCCA/KCCA area provides an effective framework in which to assess the subwatershed's water budget parameters from a surface water and groundwater perspective. On a regional basis, the predicted hydrologic response for various hydrologic units and subwatersheds is consistent with expectations and field observations.

Water demand, precipitation, evapotranspiration, runoff, recharge, groundwater discharge and inter-basin groundwater flow have been quantified for the 31 subwatersheds. The water budget methodology employed is consistent with the direction of the Province's source water protection framework.

7.6 FLOW SYSTEM UNDERSTANDING

The integrated GAWSER / FEFLOW modelling developed for the LPRCA/CCCA/KCCA area has provided a set of physically-based tools to enhance our understanding of the surface and groundwater flow systems, and particularly their interaction. The groundwater flow system and linkages between recharge and discharge locations are illustrated through the application of particle tracking. This analysis has shown that in areas of relatively low topographic relief, the groundwater and surface water divides are coincident. However, areas along the subwatershed and watershed divides may be linked to deeper groundwater flow systems that can lead to discharge directly to Lake Erie or into adjacent watersheds. Understanding these flow conditions, along with the volumetric flow calculations, provides a solid foundation for water management throughout the Study Area.

7.7 UNCERTAINTY CONSIDERATIONS

All water budget calculations contain inherent uncertainty due to incomplete data, data inaccuracies, and imperfect estimation and simulation tools. Many of the sources of uncertainty are documented throughout this report. For future application of the estimation and simulation tools developed herein, it is important to consider the regional-scale nature of the analysis and interpretation presented in the Report. The methods used and the amount of data available were suitable for regional water budgeting purposes but are not appropriate for more localized use. It is recommended that for local application, the tools developed thus far require further refinement and evaluation.

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