Quinte Source Protection Region

Tier 2 Water Budget

For

Ameliasburgh Subwatershed
Prince Edward County

Final Report

April 26, 2010

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1. Introduction and Purpose

It is the intention of this report to provide the ministries of the Environment and Natural Resources and the Quinte Region Source Protection Authority an assignment of Stress Category for the Ameliasburgh subwatershed in Prince Edward County based on the Technical Rules under the Clean Water Act.

The staff of Quinte Conservation completed both a conceptual water budget and a Tier 1 water budget for the Quinte Source Protection Region in 2006 and 2009 respectively. These documents were prepared following guidance documents from the province that have continued to evolve over the period of completion. The framework for undertaking the Tier 2 water budget work is now well established in the Technical Rules (November 16, 2009) for preparation of the Assessment report under the Clean Water Act.

The Quinte Source Protection Region encompasses the area shown in Map 1.1. At the conclusion of the Tier 1 water budget, which looked at potential for stress across the region on a spatial scale bounded by subwatershed and a period of time refined to monthly, authors found that there was potential for stress in one subwatershed where municipalities take water from surface. This was the Roblin Lake intake in the Ameliasburgh subwatershed which showed a summer stress level of 28% to 31%.

One other system in the Quinte Source Protection Region, the Madoc wells, required a more in-depth water budget evaluation. This was the subject of a separate study. Map 1.2 shows the catchments with stress resulting from the Tier 1 water budget work.

The Tier 2 water budget assessment has been completed for the purpose of confirming the stress assignment of the Ameliasburgh subwatershed through a refinement of the meteorological inputs and water use information using a more thorough modelling platform. It employs GAWSER (Guelph All-Weather Sequential Events Runoff model), a distributed physically-based continuous model, to develop statistical values for the basic water budget components necessary for reporting the potential stress condition of the subwatershed.

Map 1-1: Quinte Source Protection Area

Map 1-2: Subwatershed Percent Water Demand Maps – Tier 1

2. Ameliasburgh Subwatershed

Geography

The Ameliasburgh subwatershed is located on the north shore of Prince Edward County bordering on the Bay of Quinte (see Map 2.1). The catchment is defined on the north by the edge of the Bay of Quinte, on the south by a drainage divide, on the west by a municipal boundary with Quinte West and on the east by Muscote Bay.

There are several small creek systems and one larger creek called Sawguin Creek within this area. Sawguin Creek drains west to east and outlets into the extensive Sawguin Marsh between Huff's Island and Massassauga Point. Sawguin Marsh is adjacent to the Bay of Quinte and Muscote Bay. Roblin Lake is the only inland lake in this subwatershed. There is also one small impoundment north of Ameliasburgh behind the Harry Smith Dam which has a reservoir surface area of about 2.5 ha (storage of 50,000 m^3).

Also running east-west is an escarpment reaching heights as high as 40 m from Ameliasburgh through Mountainview and Demorestville. Portions of the plateau are quite flat attracting the Department of National Defence to develop it for use as air strips. Below the escarpment the valley lands are dominated by marsh with some agricultural use.

The soils are generally thin, less than one metre of cover over layered limestone above the escarpment and muck below. There are some pockets of lacustrine sediments immediately below the escarpments and west shore and till less than 3 m depth generally on the north and east shores (WESA, 1984).

Bedrock is Paleozoic over the entire region with upper layers, characterized as the Lindsay formation, found mostly above the escarpment and in small pockets west of Rednersville along the Bay of Quinte. Where the Lindsay formation is not found, the Verulam formation is predominant – this is largely in the valley areas and east to Huff's Island. A very small portion of the surficial bedrock is characterized as Bobcaygeon, which is located over most of Massassauga Point on the upper, east side of the subwatershed. There is one extraordinary exception in surficial bedrock type located in the valley between Mountainview and Rednersville. A small exposure of the Precambrian layer is found bounded by faults of the Salmon River fault zone. This is believed to be the most southerly exposure of the Canadian Shield.

Location of Intake

The municipal intake is located in Roblin Lake which is in the Village of Ameliasburgh just above the escarpment. The exact location of the intake could not be confirmed by Prince Edward County staff, but it is believed to be near the west shore in the deep section of the lake. The intake is reported to be 1.07m diameter pipe in 3 metres depth of water.

The water treatment plant services a population of 157 people by upwards of 75 service connections. Others obtain their supply directly from the lake. This has been estimated to potentially be 82 private supplies.

Roblin Lake is located at the top of the escarpment and has a surface area of just over 1 km^2. Drainage area to the lake is 3.6 km^2 draining agricultural lands mostly from the south. The lake is controlled by Roblin Lake Dam – a small concrete dam with 0.75m high x 2.6m log bay. The lake is approximately 15 m deep at the west end and tapers to 2 to 4 metres depth on the east side. The dam was originally constructed by Prince Edward Region Conservation Authority in 1992 to assist the municipality in controlling water levels for the water treatment plant.

Water flowing past the dam is conveyed by a small ditch north and disappears through a French drain for several hundred metres under tennis courts and the county road appearing again three quarters of the way down the escarpment. It is assumed this is the former location of the old mill race from the Roblin Mill which operated on the lake from 1842 to 1920.

2.1. Determination of Study Area

2.1.1. Tier 1 Study Area

In the Tier 1 Water Budget prepared by Quinte Conservation in April 2009, the subwatershed that was considered for review was delineated by aggregating one large and several small subcatchments. This subwatershed is shown in Map 2.1. Stress calculations in the Tier 1 study were completed on the entire Ameliasburgh subwatershed.

2.1.2. Tier 2 Study Area

The current Tier 2 study is narrowed in focus, as compared to the Tier 1 study area, looking at the major subcatchment of the Sawguin Creek subwatershed. The relative location of the Sawguin Creek subwatershed is shown in Map 2.2. The study area was reduced for two reasons.

First, the municipal taking is from the Sawguin Creek subwatershed. A surface water taking from Sawguin Creek would not impact upon the small peripheral subcatchments. Also, takings from these small peripheral subcatchments would not affect supply in Sawguin Creek. Performing calculations based on the larger Tier 1 area would have the effect of diluting the stress caused by the taking in the Sawguin Creek subcatchment.

Secondly, it was necessary to refine the subcatchment boundaries to the Sawguin Creek subcatchment for hydrologic modelling purposes. The model predicts hydrologic response by accumulation of runoff from defined subcatchments that are linked critically by a common drainage network. The peripheral subcatchments are not linked by a common drainage network, but instead drain directly into the Bay of Quinte at distinct points.

Therefore, the Sawguin Creek subcatchment of 53.3 km^2 was used in the current Tier 2 Water Budget Study.

Since the municipal taking occurs in Roblin Lake, the contributing drainage area to the lake will form an additional area of interest within the Tier 2 study. It is necessary to review the water budget on the scale of the drainage area to the lake (Roblin Lake subcatchment) to investigate impacts during drought conditions. This is discussed further in Section 6.

Map 2.3 shows the relationship between Roblin Lake subcatchment and the Sawguin Creek subcatchment. Map 2.4 provides a bathymetry map of Roblin Lake showing the location of the intake with respect to the bottom elevation contours.

All three study areas are listed below in Table 1:

Table 2-1: Drainage Area Summary

Location	Drainage Area
Ameliasburgh Subwatershed	132 km^2
Sawguin Creek Subcatchment	53.3 km^2
Roblin Lake Subcatchment	3.6 km^2

Map 2-1: Location of Ameliasburgh Subwatershed in Prince Edward County

Map 2-2: Comparison of Ameliasburgh Subwatershed with Sawguin Creek Subcatchment

Map 2-3: Roblin Lake and Contributing Drainage Area

Map 2-4: Roblin Lake Showing Location of Municipal Intake and Bathymetry

Water taken from Roblin Lake by the municipal drinking water system is in part returned to the local groundwater supply via private septic systems. However, the majority of the connections are on the south and west side of the lake near the topographic divide. The groundwater gradient indicates flow in this area would be northerly (see Figure 10 in Appendix B). This means that from the standpoint of Roblin Lake, not all of the water withdrawn from the lake by the municipal system is returned to the lake. Nevertheless, it would still be returned to the Sawguin Creek subcatchment.

Figure 2-1 shows the Sawguin Creek subcatchment and serves as a key map for two profile views. Elevations are derived from the provincial DEM. Figure 2-2 provides a profile of the ground surface beginning with the outlet on the left and top of the escarpment on the right. This shows the relatively gentle slope of the of the valley portion of the subcatchment in contrast to the steeply sloping ground surface on the escarpment. Figure 2-3 provides a profile through the lake and shows its relative position near the escarpment. This profile is presented showing the watershed divide on the left, the lake in the middle, and the escarpment on the right.

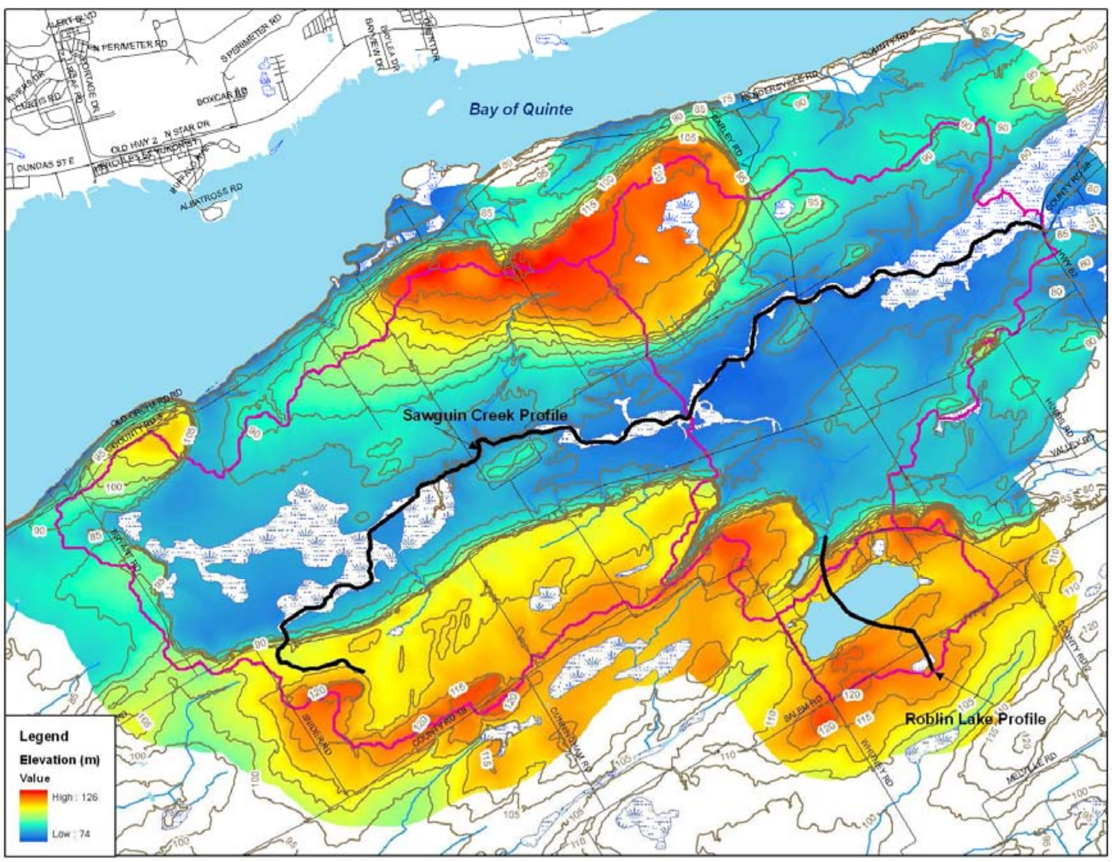

Figure 2-1: Sawguin Creek Subcatchment Showing Section Locations

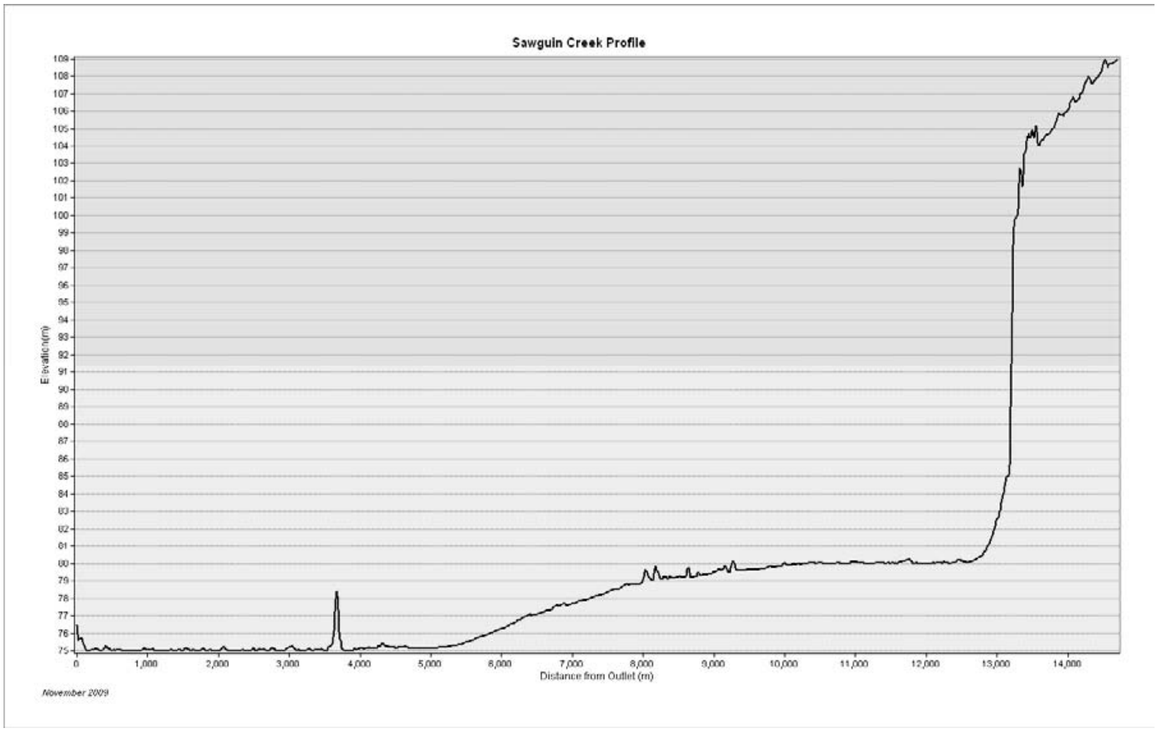

Figure 2-2: Profile 1 – View of Outlet of Sawguin Creek to Roblin Lake

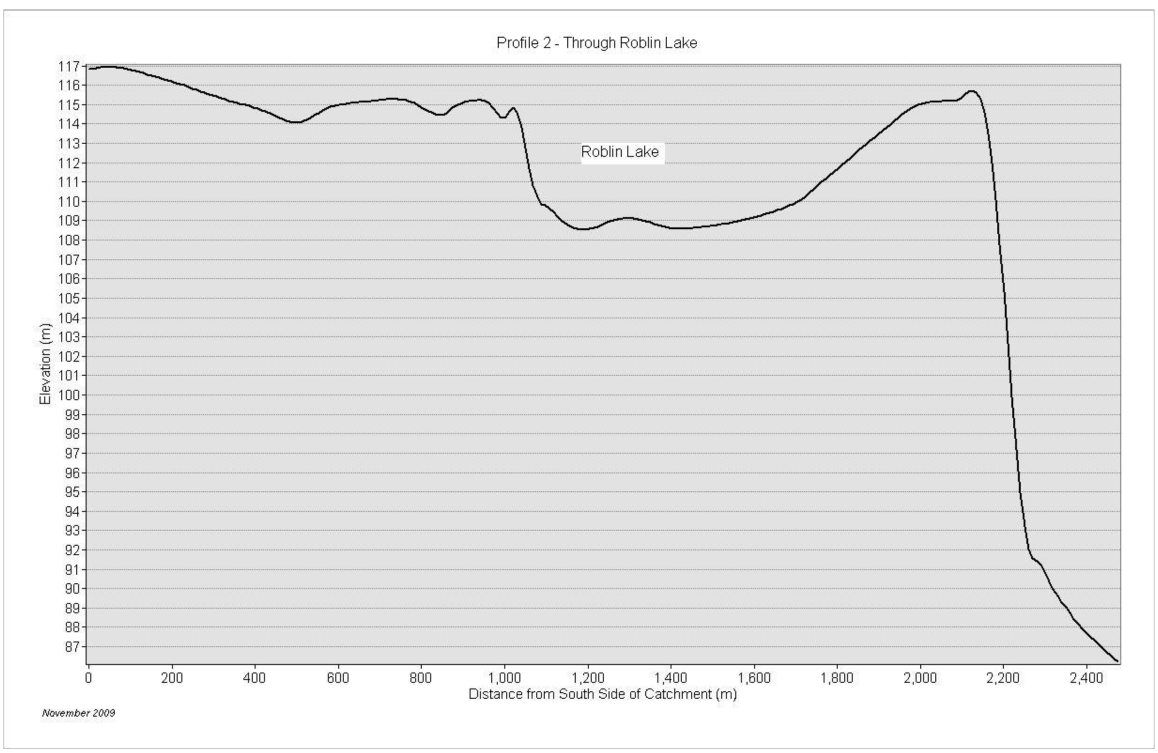

Figure 2-3: Profile 2 – View Through Roblin Lake

3. Water Budget Methodology

What is a Water Budget?
A water budget is a means of presenting quantitatively where water exists in a hydrologic system and how it moves throughout the system temporally.

The simple water budget formula below shows water inputs to a system on the left side and outputs on the right. Since inputs and outputs do not necessarily balance during shorter time scales such as the monthly period used in this study, the term ΔS is included in the equation to balance. It may be a positive or negative value.

$$P + GW_{in} = ET + Q + U + \Delta S \qquad \text{(equation 1)}$$

Where:

P = Precipitation
GW_{in} = Net Horizontal ground water flow in
ET = Evapotranspiration
Q = Stream flow out (ground water discharge + direct runoff)
U = Net water use including withdrawals and returns
ΔS = Change in storage

Work Methodology
Water budget elements (inputs and outputs) were refined in this study. To refine all elements in equation 1, the Tier 2 work followed this simplified procedure:

1. Review Water Use data (current and future)
2. Review Meteorological data (precipitation, temperature)
3. Review ET estimates
4. Refine Streamflow estimates
5. Consider Groundwater contributions
6. Determine Subwatershed Stress
7. Determine Uncertainty
8. Identify need for future work or data gaps.

3.1. Water Use Data

The current Permit To Take Water database was reviewed to determine current active permits. Permit holders were contacted regarding their usage records to determine if actual usage is similar to permitted usage. The actual usage was considered in the stress calculations. More discussion on water usage is found in Section 5.1.

3.2. Meteorological Station Data

For modelling purposes, precipitation and temperature data were used from the following six Meteorological Services of Canada Stations:

- Bancroft Auto (6161001),
- Madoc (6154779),
- Cloyne Ontario Hydro (6161662),
- Frankford MOE (6152555),
- Belleville (6150689), and
- Mountainview (615EMR7)

These stations had the longest periods of record for the Quinte area. The station locations can be found in Map 5.2 in section 5 of the report. A full discussion of the data is contained within the modelling report in Appendix C. Schroeter and Associates used data from these six stations to fill in gaps in the record. The hydrologic modelling employed data from the closest station primarily. Trenton station was also reviewed to assist in finding the lowest precipitation periods for the area.

3.3. ET Estimates

The largest output from the water budget is evaporation and transpiration (lumped as evapotranspiration or ET). Earlier water budget work used Thornthewaite method of determining Potential and Actual ET. Potential evapotranspiration (or the amount of water that would evaporate or transpire give that soils would remain saturated) is calculated theoretically in the hydrologic model by one of two methods – the climatological method and by the Linacre formula. This is discussed further in Section 5.3 and in Appendix C.

3.4. Streamflow Estimates

Previous water budget work was completed with the assistance of the GIS framework using gridded precipitation, soils, land cover, slope and temperature information. Evapotranspiration was estimated using Thornthwaite Method (1955). Precipitation data was received from Dan McKenney using Environment Canada climate station data for which spatial models were developed by Natural Resources Canada-Canadian Forestry Service (McKenney et al. 2006). Remaining geospatial data were provided under licence by Ontario Ministry of Natural Resources through Land Information Ontario program. Calculations of surplus water or ‘water availability’ were performed within the GIS environment and summarized for presentation in the Conceptual and Tier 1 reports.

The current work makes use of the same geospatial data with the exception of the gridded precipitation and temperature data. The surface water model incorporates the Environment Canada unprocessed climate station data.

Tier 2 water budget assessments are intended to employ more complex methods for validation of Tier 1 stress assessments on subwatersheds with municipal intakes showing stress in excess of 20% or Moderate to Significant stress. The Quinte Source Protection Region opted to employ a GAWSER-based surface water model of the Quinte watersheds for numerical modelling.

A complex numerical model that existed for most of the Quinte Conservation jurisdiction was expanded to include the Prince Edward County watershed area and more specifically the Ameliasburgh subwatershed. This model was selected partly because of the existence of the Moira, Salmon and Napanee models and, in part, because of the capabilities of the GAWSER platform to evaluate infiltration or recharge and provide water balance calculations.

Sawguin Creek is ungauged and the closest Prince Edward County stream gauge is found in Consecon Creek at Allisonville (02-HE002). Refer to Map 5.2 for locations of stream gauges. The surface water model was expanded to include the Consecon Creek system to provide a comparison with observed data.

Streamflow estimates are generated for Sawguin Creek for three conditions. These are:

1) Average
2) 2-Yr Drought
3) 10-Yr Drought

Average conditions in the streamflow record are generated statistically from the model. Drought conditions are distinct periods of precipitation record. Definitions of the drought periods have been provided in the Technical Rules and are reproduced below.

2-Yr Drought
The continuous two year period for which precipitation records exist with the lowest mean annual precipitation.

10-Yr Drought
The continuous ten year period for which precipitation records exist with the lowest mean annual precipitation.

As a note, the terms 2-yr and 10-yr drought appear to suggest frequencies of occurrence as would the term 100-yr flood. This is an unfortunate similarity to a common hydrologic expression and may be confusing to the reader. It will be important to recall that the drought periods are a period of time, not a frequency of occurrence. This means that the 2-yr drought will produce a smaller rainfall volume than a 10-yr drought and is the most severe in terms of the drought calculations performed later in Section 6.

3.5. Groundwater Estimates

It has been reported Roblin Lake has groundwater sources not explained by simple estimation that the groundwater contributing area is approximated by the surface water divides. For this reason, it was necessary to also complete an evaluation of potential inflow to Roblin Lake from groundwater. While the surface water model can take into account the losses and contributions from groundwater it was felt that the surface water model alone would not be adequate to determine the interaction at this location.

Quinte Conservation source protection staff worked with Golder Associates to complete a groundwater evaluation in the vicinity of Roblin Lake using the provincial water well information system and locally derived information from pump tests, bathymetric mapping and provincial groundwater monitoring network wells.

3.6. Stress Assignment

Stress thresholds employed in the Tier 1 level of study were applied in the present work for average hydrologic conditions. The thresholds are noted below in Table 3-1. Additional scenarios for drought are also required and these may be assigned a maximum stress level of Moderate based two defined drought periods.

Table 3-1: Stress Categories

Surface Water Quantity Stress Assignment	Monthly Maximum % Water Demand & 25-Year Projection
Significant	>50%
Moderate	20%-50%
Low	<20%

Stress or percent water demand is calculated over the catchment by dividing the water use (demand) by the water availability (supply less a small reserve).

$$\% \text{ Water Demand (Stress)} = \frac{Q_{Demand}}{Q_{Supply} - Q_{Reserve}} \times 100 \qquad \text{(equation 2)}$$

Where:

Q_{Demand} = Monthly surface water demand calculated as consumptive takings from streams, ponds, and lakes in the watershed. This demand is determined for study year and future growth projections.

Q_{Supply} = Monthly surface water supply calculated as monthly median flow within the watershed using the flow measured at a stream gauge or prorated from nearby gauge.

$Q_{\mathrm{Re}\,serve}$ = Surface water reserve is estimated, at a minimum, as the 10th percentile of monthly median flow.

An estimate of stress is required for existing water demand and future demand for the average flow conditions. Section 5.1 describes how the two water demand estimates were calculated. Average hydrologic conditions in the subcatchment are evaluated for potential stress by applying equation 2. The stress calculation is completed on the Sawguin Creek subcatchment.

Equation 2 is not employed to determine the stress level under the two drought conditions. Rather, the stress level under drought conditions is assessed following the Technical Rules where a Moderate Stress is assigned to the intake if at any time during the 2-yr or 10-yr drought scenarios the intake is exposed or water usage must be suspended. For this determination to be made, one needs to know the intake details (elevation of invert, obvert) and the response of the lake levels to the varying hydrologic conditions. The drought investigation is focussed on the Roblin Lake study area. The hydrologic model and bathymetry mapping provide necessary information to estimate lake levels during the two drought periods.

The two drought scenarios are defined in Section 3.4.

3.7. Determination of Uncertainty

Measurements of precipitation and streamflow are accurate within limits. These limits define what is called the uncertainty of the stated value. Perhaps even more uncertain would be the value stated for groundwater inflow as this is much more difficult to measure. The Sawguin Creek subcatchment has no streamflow gauge and estimates of streamflow are generated using the hydrologic computer model by comparing results with those from nearby gauged subwatersheds. This also introduces some uncertainty into the values.

Precipitation is measured at discrete points and this point measurement is transferred to other areas within a catchment assuming the rainfall was evenly distributed across the catchment. The rain gauge itself will have an error associated with its ability to measure the precipitation accurately. Snow measurements are also difficult to make with high levels of confidence.

Depending on the method of measurement or estimation of a parameter and depending on the combinations of parameters used in a calculation uncertainty in the stated value can be very high, perhaps as much as 50% in the calculation of discharge by modelling methods (Watt and Paine, 1991).

Section 7 considers the uncertainty in the data and methods of estimation of the reported values.

4. Surface Water Model

Quinte Conservation operates a surface water model based on the GAWSER platform for the Moira, Salmon, and Napanee watersheds but did not have a working model for the Prince Edward County area including the Sawguin Creek subcatchment. Schroeter and Associates was retained by Quinte Conservation under the source protection program to complete a hydrologic model for the Sawguin Creek subcatchment.

A hydrology report was prepared by Schroeter and Associates and is contained in its entirety within Appendix C. However, a short synopsis is presented in this section.

4.1. Model Development

Quinte Conservation GIS department supported this work by providing input data to the model. Prince Edward County was subdivided using a digital elevation model to determine subcatchments for them many small creek systems. This model included more subcatchment areas than required for the Tier 2 work as it was originally commissioned for assistance with the Tier 1 water budget.

Map 4.1 shows the subcatchments and provides catchment numbers developed for the model. The line diagram for the model has been included in Appendix C to assist the reader in identifying catchment names. The Sawguin Creek subcatchment is represented by areas 504. 505, and 506. Roblin Lake is represented by area 505.

To account for the wide variation in runoff generation response attributed to the different land cover features and soil types (e.g. source areas), the subcatchment elements were further subdivided into nine 'hydrologic response units' (HRUs); one impervious and eight pervious. These HRUs are developed within the GIS framework by overlaying the soil-type and land cover information. Within the Quinte Region watersheds, the nine most common land cover/soil type groupings determined the HRUs applied in the model. The GIS was also used to assist in finding the length and slope of channel routing reaches, length of the longest tributary within each subcatchment element, drainage areas, and the surface areas for major modelled lakes. Map 4.2 shows the coverage for the HRUs. Urban areas were assumed to have 35% impervious cover, and the remaining pervious areas were assigned to response units with low vegetative cover.

Map 4-1: Subcatchments Used in Hydrologic Model – PEC

Map 4-2: Prince Edward County Response Units

Map 4-3: Meteorological Gauging Stations in Quinte Region

Meteorological data were extracted from Meteorological Services of Canada (MSC) stations shown in Map 4.3 and processed by Schroeter and Associates to develop continuous data sets for model application.

Roblin Lake acts as a reservoir and has been incorporated into the model assuming log operations are made in spring and fall. Winter conditions have two logs in place and summer would begin with five logs.

4.2. Model Verification

Once the model was constructed several events were simulated and compared with nearby gauging stations to confirm that outflows were reasonable. Water budget summaries were also reviewed to provide assurance that evapotranspiration results were well modelled. Adjustments were made to model inputs through parameter adjustment factors to provide good agreement between measured and modelled flows for all gauges with the model running in both continuous and event modes.

The interested reader is referred to Appendix C for more details regarding the model verification/validation process.

5. Refinement of Inputs

In the earlier water budget work it was found that, during the months of August and September, there would be potential for stress in the Ameliasburgh Subwatershed of 28% and 31% respectively. This rises to 32% and 36% in future water use condition.

However, we have narrowed the focus of the current study to the extent of the Sawguin Creek subcatchment and directed our efforts to review and refine the data used to make the stress assessments.

The following sections review inputs starting from the original Tier 1 boundary and focus in to the Tier 2 study area. They have been presented in this way to provide the reader a more complete picture of the setting.

5.1. Water Use

The calculation of stress is dependant upon the amount of permitted water use (refer to equation 1). All valid permits were reviewed in the subwatershed and these are listed in Table 5-1 below. Eight valid surface water permits were found in the Ameliasburgh subcatchment and all but one were within the Sawguin Creek subcatchment. Map 5.1 shows the location of the permitted water takings.

Table 5-1: Summary of All Permits to Take Water – Ameliasburgh Subwatershed

Permit No.	Location	Purpose
00-P-4042	Tributary to Mellville Creek	Wildlife Conservation
92-P-4021	Source area to Sawguin Creek	Wildlife Conservation
97-P-4039	Tributary of Sawguin Creek	Wildlife Conservation
97-P-4049	Tributary to Sawguin Creek	Wildlife Conservation
04-P-4024	Roblin Lake	Municipal
81-P-4026	Sawguin Creek	Municipal
5560-6F7NU9 *	Sawguin Creek	Irrigation
03-P-4067 *	Sawguin Creek	Irrigation

* The latter two permits were not in the earlier PTTW database and water budget assessments but were obtained recently

The PTTW database may not always be up to date and one cannot always be sure all valid permits are listed. Quinte Conservation had knowledge of two permits within the Sawguin Creek subcatchment that were not listed. When specifically requested, the Ministry of Environment was able to provide the information for the two permits.

It is acknowledged that different water uses vary in their degree of water consumption. An example would be a water bottling operation that removes all the water from the watershed and would therefore have a consumptive factor of 1 while aggregate washing is thought to return 75% of the water thereby having a consumptive factor of 0.25. The table below shows all the consumptive factors for each category of surface water use.

Table 5-2: Surface Water Consumptive Factors

Category	Specific Purpose	Consumptive Factor
Agricultural	Other - Agricultural	0.8
Commercial	Golf Course Irrigation	0.7
Dewatering	Pits and Quarries	0.25
Industrial	Aggregate Washing	0.25
Industrial	Manufacturing	0.25
Miscellaneous	Wildlife Conservation	0.1
Water Supply	Municipal	0.2
Water Supply	Other - Water Supply	0.2

5.1.1. Review of Water Taking Permits

The eight valid permits to take water in the Ameliasburgh subcatchment were reviewed in more detail to develop a reliable estimate of consumptive water use. Four of these permits are for wetlands (wetlands that have been constructed or modified for wildlife habitat enhancement), two are for municipal water use and two are for agriculture (irrigation).

Wildlife Conservation permits were excluded from the stress calculation as our experience in Prince Edward County has shown that inclusion of the consumptive water takings for wetlands based on their permitted amounts introduces extraordinary stress values for all subwatersheds. Constructed wetlands are usually located in headwater areas and often where soils are near saturation. They capture runoff in large melt or rain events and slowly release water back to the system. Their effect is to reduce peak discharges from rapid runoff and increase the volume that shows up later as baseflow.

The remaining four permits are discussed individually.

Permit 81-P-4026 was issued for a communal drinking water system for Fenwood Gardens and has no expiry date. Due to supply and quality issues, municipal water was piped to Fenwood Gardens from the Belleville water treatment plant in the early 2000s by extension of the Rossmore water main. The water taking in this permit has ceased and is not expected to be used in the foreseeable future. We have disregarded this permit.

Permit 04-P-4024 is for the municipal system in the Village of Ameliasburgh. It is an active permit and Quinte Conservation obtained the records of usage for the past three years (2006 to 2008). Average total water withdrawal was determined to be only approximately 20% of the permitted values. Per Table 5-2, actual consumptive use is 20% of the total withdrawal. Table 5-3 includes the annual water demand for 2006 to 2008 and Figure 5-1 shows the monthly consumptive water use calculated for Ameliasburgh municipal intake.

Table 5-3: Ameliasburgh Annual Water Demand

Year	Volume (m^3)
2006	27,421.0
2007	21,752.7
2008	21,019.6
Ave	**23,397.8**

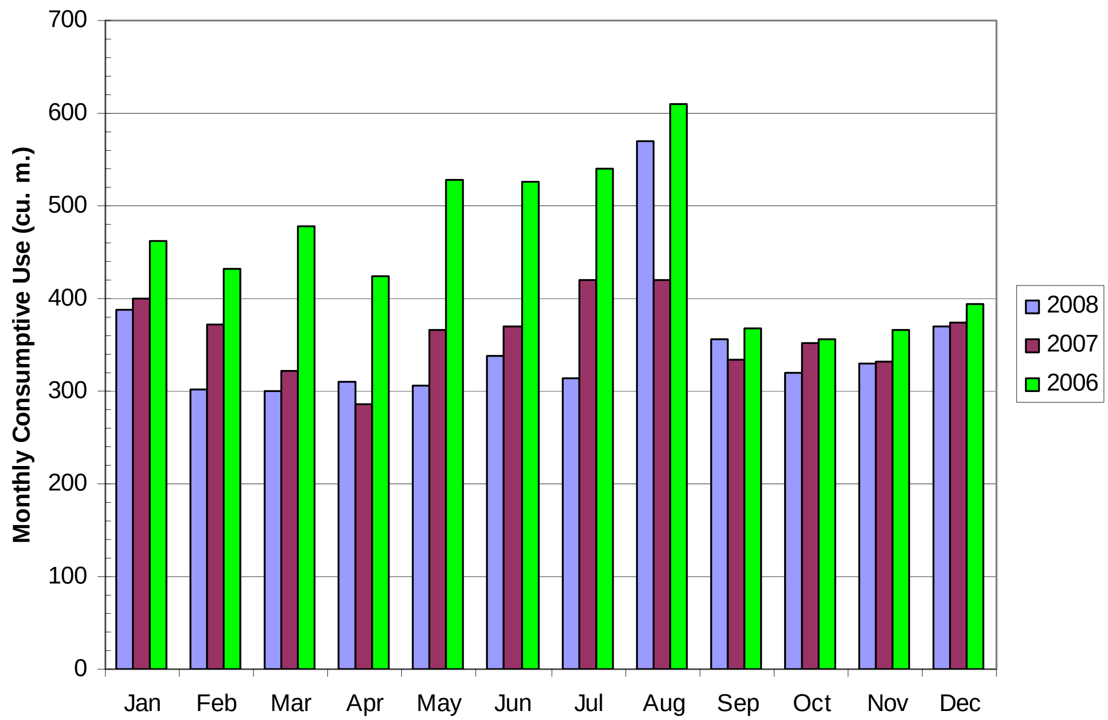

Figure 5-1: Ameliasburgh Consumptive Water Use – 2006-2008

Permit 5560-6F7NU9 is for irrigation. The pond receives overland flow during the spring freshet or large runoff events. The permit considers the taking as the filling of the pond. Maximum pond volume is13,230 m^3. This permit provides the user 307 L/min to a maximum of 441,632 L/day for 150 days in the spring freshet. It represents a potential taking of 10,600 m^3/month from January to May inclusive. Effectively, water is withdrawn in the spring and used later for spreading on the fields during dry periods in the summer. The impact of this type of taking is not expected to be significant and may be a benefit during low flow periods if the 20% that is not consumed (refer to Table 5-2) recharges groundwater or creek system. The permit holder was contacted and provided usage information in the form of annual totals. Since issuance of this permit in late 2005 only one year of taking was recorded in 2006. This is reported as 720,000 US gal or 2,725 m^3.

Permit 03-P-4067 is also issued for irrigation. This permit allows water withdrawal of 1136 L/min or 946,250 L/day from June 15 to September 15 for a total of 93 days per year. This represents a potential consumptive taking of approximately 23,500 m^3/month. Summer lowest median flow is in September with 3,800 m^3day (from Table 6-1) or 114,000 m^3/month. A taking of the entire permitted amount during September would represent 21% of the median flow. The permit holder was contacted and provided annual usage totals from 2003 to current. Two years (2004 and 2009) showed no usage. Highest year was

1,827,000 US gal or 19,000 m^3. Average annual use was calculated as 2,700 m^3 and highest annual usage was 6,915 m^3 in 2005.

Recorded water usage for both irrigation permits has been reproduced below in. Table 5-4 Usage was converted into cubic metres and summed.

Table 5-4: Records of Water Use for Irrigation Permits

Year	Permit 03-P-4067		Permit 5560-6F7NU9		Total
	Usage (U.S. Gal)	m^3	Usage (U.S. Gal)	m^3	m^3
2003	1071000	4050			4050
2004	0	0			0
2005	1827000	6920			6920
2006	14400	60	720000	2730	2790
2007	1359000	5140	0	0	5140
2008	747000	2830	0	0	2830
2009	0		0	0	0
Total	5018400	18900	720000	2730	21600
Average		**2710**		**680**	

In conclusion of the review of water usage, there are three active permits in Sawguin Creek; one municipal taking that has good actual monthly use records from Roblin Lake and two irrigation takings from Sawguin Creek for which only annual usage was provided. Monthly usage was estimated based on permitted periods. Consumptive use was calculated per criteria on Table 5-2.

5.1.2. Determination of Current and Future Water Demand

Stress calculations are performed for current demand and future demand based on Technical Rules.

Current demand is defined in the Technical Rules to be the study year (year before the terms of reference for completing the Source Protection Assessment Report were approved). The terms of reference were approved in 2008 and therefore the study year is 2007.

Water usage in Table 5-3 shows a declining demand from 2006 to 2008. The reasons for this is not known and the study team has used the average water demand instead of demand recorded in 2007 to define the current water demand conditions.

Future water demand is determined for the subwatershed considering growth of municipal demand only. All other water use is held constant. Future demand is estimated based on growth projections to the extent of municipal planning horizon. This is different than future projections used in Tier 1 where a 25 year projection was required. Census data from the Statistics Canada projects growth for Prince Edward County to be 1% per year. Quinte Conservation contacted Prince Edward County planning department to determine specific growth projections for the Hamlet of Ameliasburgh. In their 2003 Growth and Servicing Strategy Report Prince Edward County projects growth for Ameliasburgh in 2021 would be 380 to 405 persons from the current (2003) population of 325. Assuming 390 persons as a midpoint of the projection, one obtains a growth rate of 20% over 18 years. However, prorated to study year, 2007, the growth is calculated at 15% over 14 years (see Table 5-5). This is very close to the Statistics Canada projection. Future water use calculations are based on a 15% increase.

Table 5-5: Determination of Water Demand for Current and Future Conditions

	Growth Study Data	Study Year (Current Demand)	Future Demand
Year	2003	2007	2021
Population	325	339	390
Increase	NA	0	**15%**

Water budget calculations in the Tier 2 level are to be developed for a monthly time period. Monthly municipal usage is provided in Table 5-6 below.

Table 5-6: Comparison of Municipal PTTW Consumptive Use and Actual Consumptive Use

04-P-4024	J	F	M	A	M	J	J	A	S	O	N	D
Permitted Taking	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800
Actual Current Taking	2084	1843	1832	1698	1999	2057	2125	2667	1766	1715	1714	1896
Actual Current Consumptive	417	369	366	340	400	411	425	533	353	343	343	379
Future Consumptive	479	424	421	391	460	473	489	613	406	395	394	436

Note: All units are in m^3

5.1.3. Summary of Current and Future Subwatershed Water Demand

Water use has been determined for each of the two study areas.

First, the Sawguin Creek study area experiences the effects of all three permits. The summaries of water demand for Sawguin Creek are presented in

Table 5-7 for current and Table 5-8 for future water demand.

Table 5-7: Sawguin Creek Water Demand (m^3) – Current

PTTW	J	F	M	A	M	J	J	A	S	O	N	D
04-P-4024	417	369	366	340	400	411	425	533	353	343	343	379
03-P-4067	0	0	0	0	0	362	723	723	362	0	0	0
5560-6F7NU9	0	0	272	272	0	0	0	0	0	0	0	0
Total	**417**	**369**	**638**	**612**	**400**	**773**	**1149**	**1257**	**715**	**343**	**343**	**379**

Table 5-8: Sawguin Creek Water Demand (m^3) – Future

PTTW	J	F	M	A	M	J	J	A	S	O	N	D
04-P-4024	479	424	421	391	460	473	489	613	406	395	394	436
03-P-4067	0	0	0	0	0	362	723	723	362	0	0	0
5560-6F7NU9	0	0	272	272	0	0	0	0	0	0	0	0
Total	**479**	**424**	**693**	**663**	**460**	**835**	**1212**	**1337**	**768**	**395**	**394**	**436**

The second study area is Roblin Lake and the summaries of water takings are provided in Table 5-9 for both current and future water use conditions. Recalling the Roblin Lake study area assumes no water is returned to the lake, the study team has considered raw water withdrawals as a conservative approach to water demand.

Table 5-9: Roblin Lake Water Demand (m^3)

04-P-4024	J	F	M	A	M	J	J	A	S	O	N	D
Current	2084	1843	1832	1698	1999	2057	2125	2667	1766	1715	1714	1896
Future	2397	2119	2107	1953	2299	2366	2444	3067	2031	1973	1971	2181

5.2. Meteorological Data

5.2.1. Average Conditions

Since the hydrologic model used for the surface water modelling requires a time series of data that could not effectively be provided by the Forestry Services gridded data, data from climate stations collected by Meteorological Services of Canada were best suited for the model water budget development. Initially, a time series was developed from 1969 to 2005 based on water year (November 1 to October 31). Climate stations are shown on Map 4.3 and listed earlier in Section 3.2.

When considering drought periods it was concluded that the period did not include the years for which the 10-yr drought was anticipated by streamflow records. The meteorological dataset was increased to a period from 1950 to 2005. Missing data for some stations were provided by a Data Fill-in project by Schroeter and Associates discussed in Appendix C.

5.2.2. 2-yr and 10-yr Drought

The drought periods specified in the Technical Rules are to be determined from the meteorological data set. As discussed earlier, precipitation data measured at discrete locations scattered throughout a watershed may not accurately represent depth of actual rain over the entire watershed. Rain events are not evenly distributed spatially. However, precipitation that falls on a subwatershed in a pattern that is unevenly distributed is integrated by runoff response and recorded as streamflow as it leaves the subwatershed. Streamflow provides an important check on the selection of drought period.

By inspection of the precipitation records (see Appendix A), we found the lowest 10-yr precipitation period for the region was November 1, 1956 to October 31, 1966 which was accurately predicted by the stream gauge data. Mountainview's 10-yr low period varied from that for the region and covered the period from November 1, 1961 to October 1, 1970. However, the drought period for the region was selected.

The 2-yr drought period was determined in the same way by averaging all six precipitation stations and was found to be years 1963 and 1964.

Table 5-10 below has been extracted from the hydrologic modelling report contained in Appendix C to show the periods of drought determined at each precipitation station. The final drought period was selected by averaging all the stations. This was also compared to Trenton Airport where the same period was determined.

Table 5-10: Summary of Precipitation Amount for Selection of Drought Years

Climate Station	***1950-2005 Mean Annual***	***1950-2005 Minimum***	***1950-2005 Maximum***	***Minimum 2 Years***	***Minimum 10 years***
Bancroft	910	660 (1964)	1260 (1999)	700 (1963-1964)	780 (1956-1965)
Cloyne Ontario	860	620 (1961)	1170 (1996)	620 (1963-	690 (1955-

Hydro				1964)	1964)
Madoc	920	740 (1982)	1140 (1955)	770 (1982-1983)	870 (1957-1966)
Frankford MOE	870	580 (1963)	1180 (1986)	670 (1962-1963)	760 (1957-1966)
Belleville	880	680 (1989)	1120 (1955)	700 (1988-1989)	780 (1961-1970)
Mountainview	880	600 (1963)	1100 (1976)	640 (1963-1964)	750 (1961-1970)
6 Station Average	890	680 (1963)	1070 (1996)	700 (1963-1964)	780 (1957-1966)

Note: The model used Water Years for the calculation. This would be from November 1 to October 31. For example, the 1963 water year is from November 1, 1962 to October 31, 1963.

Figure 5-2 below presents graphically how the dry periods were identified using the example of Mountainview station. The vertical axis records the annual precipitation and the horizontal axis the year. Drought years were revealed by calculating a moving average of two and ten consecutive years of annual precipitation. The lowest point on each of the 2 and 10-yr moving averages revealed the last year of the drought period. The 5-yr moving average was also included in the chart for comparison.

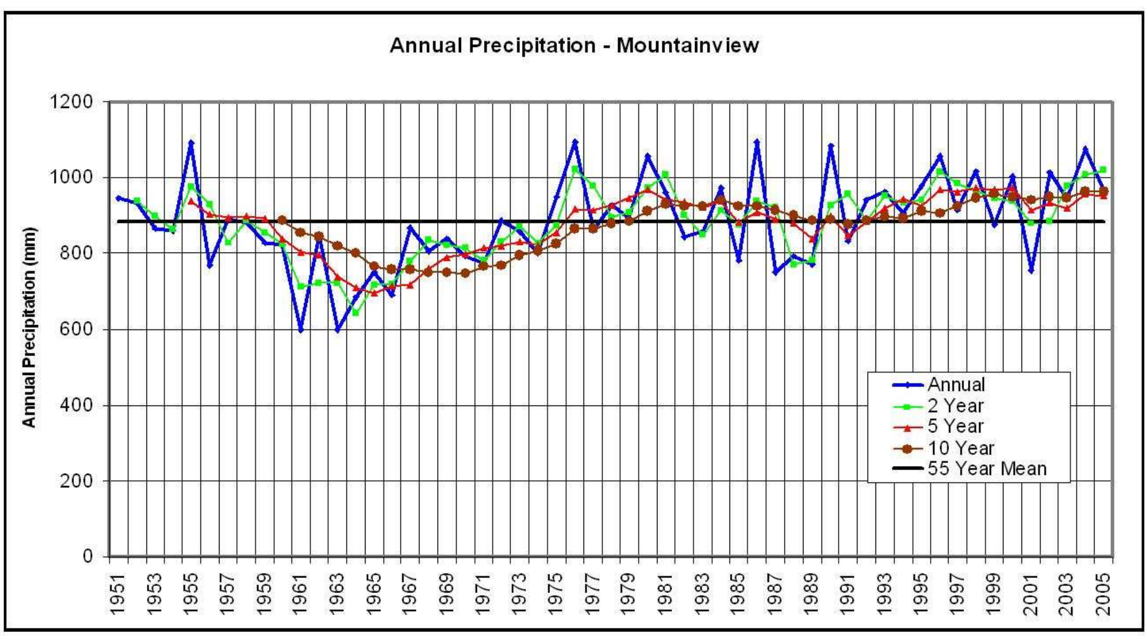

Figure 5-2: Annual Precipitation for Mountainview with Moving Averages

As a check on the drought periods determined from precipitation gauges, a comparison was made to stream gauge data. Stream gauges measure output from a catchment that in effect integrates precipitation depths over the watershed. The drought periods were confirmed in this way. The stream gauge locations are included on Map 5.2.

10-yr Drought

A review of Moira River at Foxboro (02HL001) reveals the lowest 10-yr flow period is 1957 to 1966. The same low flow period was found in Napanee River at Napanee (02HM001) showing the region experienced lowest runoff during the drought period. The nearest stream gauge to Sawguin Creek subcatchment is Consecon Creek (02HE002). It has a period of record from 1969 to current which did not date back to the longest period of drought. Three figures below show the 10-yr moving average of the streamflow records for Moira River (Figure 5-3), Napanee River (Figure 5-4), and Consecon Creek (Figure 5-5).

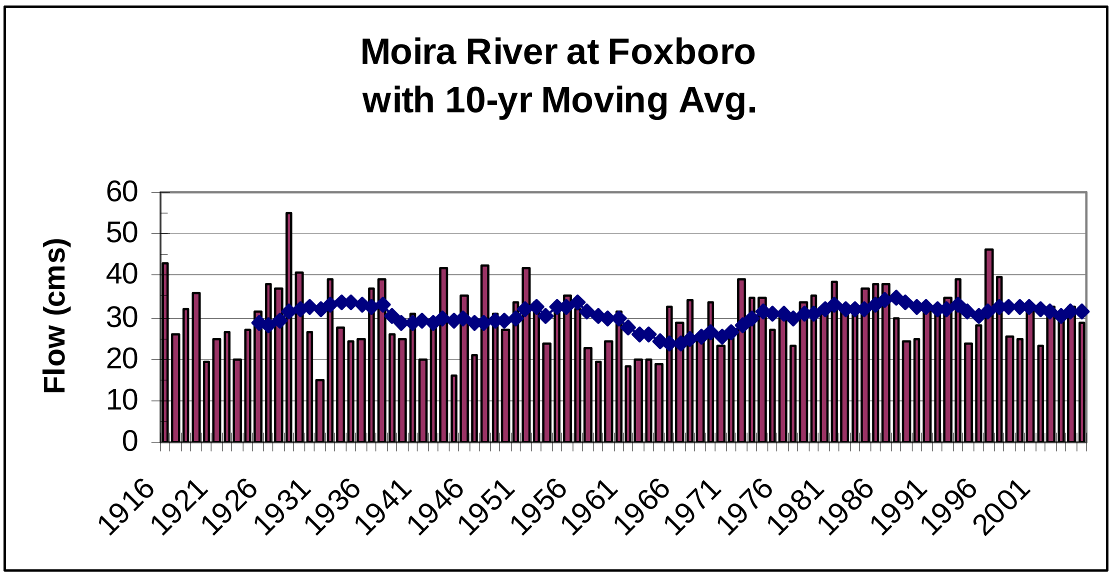

Figure 5-3: Moira River @ Foxboro Mean Annual Flows and 10-Yr Drought

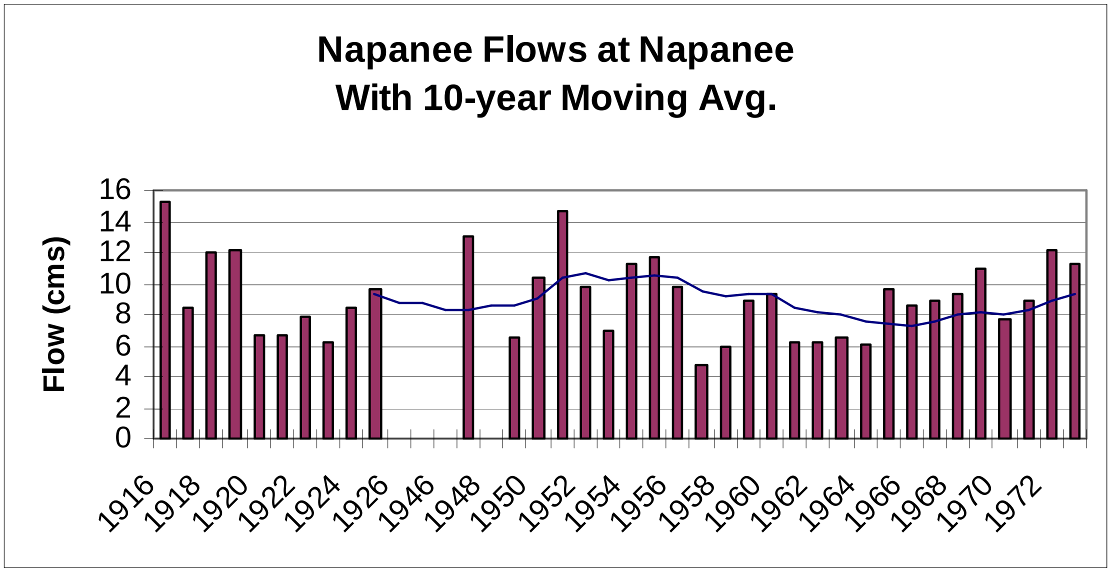

Figure 5-4: Napanee River @ Napanee Mean Annual Flows and 10-Yr Drought

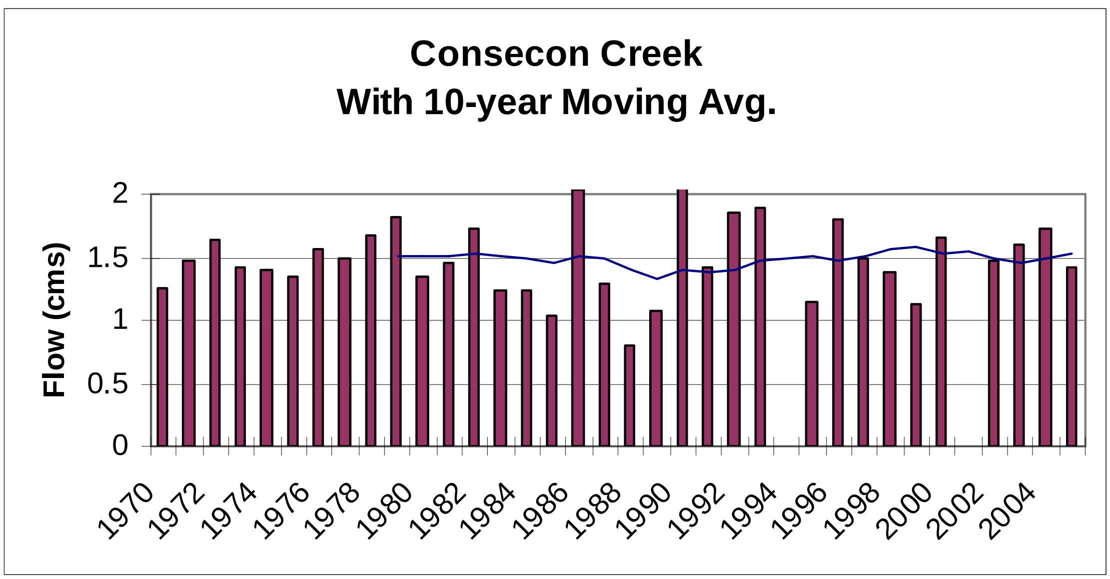

Figure 5-5: Consecon Creek @ Allisonville Mean Annual Flow and 10-Yr Drought

The drought periods shown in Table 5-10 were confirmed and the average of all stations values was used in the drought analysis. These are again,

- 2-year drought = 1963 – 1964
- 10-year drought = 1957 – 1966

5.3. Evapotranspiration

In the GAWSER program, there are two approaches for estimating the potential evapotranspiration (PET). The first method uses a table of lake (or other potential) evaporation estimates (see Table 5-11 and Table 5-12) to assign daily rates for each day of the year. This method is referred to as the 'climatological' approach. The second procedure uses the Linacre formula directly. The main advantage it has over the climatological approach is that PET estimates can be immediately linked to position on the ground (through latitude and elevation), and air temperature. The ETFAC factor allows for the Linacre formula to be calibrated for local conditions, which is a fairly common approach in all PET estimates, as noted in the sample documents by Bautista et al. (2009); Weiss and Menzel (2008), and Saxton and McGuiness (1982). The Linacre formula has been operational in GAWSER since 1991, but has only been reported in water management studies within the last 10 years. Since then, the Linacre approach in GAWSER has been applied in more than 20 watershed studies, where the value of ETFAC has been in the range of 0.54 and 0.60 for southern Ontario watersheds.

In a typical GAWSER application, the climatological method is usually employed first until there is reasonable agreement between the annual totals given in several climate reports (see OMNR, 1984; McKay et al. 1974). Then, the Linacre approach is switched on, and the ETFAC is adjusted (if need be) until the mean annual actual ET values from both methods are in agreement.

Table 5-11: Pan Evaporation Measurements

Monthly distribution of lake evaporation at selected locations in southern Ontario													
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Windsor	18	18	18	84	117	133	145	122	81	52	35	20	843
Harrow	18	18	18	101	129	148	154	128	93	66	35	20	928
Ridgetown	18	18	18	85	118	131	150	122	89	58	35	20	862
Langton	18	18	18	90	124	138	155	138	88	36	35	20	878
Delhi	18	18	18	85	116	133	142	118	80	49	35	20	832
Simcoe	18	18	18	90	120	139	152	127	89	53	35	20	879
Hamilton	18	18	18	98	111	125	144	123	81	46	35	20	837
Guelph	15	15	15	80	122	138	147	118	78	48	30	18	824
Elora	12	12	12	78	117	133	143	117	75	43	30	18	790
Blue Springs	12	12	12	70	100	115	140	112	72	42	30	18	735
Hornby	12	12	12	70	111	125	151	129	80	49	30	18	799
Burketon	12	12	12	75	94	120	128	109	67	43	30	15	717
Bowmanville	12	12	12	75	115	124	142	119	77	48	30	15	781
Lindsay	10	10	10	70	118	131	150	146	80	45	30	15	815
Morven	10	10	10	50	115	114	145	135	80	49	25	15	758
Hartington	10	10	10	50	102	116	138	120	73	43	25	12	709
Kemptville	10	10	10	35	123	125	130	113	71	49	20	12	708
Ottawa	10	10	10	35	113	131	141	112	73	41	20	12	708
Notes: 1. values taken from pan evaporation measurements summarized in AES documents.											2. Amounts given in mm		

Table 5-12: Daily Potential Evapotranspiration Rates

Daily Potential Evaporation & Evapotranspiration Rates													
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Windsor	0.58	0.64	0.58	2.80	3.77	4.43	4.68	3.94	2.70	1.68	1.17	0.65	2.31
Harrow	0.58	0.64	0.58	3.37	4.16	4.93	4.97	4.13	3.10	2.13	1.17	0.65	2.54
Ridgetown	0.58	0.64	0.58	2.83	3.81	4.37	4.84	3.94	2.97	1.87	1.17	0.65	2.36
Langton	0.58	0.64	0.58	3.00	4.00	4.60	5.00	4.45	2.93	1.16	1.17	0.65	2.40
Delhi	0.58	0.64	0.58	2.83	3.74	4.43	4.58	3.81	2.67	1.58	1.17	0.65	2.28
Simcoe	0.58	0.64	0.58	3.00	3.87	4.63	4.90	4.10	2.97	1.71	1.17	0.65	2.41
Hamilton	0.58	0.64	0.58	3.27	3.58	4.17	4.65	3.97	2.70	1.48	1.17	0.65	2.29
Guelph	0.48	0.53	0.48	2.67	3.94	4.60	4.74	3.81	2.60	1.55	1.00	0.58	2.26
Elora	0.39	0.42	0.39	2.60	3.77	4.43	4.61	3.77	2.50	1.39	1.00	0.58	2.16
Blue Springs	0.39	0.42	0.39	2.33	3.23	3.83	4.52	3.61	2.40	1.35	1.00	0.58	2.01
Hornby	0.39	0.42	0.39	2.33	3.58	4.17	4.87	4.16	2.67	1.58	1.00	0.58	2.19
Burketon	0.39	0.42	0.39	2.50	3.03	4.00	4.13	3.52	2.23	1.39	1.00	0.48	1.96
Bowmanville	0.39	0.42	0.39	2.50	3.71	4.13	4.58	3.84	2.57	1.55	1.00	0.48	2.14
Lindsay	0.32	0.35	0.32	2.33	3.81	4.37	4.84	4.71	2.67	1.45	1.00	0.48	2.23
Morven	0.32	0.35	0.32	1.67	3.71	3.80	4.68	4.35	2.67	1.58	0.83	0.48	2.08
Hartington	0.32	0.35	0.32	1.67	3.29	3.87	4.45	3.87	2.43	1.39	0.83	0.39	1.94
Kemptville	0.32	0.35	0.32	1.17	3.97	4.17	4.19	3.65	2.37	1.58	0.67	0.39	1.94
Ottawa	0.32	0.35	0.32	1.17	3.65	4.37	4.55	3.61	2.43	1.32	0.67	0.39	1.94
NOTE: Rates given in mm/day													

Thornthwaite method has not been programmed into GAWSER primarily because the method does not work well during cold months (see Whiteley, 2008).

It should be re-enforced, that once PET is determined, the major control on the actual ET is the available supply of water, and this is controlled by the input precipitation and the infiltration (or loss) model.

Annual evapotranspiration losses for Sawguin Creek subcatchment over the period 1950 to 2005 is estimated at 552 mm in the hydrologic model (see Table 6-2 following) as compared to 602 mm by the GIS methodology used in the Tier 1 work for period of record 1971 to 2000 precipitation and temperature gridded data.

6. Water Budget Results

Results from the hydrologic model are presented in this section including the evaluation of stress for the hydrologic conditions noted in Section 3.4. The modelled outflows of Sawguin Creek at the outlet (highway #62 crossing) are shown graphically on Figure 6-1 along with Roblin Lake inflows and outflows. These have been reduced to dimensionless values by converting to mm depth of runoff for comparison. Figure 6-2 shows the results of the most critical drought scenario – the 2-yr drought.

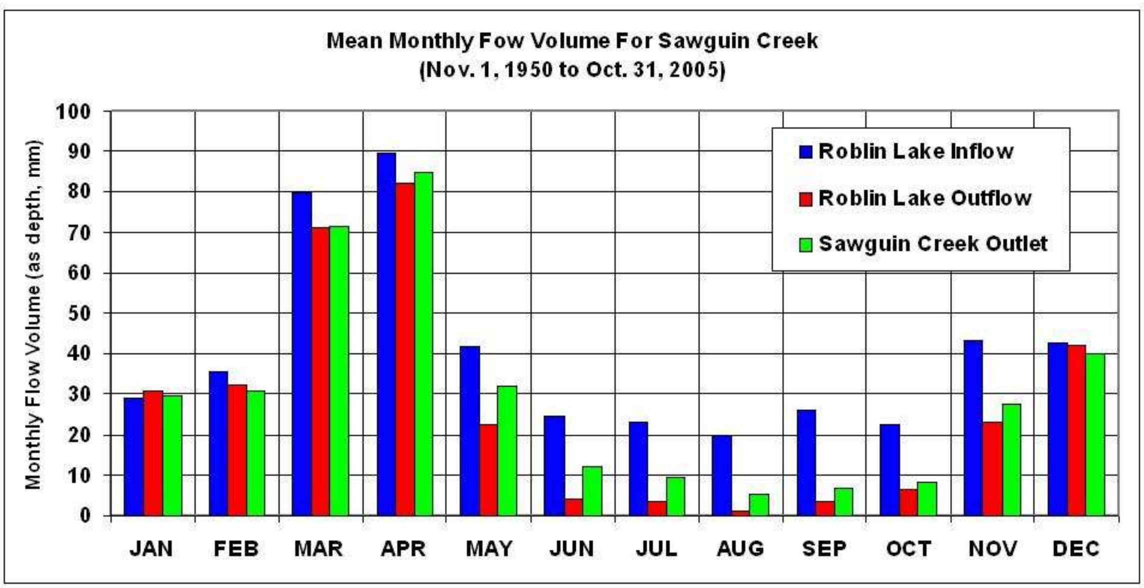

Figure 6-1: Mean Monthly Flows for Sawguin Creek and Roblin Lake – Average Hydrologic Conditions

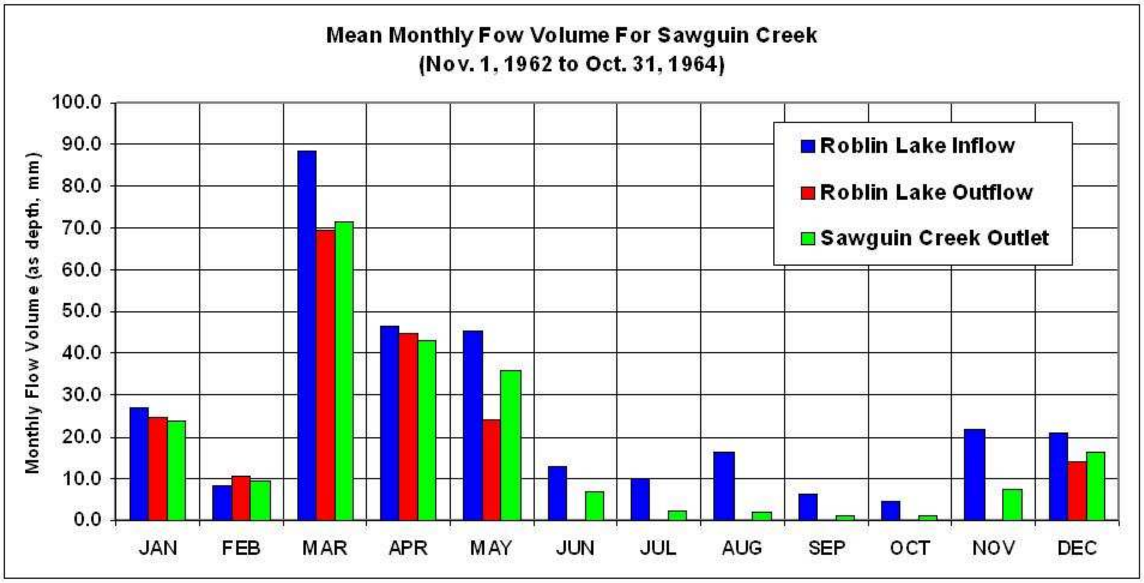

Figure 6-2: Mean Monthly Flows for Sawguin Creek and Roblin Lake – 2-Yr Drought Hydrologic Conditions

6.1. Model Output for Node 2506 – Sawguin Creek

Table 6-1 contains the flow summary for the model output of Sawguin Creek at Highway 62 (see Map 2.2). Median flows are understood as the 50% duration flows. Reserve flows used in the water budget (equation 2) are understood as the 90% duration flows.

Table 6-1: Sawguin Creek Modelled Flows – Average Hydrologic Conditions

Month	Mean	Highest	Lowest	Median	Reserve
JAN	0.61	15.1	0.02	0.24	0.15
FEB	0.75	19.9	0.01	0.20	0.13
MAR	2.18	23.0	0.01	0.83	0.19
APR	1.92	25.4	0.05	0.62	0.27
MAY	0.40	18.3	0.01	0.19	0.04
JUN	0.06	7.6	0.00	0.02	0.00
JUL	0.08	13.6	0.00	0.00	0.00
AUG	0.06	7.2	0.00	0.01	0.00
SEP	0.09	10.5	0.00	0.01	0.00
OCT	0.12	20.8	0.00	0.03	0.01
NOV	0.50	16.4	0.00	0.17	0.01
DEC	0.83	22.5	0.01	0.27	0.12
Annual	0.63	25.4	0.00	0.15	0.00

Note: All flows given in m^3/s

The hydrologic model also has the capability to produce a water budget summary for the subcatchment and this has been included as Table 6-2 below. Total annual precipitation is 892 mm. Of this 517 mm is lost to evapotranspiration and 375 mm leaves the system as runoff during an average year. The lowest months for runoff are June to September having only 3 to 4 mm of runoff. Highest month is March with 109 mm of runoff. Highest month for evapotranspiration is June with 99 mm and lowest months are December to March with 7 to 8 mm of actual ET. Precipitation varies from about 60 mm to 100 mm. Highest precipitation depths are November and December.

Table 6-2: Water Budget Summary for Sawguin Creek 1950 to 2005

Month	Rainfall	Snowfall	Precip	ActualET	TotalFlow	Runoff	Baseflow	NetStor
JAN	28	51	79	8	31	21	10	40
FEB	32	30	61	7	34	26	8	21
MAR	51	21	72	8	109	99	11	-45
APR	75	7	82	45	94	83	12	-57
MAY	71	0	71	98	20	13	7	-48
JUN	57	0	57	99	3	2	1	-45
JUL	66	0	66	69	4	3	1	-7
AUG	71	0	71	64	3	3	0	3
SEP	77	0	77	53	4	3	1	20
OCT	63	1	64	39	7	4	2	18
NOV	83	18	100	19	25	19	6	57
DEC	55	37	92	7	42	32	10	43
Total	727	165	892	517	375	307	68	0

Note: All units are in mm depth

Percent Water Demand Calculation

From equation 2, the percent water demand on the Sawguin Creek subcatchment is calculated using median and reserve flows obtained from the model and water demand determined from actual consumption. The calculation results are summarized in

Table 6-3 below.

Stress during average hydrologic conditions varies from a low of 0% in winter and spring months to a high of 12% in July with current municipal usage. In Future usage conditions the percent water demand rises slightly in the same month to 13%. A Low stress is indicated during Average conditions.

Table 6-3: Percent Water Demand – Average Hydrologic Conditions

Month	Flow (cms)		Demand (L/s)		Stress (%)	
	Q_{Supply}	$Q_{Reserve}$	Current	Future	Current	Future
Jan	0.23	0.15	0.2	0.2	0	0
Feb	0.19	0.12	0.2	0.2	0	0
Mar	0.83	0.18	0.2	0.3	0	0
Apr	0.60	0.24	0.2	0.3	0	0
May	0.18	0.04	0.1	0.2	0	0
Jun	0.02	0.00	0.3	0.3	2	2
Jul	0.00	0.00	0.4	0.5	12	13
Aug	0.01	0.00	0.5	0.5	5	6
Sep	0.01	0.00	0.3	0.3	3	3
Oct	0.03	0.01	0.1	0.2	1	1
Nov	0.16	0.01	0.1	0.2	0	0
Dec	0.25	0.12	0.1	0.2	0	0

Stress Assessment for 2-Yr and 10-Yr Droughts

Water availability is decreased during drought periods. Precipitation depth for the two drought periods are summarized in Table 5-10 earlier. The 2-yr drought calculation (Nov 1962 – Oct 1964 water years) shows a decrease in water availability to 700 mm on average across the Quinte Region. Water availability during the 10-yr drought (Nov 1956 – Oct 1966) rises to 780 mm across the region.

To determine stress on the subcatchment during drought periods the impact of the drought on the lake levels must be forecasted and compared to the known elevations of the intake structure. Only a Moderate or Low stress can be assigned. A moderate stress would be indicated if the intake is exposed or pumping must be suspended during the drought.

The exact elevation of the intake could not be confirmed by the municipality. However, they were able to provide the length and size of the intake pipe and by comparing to the bathymetry data we estimate the elevation of the invert to be 3.0 metres below top of water (at time of survey water level was 110.54 m) and obvert would be 1.93 m below top of water. The critical water elevation is then 110.54 – 1.93 = 108.6 m. If the water level approaches this elevation the municipality would experience difficulty with supply.

Roblin Lake was modelled within the hydrologic model for the two drought conditions as well as for the average conditions. An estimate of lake level was provided based on the dam settings for winter and summer conditions. The following Figures 6-3, 6-4, and 6-5 show the estimated lake levels for Average, 2-

Yr and 10-Yr drought conditions respectively. Lowest water mean water elevation is experienced during the months of September or October reaching as low as 109.9 m in October during the 2-Yr drought. This is about 1.3 metres higher than the estimated top of the intake structure.

Water usage from the lake must also be considered in determining if the intake would be exposed. A conservative approach would be to look at raw water withdrawals from the lake. The monthly totals were provided in Table 5-6. The total depth of water withdrawal is determined by dividing raw water withdrawal by the lake area of 1 km^2. Amounts would be in the 2-3 mm range for the highest monthly water taking in August. Again, a conservative approach would be to consider the annual withdrawal and subtract this amount from the total depth of water over the intake found above. Annual withdrawal totals 23,400 m^3. This is in the order of 25 mm depth over the lake. With the annual water usage considered during existing and future conditions the cover over the intake would be above 1.28 metres (Figure 6-3).

The mean values represent mean monthly water level. Upper and lower lines on the charts show the maximum and minimum lake level determined from the hourly simulations. These are provided to ensure fluctuations of high and low days within the mean would not expose the intake. Recalling the critical elevation is 108.6, one can see from Figure 6-4 and Figure 6-5 that the intake is not exposed, nor would the pumping need to cease at the treatment plant during either of the two drought scenarios. A Low stress for drought conditions is indicated.

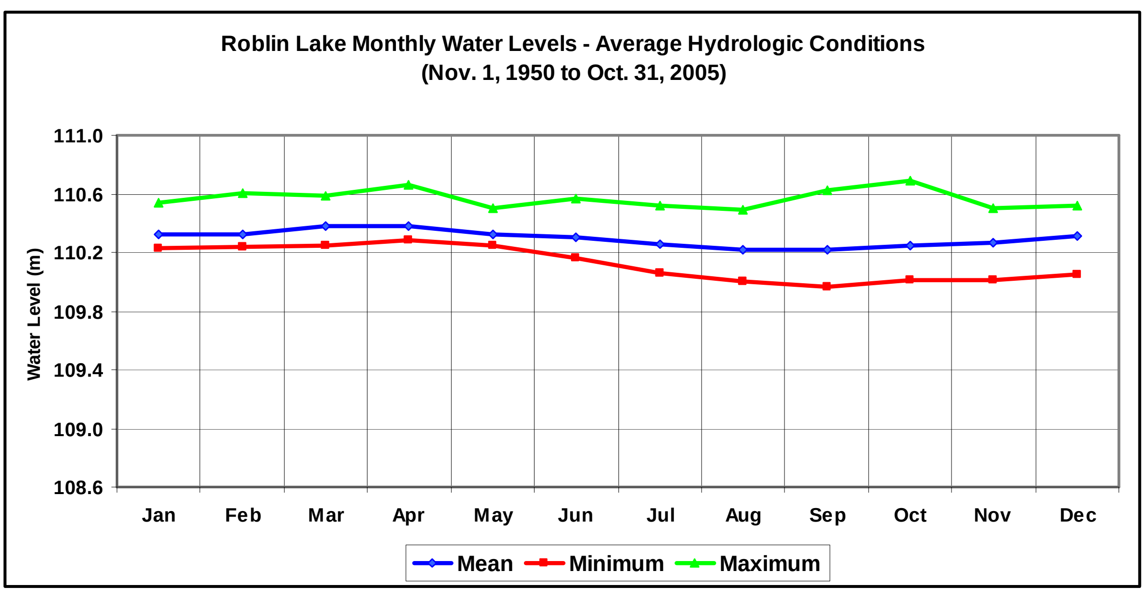

Figure 6-3: Roblin Lake Level – Average Hydrologic Conditions

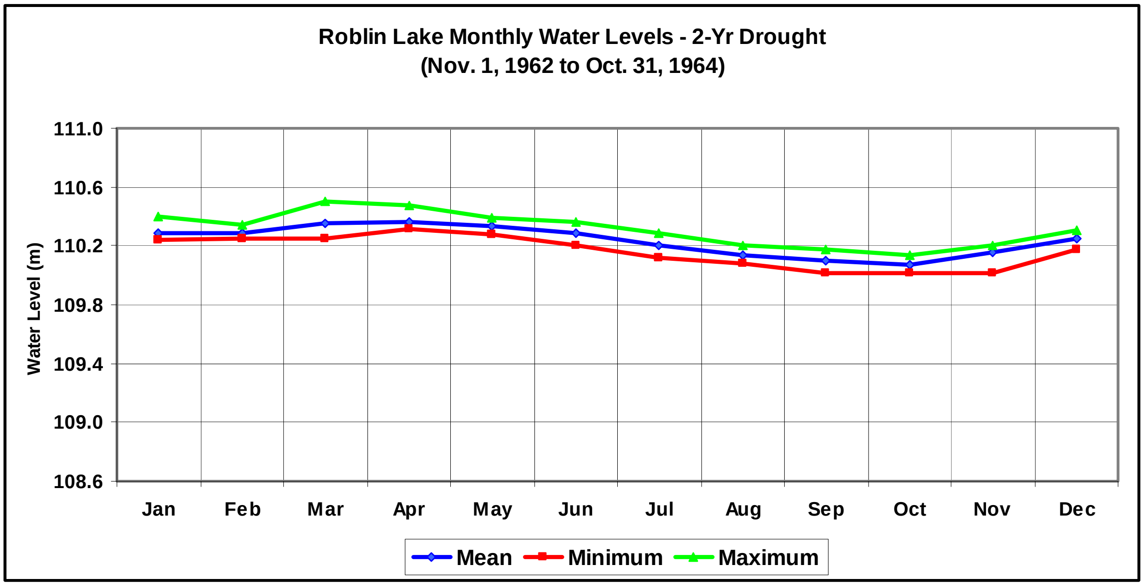

Figure 6-4: Roblin Lake Level – 2-Yr Drought

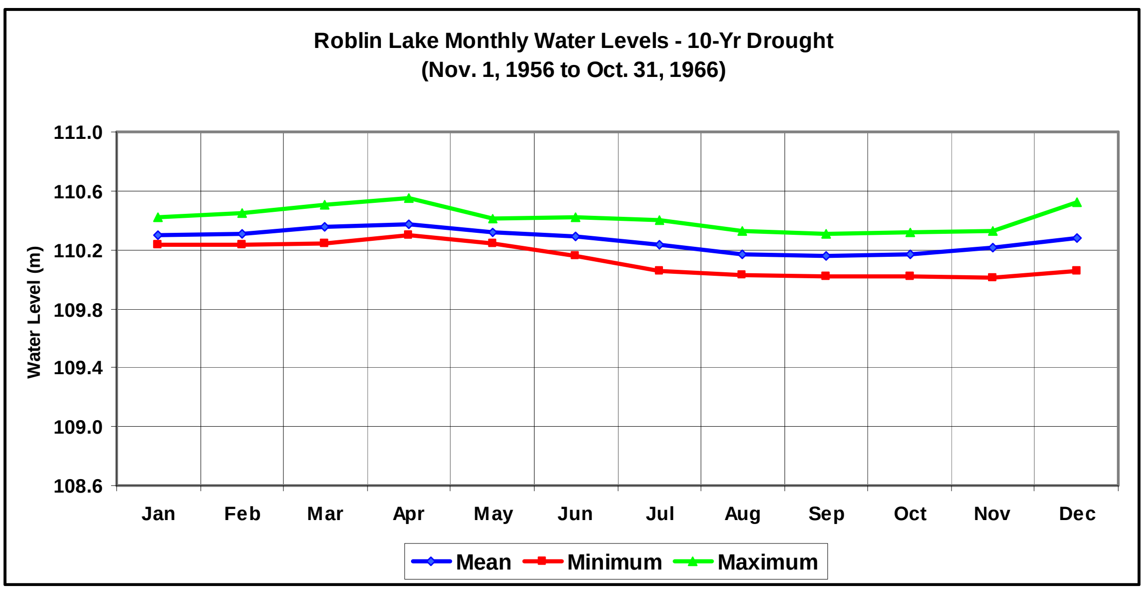

Figure 6-5: Roblin Lake Level – 10-Yr Drought

Maps 6.1 and 6.2 depict the results of the stress assessments for Sawguin Creek for current and future water use under Average hydrologic conditions.

Section 6.2 contains a more detailed review of groundwater conditions and considers the water availability in the lake with respect to surplus water and usage.

6.2. Groundwater Investigation

If there were groundwater discharges to the lake from outside the assumed contributing area it would have an effect on the water budget calculation and stress assignment (see equation 1). For the purpose of a Tier 2 water budget, it is assumed that groundwater divide is approximated by the surface water divide. Based on local knowledge, Quinte Conservation staff recognized there is some uncertainty as to the source of the Roblin Lake input. Local residents reported groundwater seeps in the lake.

There have been no recent reports of low lake levels that have disrupted municipal water taking. However, the small dam located at the lake outlet was found to have been constructed in 1992 to support lake levels for municipal water taking.

A better understanding of the interaction between surface and groundwater was necessary to guide the water budget study. Golder Associates provided a hydrogeologic interpretation for this work. The complete Golder report is included in Appendix B.

Map 6-1: Stress – Existing Water Demand

Map 6-2: Stress – Future Water Demand

Golder completed a 3-D numerical groundwater model of an 11 km x 11 km area approximately centring on the lake. They obtained soils and bedrock geology information from GIS layers provided by the Ministry of Natural Resources through Land Information Ontario. This information was supplemented with water well records from the Water Well Information System.

Surficial contours were provided by Quinte Conservation obtained using LiDAR that assisted in developing the 3-D model. In addition, Golder obtained bathymetry information using sonar and GPS.

The hydraulic conductivity of the weathered limestone layers was inferred by falling head tests performed by Quinte Conservation hydrogeologist. A local pump test by Quinte Conservation staff determined the unweathered limestone had an inferred hydraulic conductivity of 5×10^{-7} m/s. Golder estimated that there is a total recharge to the lake from groundwater sources south of the lake of 215 m^3/day and total discharge from the lake to groundwater of 20 m^3/day.

Model setup was checked and adjusted to attempt to match observed groundwater elevations. Insufficient observed flow data was available to check discharges. Quinte Conservation staff also provided water level measurements for several shallow dug wells surrounding the lake.

Modelling results suggest that groundwater flow is from south to north toward the escarpment. Roblin Lake intersects the groundwater table several hundred metres south of the escarpment. Groundwater discharge to the lake is estimated to be 215 m^3/day and recharge from the lake to the rock is estimated to be 20 m^3/day occurring on the north side.

What does this mean for the stress assessment?
The inferred area of groundwater contribution was found to be very similar to the topographic divides. Golder's estimate of 195 m^3/day net groundwater discharge to the lake (see Appendix B) is compared to findings from Schroeter and Associates hydrologic model of approximately 39 mm/yr of "infiltration" (based on Outflow from Roblin Lake which takes into account conditions in the lake – see Table 6-4). Infiltration from the surface water model is intended to represent that portion of the precipitation that is measured at a streamflow gauge as slow runoff. It is interpreted as precipitation that recharges groundwater. The calculations for groundwater contribution are compared below.

Golder estimate of groundwater discharge to the lake
195 m^3/day x 365 days = 71,200 m^3/year

$$\frac{71{,}200\, {}^{m^3}\!/\!_{yr}}{3.6 km^2} = 20mm$$

Schroeter's Infiltration Estimate

$39 mm/yr$

Golder's calculated groundwater contribution to the lake is less than the value calculated by the surface water loss model. A volume of groundwater discharge from the Golder study that would have been much higher than the surface water model's estimate would suggest some "hidden" groundwater input is occurring. This is not likely the case.

This means that there is likely no large input of groundwater outside the inferred groundwater divide. The GWin term in the water budget equation 1, drops out of the equation and the water budget for the Sawguin Creek system remains as it is presented in Table 6-2.

Table 6-4: Water Budget Summary for Node 5505 – Roblin Lake Outflow for Average Hydrologic Conditions

Month	Rainfall	Snowfall	Precip	ActualET	TotalFlow	Runoff	Baseflow	NetStor
JAN	28	51	79	8	31	23	8	40
FEB	32	30	61	7	30	25	5	24
MAR	51	21	72	8	96	91	5	-32
APR	75	7	82	45	102	93	9	-64
MAY	71	0	71	95	12	10	2	-37
JUN	57	0	57	106	0	0	0	-49
JUL	66	0	66	85	0	0	0	-19
AUG	71	0	71	74	0	0	0	-3
SEP	77	0	77	56	0	0	0	22
OCT	63	1	64	39	12	11	1	14
NOV	83	18	100	19	21	19	2	60
DEC	55	37	92	7	40	34	7	44
Total	727	165	892	548	344	305	39	0

Note: All units are in mm depth

The conclusion is that there is adequate supply for the municipal use. The lake level is regulated by the dam and the capacity exists to ensure adequate supply for current and future needs.

No stress is indicated for the Sawguin subcatchment in any of the hydrologic conditions.

7. Uncertainty

The stress assessments are made using low values of water usage and water availability. Any uncertainty in the data or model methodology could result in significant changes in the stress calculation. In Section 7.1 the authors review sources of uncertainty and potential effect on reliability of the results of the modelling work. In Section 7.2 the modelled flows are compared to nearby surface water gauges to provide a level of confidence in the model results. Finally, in Section 7.3 the concluding statement of level of uncertainty in the stress assessment calculations is provided.

7.1. Uncertainty with Hydrologic Modelling and Data

In the previous Tier 1 work, the uncertainties in the data used in the computations were outlined in detail. The disagreement or uncertainty in the calculations is a product of the error within the data measurements and the methodology employed in the data manipulation. For the precipitation data, the potential error was conservatively estimated at 10%. Streamflow measurements were considered to be reliable to within 5%. The uncertainty also considered the standard error of the data. The total potential uncertainty within the water budget calculations was determined by taking the square root of the sum of the squares of the uncertainty for each value. In this regard, the uncertainty in the calculated actual evapotranspiration (AET) values was determined within 18%.

For the Tier 2 work reported here, a physically-based distributed hydrologic model was developed and applied for the monthly water balance calculations required in the risk assessments. Utilizing monthly values for hydrologic quantities, instead of annual totals as was done in the Tier 1 assessments, introduces additional uncertainties in the estimates. Because there is uncertainty associated with hydrologic modelling, the uncertainty should be accounted for in model application and evaluation (Harmel et al., 2007). Hydrologic modelling uncertainty involves model uncertainty caused by model structure and parameterization, and uncertainty inherent in natural processes, including input data errors. The representation of the watershed through finer spatial delineation of modelling elements (e.g. subcatchments, hydrologic responses units, and blocks of equivalent snow accumulation) helps to reduce the uncertainty associated with the over-simplification of the hydrologic processes by making better use of mapped information. The combined effect of all these factors is reflected in the model output, which consists of predicted flows and other hydrologic quantities (e.g. the water balance). Although the uncertainty associated with measured data used to calibrate and validate hydrologic models is generally acknowledged, measurement uncertainty is rarely included in the evaluation of model performance. As noted by Harmel et al. (2007), one reason for this omission is the general lack of information on the uncertainty associated with hydrologic data.

The most common objective measures of model of performance, such as the Nash-Sutcliffe model efficiency index, the root mean square error, and the mean absolute error all suffer from being overly sensitive to extreme values, and do not directly incorporate the uncertainty in measured data (Beven, 2000; McCuen et al., 2006; Harmel et al., 2007). Most experienced modellers recognize these deficiencies, and will inherently evaluate model performance qualitatively based upon a combination of intuition, judgement gained through the model building experience and the objective measures noted earlier. In this regard, the use of sensitivity testing is a valuable tool in the assessment procedures where the objective is to find out how sensitive the model output is changes in the input data. The inputs are then only adjusted by the amounts indicated in the error measurements.

For this purpose, we made a number of additional runs of the Prince Edward County portion of the overall Quinte Conservation hydrology model with adjustments primarily to model inputs, and presented the results as mean monthly flow volumes in Figure 7-1 together with the observed values. The adjustments made to the model are summarized below:

1. The results noted as 'Modelled-Dec 12' are those published in the previous draft of the report prior to the peer review meeting in December. This run uses the Linacre PET formula and the meteorological inputs from the Mountainview climate station. The modelled mean annual total flow volume of 387 mm is 1.4% less than the measured value of 392 mm.

2. The histogram labelled as 'Modelled Feb. 17' essentially represents the December 12 model with a change in the PET estimates. In this case, the 'climatological' procedure is applied using the Hartington Lake evaporation estimates given in Table 3. Although the mean annual ET was slightly reduced by 4.8%, the main impact of this adjustment was to increase the mean annual total flow volume by 4% (to 404 mm), reduce the day-to-day variations in the daily PET rates, and a slight change in the month-to-month totals of actual ET. Previously, using the Linacre formula, the actual ET for June, July and August were 99, 109, and 87 mm, respectively. With the change in PET modelling procedure, the actual ET amounts for the same months become, 106, 96, and 75 mm, respectively.

3. The results labelled as 'Modelled-Trenton A' are basically the Feb. 17 model with a complete change in meteorological input data. Here, the Mountainview data set has been replaced by the Trenton Airport dataset. The main effect of this adjustment was to increase the mean annual precipitation amounts by 1.3%, which included an increase in the mean annual snowfall for 3%. This change in the meteorological dataset caused the annual total flow volume to increase by 9%, with a slight decrease in the mean annual actual ET by 4%.

4. The histogram noted as 'Modelled-Picton' is the Feb 17 model with the Mountainview dataset replaced by the Picton dataset. The impact of this adjustment was to apply a climate dataset to the model that had 8.4% more precipitation, resulting primarily from an increase in mean annual snowfall of 42%. These increases in precipitation caused the mean annual total flow volume to increase dramatically by 26%.

5. The results labelled as 'Modelled-Mountainview V1' represent the Feb. 17 model, but with some minor adjustments to the monthly precipitation amounts in the Mountainview input dataset. These adjustments were suggested by re-examining the monthly precipitation amounts (both rainfall and snowfall) across Prince Edward County by comparing the monthly normals for the Bloomfield and Mountainview climate stations. These adjustments caused a slight increase in the mean annual total flow volume of 4%, with a slight decrease in the actual ET total of 5%.

6. The histogram plot labelled 'Modelled-Mountainview V2' is essentially the V1 model, but with a slight change in the monthly air temperatures. From a comparison of the Trenton A, Picton and Mountainview mean monthly air temperatures, it was inferred that the air temperatures across Prince Edward County could be lower than those indicated in the Mountainview records by about 0.4 C. From these adjustments, the mean annual total flow volume was within 1.5% of the observed value, and the agreement between the individual monthly volumes was much improved as noted in Figure 7-2. For the purpose later discussion, we will refer to this model result as 'Model 6'.

Upon examination of Figure 7-1, notice that each of the successive adjustments made to the model inputs had the effect of improving the agreement between the measured and modelled monthly flow volumes for some months, and worse in others. Clearly, the agreement between the observed and simulated flows is highly influenced by the meteorological input dataset (e.g. precipitation as snow and rainfall, and air temperatures). The best overall result appears to be those for 'Model 6'.

Earlier it was noted by Harmel et al. (2007), that the evaluation of model performance needs to take account of the uncertainty in the measured data. It is acknowledged that the uncertainty associated with measured physical inputs to the model, like drainage areas, soil type and land cover areas, channel cross-sections, and control structure characteristics is very low compared with streamflow and meteorological data. In our present application, there is uncertainty in the measured time-series of flows used to compare with model output, as well as uncertainty in the measured meteorological input data series used to drive the model. From the Tier 1 work, we know that the uncertainty in the precipitation data is about ±10%, incorporating sampling and measurement errors in the estimate. How does the uncertainty in the precipitation data influence the model output? This can only be assessed by running the model with the precipitation inputs being adjusted by the estimated uncertainties. Consequently, two additional runs were made of Model 6 with the precipitation amounts adjusted by ±10%. A decrease in the mean annual precipitation amount resulted in a decrease in the mean flow volume of 19.7% (say 20%), whereas an increase in the mean annual precipitation of 10% resulted in an increase in the mean annual total flow volume of 16.8%.

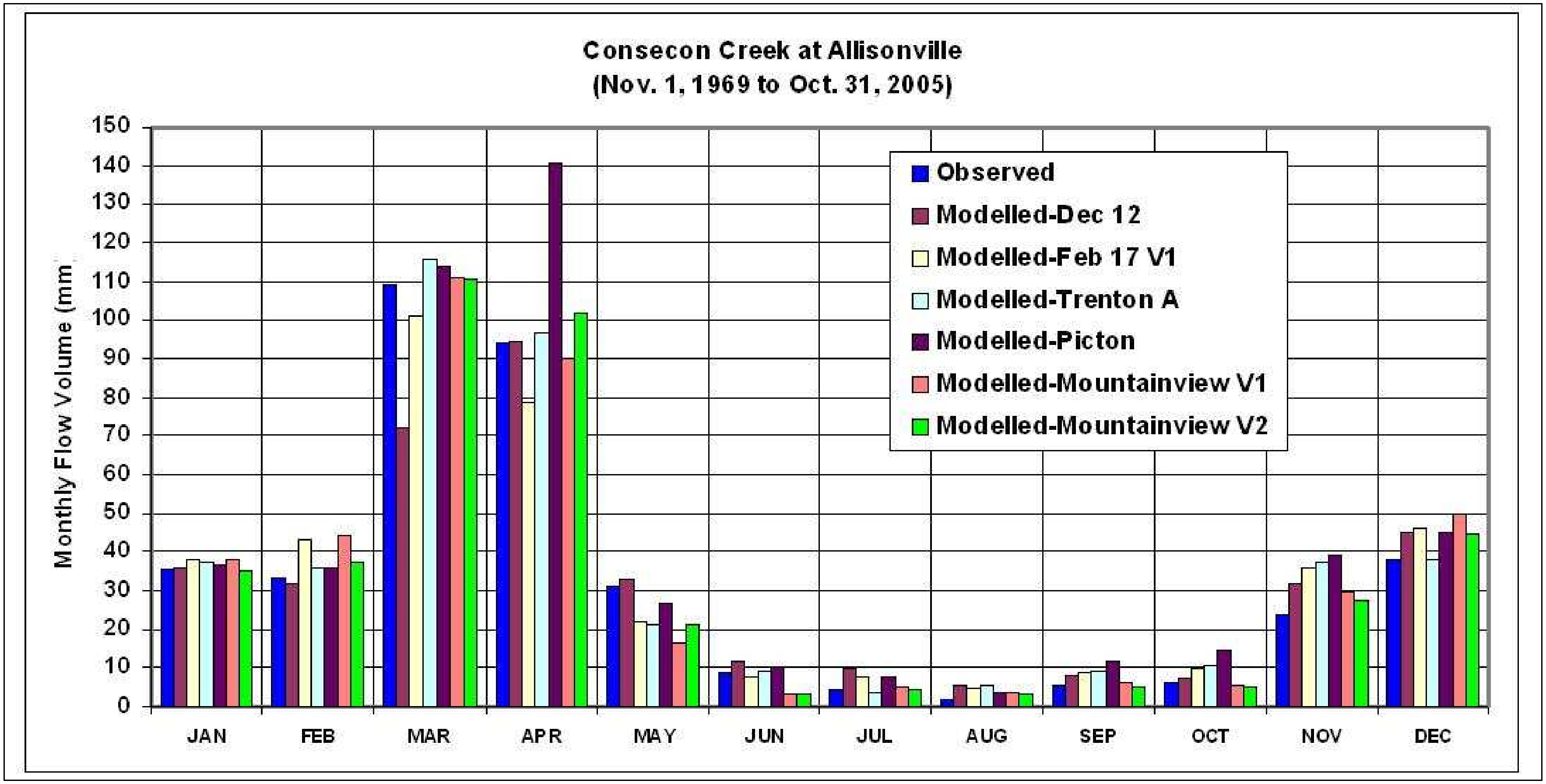

Figure 7-1: Observed and Simulated Monthly Flow Volumes for the Consecon Creek at Allisonville Gauge Resulting from Different inputs and Parameter Adjustments

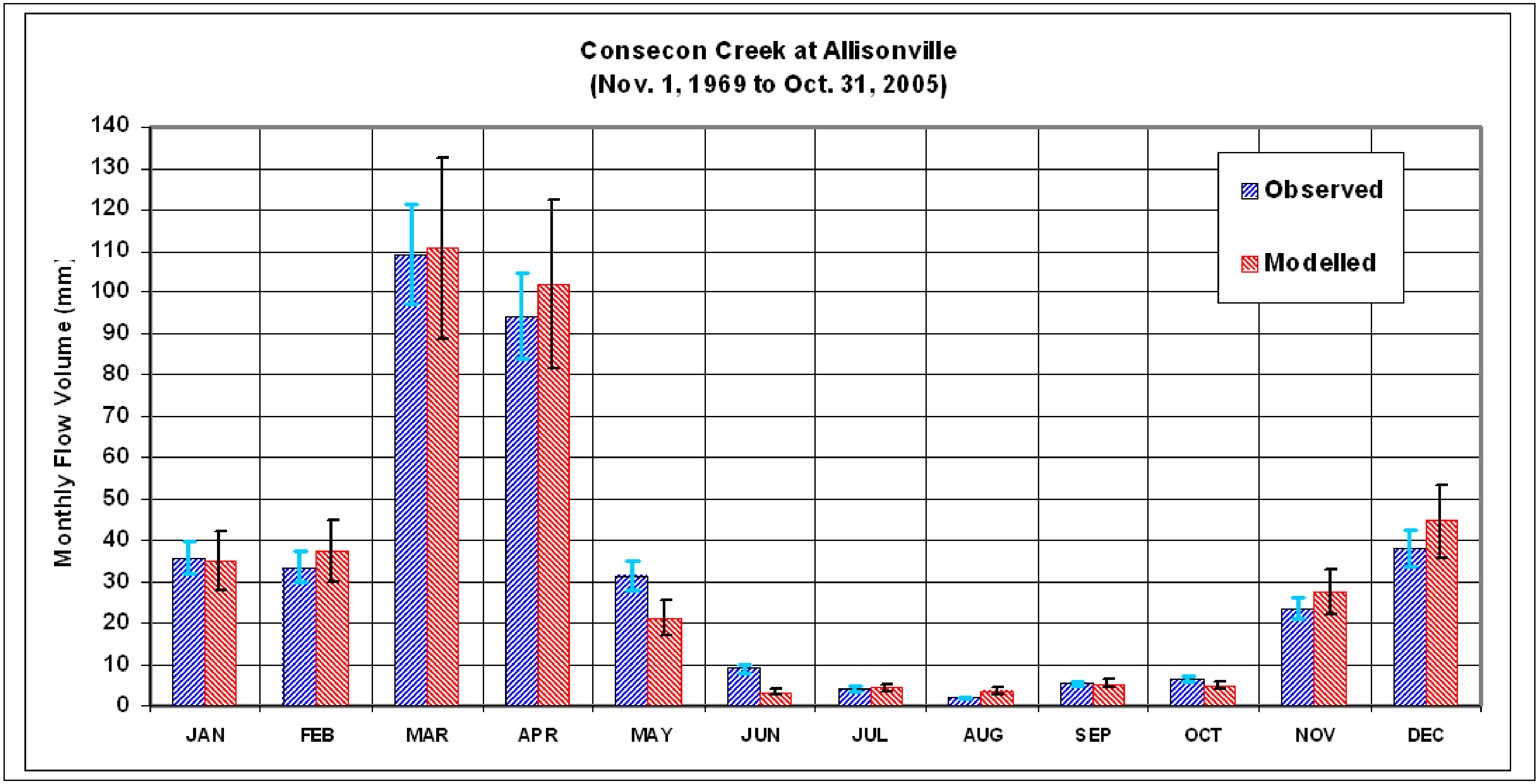

Figure 7-2: Measured and Modelled Monthly Flow Volumes for the Consecon Creek at Allisonville Gauge using the Refined Mountainview Climate Data and Additional Parameter Adjustments.

Using upper bound logic (see Bragg, 1974; Speigel, 1975; UNC, 2009), the uncertainty in the mean annual flow volumes resulting from the uncertainty in the precipitation data would be ±20%.

In the Tier 1 work, it was stated that the uncertainty in the streamflow measurements was ±5%. This would apply for the best or open water conditions, but it is known that streamflow measurements do not have the same uncertainty over the entire regime of expected flows (see Harmel et al., 2006 and 2007). Harmel et al. (2006) notes that the uncertainty in flow measurements when the flow has overtopped the stream banks and spilled into the flood plain could be as high as 200%. Uncertainty in low flows and during ice-covered conditions can easily be on the order of 20 to 100% as well. Now granted, that these uncertainties in the flow regime would not apply for the whole year, and would have to be time-weighted. In a typical year, the stream at the Consecon Creek near Allisonville gauge is under ice-covered conditions for all of January and February, and about half of March. In some years, ice-covered conditions could occur earlier (like in December) or later (late January), and could persist until April. But for this illustration, let's assume that the ice-covered flows occur for all of January and February, a period of about 59 days, or 16% of the year (say 15%). Similarly, the low flow conditions (or even zero flows) occur mostly in the summer months of July, August and September. You could also define the low-flow period as being any flows less than 10 L/s (or 0.01 m^3/s). According to the observed flow duration curve for the Allisonville gauge (see Appendix C, Figure 13), a flow of 0.01 m^3/s occurs at the 80% duration, meaning that 20% of the time the flow is less than 0.01 m^3/s. Exceptionally high flows are those that spill the banks, and can be identified by estimating the bankfull flow. Using the Annable (1996) composite bank flow formula (Q_B in m^3/s) for southern Ontario, the bankfull flow for Consecon Creek can be estimated as:

[1] $Q_B = 0.52\, A_D^{\ 0.75} = 0.52\, (116.9\ km^2)^{0.75} = 18.4\ m^3/s$

where A_D is the drainage area in km^2. Use could also estimate Q_B as being the high flow that has a return period of 1.25 to 1.75 years (see Annable, 1996). For Consecon Creek (see Figure 13 in Appendix C), these flows occur less than 1% of the time, and so for this illustration, we'll assume their occurrence is negligible in terms of significant amounts of time.

To get a time-weighted uncertainty range for streamflow measurements, let us assume that the flows under ice-covered conditions occur for 15% of the year, with measurement uncertainty of about 20%. During low flows, which occur about 20% of the time, we'll assume the measurement uncertainty is 50%. The 'best' flow conditions occur for the remaining 65% of the time with an uncertainty is +5% as noted before. The probable error range (PER) or uncertainty for measured streamflows can be estimated as:

[2] $PER = [(0.15 \times 20\%)^2 + (0.20 \times 50\%)^2 + (0.65 \times 5\%)^2]^{1/2} = 11\%$

Now we can assess the agreement between the measured and modelled flows using an overlap of error or confidence bands procedure (see Bragg, 1974; Speigel, 1975; Richter, 1997; UNC, 2009). In Figure 7-2, we present the mean monthly observed and simulated flow volumes (using Model 6), and place the error bars on the measured and modelled flow volumes according to the PERs we have just computed. Where ever the error bounds overlap, the numbers are said to be in agreement. Since the error bounds are difficult to see in Figure 16 for the low flow volume months, the numeric results of the error bound assessment are given in Table 7-1. Upon examination of this table, we can see that the flow volumes are in agreement for 9 of the 12 months (or 75%). Table 7-1 represents the 68% confidence bands. If we double the error bands, we would be assessing the agreement between the measured and modelled flows at the 95% confidence level. In that event, the agreement between the observed and simulated flows would occur for 11 of the 12 months (or 92%). From this analysis, we can conclude that the developed model for Consecon Creek is a reasonable representation of the hydrology for that watershed and all those in the immediate vicinity, including Sawguin Creek

As part of the model performance evaluation, we found that the time-series of the deviations between each pairing of measured and modelled flows was independent by computing the autocorrelation function up to lag 12 for monthly flows. Consequently, we can now determine the total uncertainty for the modelled flows as follows:

[3] $PER_{TUMF} = [\ (11\%)^2 + (20\%)^2]^{1/2} = 22.8$ or 23%

Where: PER_{TUMF} is the total uncertainty for the modelled flows.

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Table 7-1: Comparison of Observed and Simulated Flow Volumes with Error Bound Limits

Month	Observed Volumes (mm)	Observed Lower Bound (mm)	Observed Upper Bound (mm)		Simulated Volumes (mm)	Simulated Lower Bound (mm)	Simulated Upper Bound (mm)	Agreement?
January	36	32	40		35	28	42	Yes
February	34	30	37		37	30	45	Yes
March	109	97	121		111	88	133	Yes
April	94	84	105		102	81	122	Yes
May	31	28	35		21	17	26	No
June	9.0	8.0	10		3.2	2.6	3.8	No
July	4.2	3.7	4.7		4.2	3.4	5.0	Yes
August	1.9	1.7	2.1		3.5	2.8	4.2	No
September	5.4	4.8	6.0		5.2	4.2	6.2	Yes
October	6.4	5.7	7.1		4.9	3.9	5.9	Yes
November	24	21	26		27	22	33	Yes
December	38	34	42		45	36	54	Yes
Totals	**393**	**349**	**436**		**399**	**319**	**479**	**Yes**

Note: Observed uncertainty is ±11%, simulated uncertainty is ±20% These are 68% confidence bands

7.2. Comparison with Other Prince Edward Stream Gauges

The modelled outflows for Sawguin Creek were derived in part from Consecon Creek flows as the calibration gauge. There was close agreement with the outflows. The median and reserve flows generated by the model for Sawguin Creek are small values and stress calculations are quite sensitive to small variations in such low flow values.

As a further check on the values of flow generated by the model for Sawguin Creek, three nearby stations were used to develop simple basin comparisons employing simple proration and a basin transfer technique. Simple proration uses a direct ratio of basin areas to factor up or down the flows from a gauged station to the location of interest.

Proration: $Q_2 = Q_1 * A_1/A_2$

Where: Q_1 is flow at gauged station
Q_2 is flow at area of interest
A_1 is flow at gauged station
A_2 is flow at area of interest

The second technique is similar but uses an exponent to reduce the influence of the area differences. It is from Hydrology of Floods in Canada and is intended for inter-basin transfer between sites within 0.5 to 2.0 times the gauged area, but is used here between basins for information purposes only.

Basin Transfer: $Q_2 = Q_1 * (A_1/A_2)^n$

Where: Q_1 is flow at gauged station
Q_2 is flow at area of interest
A_1 is flow at gauged station
A_2 is flow at area of interest
$n = 0.9$

Table 7-2 contains the summary of the comparisons.

Table 7-2: Calculated Median Flows for Sawguin Creek Using Nearby Stream Gauge Stations

Gauge Station	Consecon		Bloomfield		Demorestville		Method 1: Sawguin Projected Flow Using Proration					Method 2: Sawguin Projected Flow Using Basin Transfer				
Area (km2)	**116.9**		**13.9**		**29.3**			**53.3**		**Average**					**Average**	
	Flow	**Flow/ km2**	**Flow**	**Flow/ km2**	**Flow**	**Flow/ km2**	**Con**	**Bloom**	**Dem**	**All**	**Excl Bloom**	**Con**	**Bloom**	**Dem**	**All**	**Excl Bloom**
January	1.21	0.010	0.16	0.012	0.23	0.008	0.552	0.625	0.412	0.530	**0.482**	0.646	0.478	0.366	0.496	**0.506**
February	1.05	0.009	0.17	0.013	0.36	0.012	0.479	0.667	0.654	0.600	**0.566**	0.560	0.510	0.580	0.550	**0.570**
March	5.07	0.043	0.46	0.033	1.56	0.053	2.312	1.766	2.838	2.305	**2.575**	2.705	1.350	2.518	2.191	**2.611**
April	3.66	0.031	0.37	0.027	1.06	0.036	1.666	1.432	1.921	1.673	**1.794**	1.950	1.095	1.704	1.583	**1.827**
May	1.22	0.010	0.14	0.010	0.29	0.010	0.554	0.518	0.520	0.531	**0.537**	0.648	0.396	0.462	0.502	**0.555**
June	0.28	0.002	0.06	0.004	0.04	0.001	0.129	0.219	0.079	0.142	**0.104**	0.150	0.167	0.070	0.129	**0.110**
July	0.03	0.000	0.03	0.002	0.01	0.000	0.014	0.104	0.018	0.045	**0.016**	0.016	0.079	0.016	0.037	**0.016**
August	0.01	0.000	0.02	0.001	0.00	0.000	0.002	0.073	0.002	0.026	**0.002**	0.003	0.056	0.002	0.020	**0.002**
September	0.01	0.000	0.02	0.001	0.00	0.000	0.002	0.063	0.002	0.022	**0.002**	0.003	0.048	0.002	0.018	**0.002**
October	0.03	0.000	0.04	0.003	0.00	0.000	0.011	0.140	0.007	0.053	**0.009**	0.013	0.107	0.006	0.042	**0.010**
November	1.01	0.009	0.10	0.007	0.05	0.002	0.461	0.387	0.096	0.315	**0.278**	0.539	0.296	0.086	0.307	**0.312**
December	1.31	0.011	0.14	0.010	0.23	0.008	0.597	0.548	0.411	0.519	**0.504**	0.699	0.419	0.365	0.494	**0.532**
						A1/A2	0.456	**3.8**	1.819							

Note: All flows given in cms

Consecon Creek and Demorestville Creek produced results that more closely agreed to the modelled flows. Bloomfiled Creek produced comparitively high flows. This gauge was known to experience backwater conditions at the low flow weir that were influenced by weed and debris accumulation and values are not believed to be reliable (personal communication with Mr. Jim Millman, Water Survey of Canada). Bloomfield Creek has dissimilar geology with 84% of the watershed having medium to highly drained soils, whereas Demorestville, Consecon and Sawquin have values of 45%, 54%, and 59% medium to highly drained soils respectively (refer to Table 3 in Appendix C). Results were averaged for all three stations and also for just the Consecon and Demorestville stations. Bloomfield results were ignored.

By these methods August flows for Sawguin Creek would be less than those derived by the model. Stress calculated based on the basin transfer method would be in the order of 22% for average current water use and 25% for future water use which is in the Moderate stress category (refer to Table 3-1).

7.3. Uncertainty Assignment

Based on the foregoing and despite a calculated uncertainty of 23%, there is sufficient variation in the potential flow results found in Section 7.2 to assign a High uncertainty to the results of the stress assessment.

The results of the uncertainty calculations would not change the Low stress assignment for the Sawguin Creek subcatchment. According to the Technical Rules, all of the three following conditions must be satisfied for a Moderate stress to be assigned:

1. Stress for average hydrologic conditions must be between 18% and 20%
2. Uncertainty must be High
3. A sensitivity analysis must suggest the stress level could be Moderate

The first condition fails since the stress calculation reveals 12% and 13% stress under current and future water use conditions respectively.

8. Conclusions and Recommendations

The Ameliasburgh subwatershed was reviewed by Quinte Conservation in this report and refinements were made to:

- Area of Study
- Precipitation and Temperature Source Data
- Method of Calculation for ET
- Model
- Duration of Record for Meteorological and Flow Data

A detailed continuous model was developed based on the GAWSER platform to assist the investigation by providing an estimate of monthly water availability for each area of study. The model also provided water budget summaries for Average, 2-yr Drought and 10-yr Drought hydrologic conditions.

Model runs were enhanced by using continuous meteorological data derived from Meteorological Services of Canada station at Mountainview for the period between 1950 and 2008. Drought years were selected by averaging the records across the Quinte Region to determine the periods with the two lowest back to back precipitation years (1963-1964) and ten lowest back to back precipitation years (1957-1966).

Results are reported for the Sawguin Creek subcatchment where Low Stress is indicated for Average, 2-yr Drought and 10-yr Drought conditions. Future water demand was also investigated. It was determined that water demand for Prince Edward County is expected to increase 15% in 2021. The stress on the water supply was found to also be Low during future water demand.

The local area at the municipal intake (Roblin Lake Subcatchment) was reviewed in greater detail to look at the local effect of the water taking. A groundwater investigation, bathymetry mapping, and improved topographic information did not reveal any significant groundwater inputs that could not be explained by the surface water model. The lake levels are controlled by a small operable dam that was built to assist the control of the supply for the municipality. Responsible operation of the dam would compensate for low water periods in the 2-yr drought conditions and assure an adequate water supply for the municipal need.

It is recommended that the water budget investigations for the Ameliasburgh municipal intake in the Quinte Source Protection Region be concluded by assigning a Low stress to water quantity.

It is further recommended that the dam operation be reviewed and an Operations Manual be prepared to be more reflective of these findings.

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APPENDIX A

Water Survey of Canada Stream Monitoring Stations

And

Meteorologic Data

APPENDIX B

Groundwater Evaluation

By

Golder Associates

APPENDIX C

Hydrologic Model Report

By

Schroeter and Associates

Table 1: Stream Gauging Stations[1]

Station Name	Drainage Area (km2)	WSC ID	Period of Record	Mean Annual Flow (cms)	Runoff Expressed as mm/yr
Moira River Near Deloro	308	02HL005	1965 - 2004	3.77	386
Black River Near Actinolite	401	02HL003	1955 - 2004	5.15	405
Skootamatta River Near Actinolite	712	02HL004	1955 - 2004	8.42	373
Moira River Near Tweed	1770	02HL007	2002 - 2004	21.4	381
Moira River Near Tweed	1770	02HL101	1968 - 1977	26.9	479
Moira River Near Thomasburg	2210	02HL104	1969 - 1970	25.2	360
Clare River Near Bogart[2]	160	02HL102	1968 - 1977	2.79	550
Parks Creek Near Latta	205	02HL006	1984 - 1992	2.28	351
Parks Creek Near Latta[3]	199	02HL103	1968 - 1977	3.13	496
Moira River Near Foxboro	2620	02HL001	1915 - 2005	30.4	366
Salmon River Near Shannonville	891	02HM003	1958 - 2004	10.7	379
Napanee River at Camden East	694	02HM007	1974 - 2004	8.69	395
Napanee River at Napanee	777	02HM001	1915 - 1974	9.13	371
Depot Creek at Bellrock	189	02HM002	1957 - 2004	1.98	330
Bloomfield Creek at Bloomfield	13.9	02HE001	1970 - 1992	0.168	381
Consecon Creek at Allisonville	114	02HE002	1970 - 2004	1.48	409
Demorestville Creek at Demorestville	29.3	02HE003	1970 - 1977	0.404	435

[1] Entire flow records were used where possible to represent the subcatchments under study. Periods of record that were short or not considered reliable were not used to generate statistics for the water budget exercise. An example of this is Demorestville Creek that has 6 ½ years of record and had average flows of 0.00 for several months.

[2] Record did not compare well with Moira at Foxboro (about 20% higher). Flow records used with caveat that they were high.

[3] Record did not compare well with Moira at Foxboro and was not used as older station record was available.

Stream Gauge Stations

Monthly Total Rainfall Depth (mm) for BANCROFT AUTO 616I001

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	83.2		4.6	34.9	32	39.9	85.6	111	20.6	51.8	29.4	14	507.5	
1951	58.9	9.1	78.8	51.8	29	81.7	83.1	45.1	82.5	56.5	37.3	19.8	633.6	619.9
1952	4.6	11	47.8	60.1	89.6	37.8	90.7	100	73.7	11.4	71.3	56.1	654.1	583.8
1953	29.2	4.3	88.7	61.2	82	109	99.6	29	117	27	25.7	20.5	693.6	774.4
1954	14	10.1	18.5	95.5	51.8	83.9	78.3	110	128	62.4	37.4	10.2	700.5	698.7
1955	1.2	6.3	36.6	56.9	41	26.9	92.2	89.4	51	227	36.8	8.6	674.1	676.1
1956	2.6	12	10.1	102	88.6	81.4	91.5	74.1	75.1	28.2	55.5	15.1	636.2	611.0
1957	11	18.9	17.1	62.8	59.3	193	33.6	36.7	135	78.9	71.9	54.6	773.7	716.9
1958	0.5	9	3.3	17.5	38.3	77.3	63.3	106	79.1	90.8	47.2		532.1	611.6
1959	15.5		10.7	71.7	68.6	44.6	47.3	120	112	119	79.7	19.3	708.9	656.6
1960		17.1	5.8	70.5	128	103	61.7	44.2	16.5	52.3	71.8	0.5	571.4	598.1
1961	0.5	14.7	18.3	52.7	69.9	74.6	103	55.4	93.3	17.8	49.9	49.6	600.0	572.5
1962		6.9	1.3	47.3	72.8	67.2	86	58	108	116	46.3	31.5	641.6	663.0
1963			51.3	50.1	57.5	39.5	73.4	92.9	114	32.5	82.2		593.1	589.0
1964	24.4		22.9	71.9	80	34.5	69.3	76.1	38.7	32.9	52.6	54.3	557.6	532.9
1965	13.7	34.1	1	48	36.7	20.3	49.6	122	104	115	52.6	49	646.6	651.3
1966		31.2	67.8	29	110	54.2	26.4	86.5	63.5	58.1	148	49.8	724.8	628.3
1967	19.6		9.9	60.2	75.2	205	121	80.7	122	157	70.5	40.1	961.5	1048.4
1968	4.8	35.3	34.6	29.5	43	113	46.3	55.8	119	57.1	38.8	20.3	597.2	649.0
1969	12		29.6	97.2	115	154	70	72	47.2	74.1	84.6	3.8	759.3	730.2
1970	1.8	9.4	14.2	35.9	119	49.9	194	53.8	54.1	60.5	76.2	6.1	674.7	681.0
1971	8.6	6.4	6.8	35.9	36.6	94.5	125	59.6	88.2	45.3	40.8	31.6	579.5	589.2
1972	19.1	4.3	23.9	52	86.9	204	100	72	96.5	83.3	59.5	30.6	832.3	814.4
1973	20.5	12	64.8	79.8	89.3	112	105	110	61.1	91.9	64.5	21.1	832.7	836.5
1974	40.5	23.3	63.6	101	118	73.2	62.3	88.4	86	58	88.9	15.5	818.1	799.9
1975	14.7	25.9	77.8	21.1	48.1	121	71.2	55	82.3	41.7	52.3	23.4	634.4	663.2
1976	6.1	21.1	89	13.2	87.4	113	42.2	97.5	116	61.5	34.5		681.3	722.7
1977		13.7	36.4	47.5	23	52.3	44.8	103	103	83.7	76.7	9.2	593.5	541.9
1978	37.5		31.6	48.5	66.2	76.1	45.9	144	95.3	44.6	57.5	43.1	689.8	675.6
1979	8.3	14	52.9	63.1	112	50.2	34.7	97	38	135	73.9	39.3	719.1	705.8
1980	39		62.8	117	49.3	89.4	111	35.2	69.3	118	42.2	17.9	751.4	804.2
1981		90.3	33.6	61.5	70.1	62.9	38.9	120	219	82.6	15.6	4.6	799.4	839.0
1982	7.2		27.8	47.4	87.2	103	55	55	107	58.1	130	82.7	759.9	567.9
1983	20.7	39	35.6	60.8	136	94.5	38.6	111	59.7	120	40		755.8	928.6
1984		32.6	40.5	89.7	70	67.1	54.5	150	83.6	49.4	86.8	49.9	773.7	677.4
1985	1.3	22.5	38.8	18.5	164	80.1	62	72.6	95.4	64.4	71.6	20.8	712.1	756.3
1986	22	9.4	50.8	26.6	142	140	94	72.6	165	64.6	19.6	5	811.2	879.4
1987			11.6	43.9	55.8	94.3	57.2	46.3	97.9	84.8	73.2	20.3	585.3	516.4
1988	29	9	30.1	123	76.2	16.6	29.3	65.9	74.2	92.7	85.3	17.2	648.0	639.5
1989	23.4	0.8	57	23.5	94.2	153	16.2	21.6	69	71	93.1	9	632.2	632.2
1990	34	16.8	47.7	87.4	61.6	45.2	58	33	54.8	122	69	24.2	653.2	662.6
1991	1.1	9.7	74.3	94.6	109	22.2	103	12.9	76.1	97.3	48	20.8	669.0	693.4
1992	7.9	7.8	59.1	25.1	90.5	36.1	137	94.9	96.4	58.6	92.3	15.9	721.5	682.2
1993	35.2			55.3	125	101	108	110	103	87.3	80.1	21.5	826.0	833.0
1994	21.4	2.9	14.3	32.2	105	66.6	117	98.3	89.9	52.1	88.2	14.6	703.1	701.3
1995	60.3	0.3	43.6	67	65.9	67.4	125	115	53.1	158	95.5	4.1	855.3	858.4
1996	32.2	23.4	8.4	90.2	71.2	76.7	100	76.4	188	98.5	46.9	47.4	859.5	864.6
1997	31.5	51.4	10.2	41.4	92.4	60.6	69.8	101	91.6	42.6	34.6		627.1	686.8
1998	15.6	7.1	107	43.5	48.4	93.2	91.8	96	78.3	36	48.2	17	681.7	651.5
1999	32.4	24.5		31.6	134	173	149	87.4	272	135	72.3	39.6	1150.4	1104.1
2000	23.8	18.8	15.5	83	158	235	148	96.6	184	30.5	58	14.5	1066.5	1105.1
2001		47.6	0.4	23.1	59	70.8	51.9	70.2	78.8	119	52.5	22.9	596.4	593.3
2002	2.4	34	32.5	79.2	105	180	35	44	73.4	78.7	37.1	11.5	712.0	739.6
2003			17	16.6	130	108	85.2	80.4	162	130	88.8	34.4	852.0	777.8
2004	10.6		62.6	61	123	66.6	100	57.8	33.4	95.5	51.6	21.8	684.0	733.7
2005	10.9	3.1	9	108	31.1	103	48.6	77.1	97.5	31.4	98.3	26.4	644.4	593.1

Summaries:

Mean=	712.1
Maximum=	1105.1
Minimum=	516.4

Monthly Total Snowfall Depths (cm) for BANCROFT AUTO 616I001

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	41.5	68.2	12.8	10.2							39.3	28.4	200.4	
1951	41.2	41.4	32.7	7.1							54.1	74.2	250.7	190.1
1952	20.8	12.7	21.9									18.6	74	183.7
1953	10.2	41.8	8.9								26.7	43.4	131	79.5
1954	50.4	41.1	47.5	5							20.3	80.2	244.5	214.1
1955	30.7	32.5	44.6	1.3							16.6	27.6	153.3	209.6
1956	17.1	37.6	28.4	5.8	0.9				0.3		25.5	30.4	146	134.3
1957	51.7	23.8	5.9	2.5						0.3	18.7	42	144.9	140.1
1958	31.1	26.5	23.7	3.6	0.3						26.2	58	169.4	145.9
1959	47.1	54.5	37.4	7.6						3.8	39.1	43.4	232.9	234.6
1960	48.7	67.6	20.6	8.9							3.1	29.2	178.1	228.3
1961	8.3	15.5	33.9	10.6	5.1						4.6	18.9	96.9	105.7
1962	59.2	64.6	12.7	5.1						2.8	6.1	39.7	190.2	167.9
1963	23.9	41.8	25.3	7.6	10.2						5.1	23.2	137.1	154.6
1964	52	13.6	30.6	2.9							21.6	31.4	152.1	127.4
1965	50.8	52.2	32.6							2.5	19	41.1	198.2	191.1
1966	54.5	22.4	18.5	10.2							12.8	35.6	154	165.7
1967	63.3	45.6	10.1	5.1						10.2	38.3	25.3	197.9	182.7
1968	35.3	20.4	27.9								50.7	78.6	212.9	147.2
1969	25.4	15.1		2.5						5.1	22.7	22.8	93.6	177.4
1970	25.3	48.2	15.3	22.8							10.1	73.7	195.4	157.1
1971	63.5	68.4	45.5	5							35.6	40.6	258.6	266.2
1972	37.8	58.2	48.3	15.1						0.6	17.6	74	251.6	236.2
1973	25.7	36.9	44.7	7.6							10.1	91.3	216.3	206.5
1974	39.3	20.4	55.9	0.5	1.3					7.6	17.8	33.6	176.4	226.4
1975	42.6	50.8	15.1	54.1							17.8	61	241.4	214.0
1976	83.8	83.8	62.3	2.5	2.5					19.3	27.8	57.2	339.2	333.0
1977	72.6	44.1	24.7	10	1						23	132	307.6	237.4
1978	70.3	6.5	17.2	1.3							17.4	44.5	157.2	250.3
1979	79.2	24.1	5.3	39						11.2	11.3	22	192.1	220.7
1980	21.4	21.6	20.7	3							8.3	69.7	144.7	100.0
1981	19	25	17							10	9	47	127	149.0
1982	75.4	34.6	51	1							15.7	16.6	194.3	218.0
1983	35.9	21.8	23.2	29							55.6	101	266.4	142.2
1984	39.8	33.1	23.6	4.4							0.8	55	156.7	257.5
1985	80.8	45.9	23.1								30.8	55	235.6	205.6
1986	29.8	32	33.2	2.6							23.2	56.8	177.6	183.4
1987	44.7	36.5	38	9.3						6.7	33.5	74.6	243.3	215.2
1988	39.4	78.6	5.6	6.2							13.7	26	169.5	237.9
1989	56.3	38	49.9	9.8						0.6	27.2	33.2	215	194.3
1990	43.6	46.4	6.4	14.6							26.1	44.2	181.3	171.4
1991	55.4	25.8	21.9	14.3						2.8	12	50.5	182.7	190.5
1992	38.7	58.1	42.7	32.5					0.2	9.5	51.2	71.5	304.4	244.2
1993	57.3	33.4	45.4	20.4						2.8	14.8	37.3	211.4	282.0
1994	56.2	33.8	28	4.3	4.7						37.1	34.3	198.4	179.1
1995	62	43.9	17.1	13.5						5.4	71.1	58.8	271.8	213.3
1996	32.6	24.5	49.1	34.2	0.8					5.4	26	51.7	224.3	276.5
1997	87.2	39.4	62.9	24.7	0.8					21	29.6	29.4	295	313.7
1998	107	9.9	43.3								6.8	26.8	194.2	219.2
1999	68.5	25.5	27.2							1	2	29.9	154.1	155.8
2000	18.4	26	22	20.8						1.3	28	65.7	182.2	120.4
2001	47.5	38.2	31.2								30.5	48.6	196	210.6
2002	28.3	27.5	62.7	11						6.6	38.1	8.7	182.9	215.2
2003	24.2	39.5	32.2	19.3							44.4	30	189.6	162.0
2004	36.5	35.5	16.5	2							22.9	133	246.1	164.9
2005	76.7	39.5	28.4	0.6							35.6	36.8	217.6	301.1

Mean=	197.3
Maximum=	333.0
Minimum=	79.5

Monthly Total Rainfall Depth (mm) for CLOYNE ONT HYDRO 6161662

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	82.8		32	59	41.4	22.6	62.5	85.3	16	48.7	71	15.2	536.5	
1951	32.3	19.7	60.7	91.7	36.8	122	67	79.5	82.7	55.7	7.1	14.6	669.8	734.3
1952	6.4	2.5	23.4	53.9	96.8	51.1	53.2	98.9	49.7	27.2	59.5	59.4	582	484.8
1953	34.6	11.7	102	56.2	76.2	89.9	103	56.1	116	23	42.6	32.7	743.1	787.6
1954	12.8	3.1	25.7	86.3	65.4	114	50.3	82.9	123	54.4	47.4	13.2	678	693.2
1955			2.5	55.5	42.3	35.1	33.7	82.3	39.2	223	21.8		535.7	574.2
1956	6.8		7.6	102	103	53.2	72.7	81.6	23.9	24.7	22.8	11.6	509.9	497.3
1957	37.6	16.3	8.6	39.8	54.6	143	49	9.3	111	61.6	55.3	52.3	638.4	565.2
1958		2.5		21.1	42.7	64.1	56	69.3	148	38.3	30.8	13.5	486.5	549.6
1959	20.4			40.9	39.3	54.7	88.8	75.5	116	103	53.2	20.9	613.3	582.9
1960		25.9	5.9	62	55.4	56.6	52.1	27.4	28.5	59.1	38.7	2.8	414.4	447.0
1961		25.9	15	62.2	87.3	60.2	105	50.3	48	14.3	37.4	24.6	530	509.7
1962	12.7		2.5	47.7	32.9	95.2	80.1	20	78.6	96.2	55.9	24.1	545.9	527.9
1963			6.4	46.3	54.7	21.2	63	73.9	109	21.9	130		526.2	476.4
1964	31.2		19.4	39.3	43.4	35.8	59.6	56.5	26.7	38.1	48.2	57.9	456.1	480.0
1965	4.1	8.9		41.4	30.3	38.4	56	109	110	99.2	54.1	16.3	567.8	603.4
1966	3.6	23.6	39.6	11.8	72.1	76.6	24.7	69.1	48	30.9	133	87.6	620.1	470.4
1967	8.1			55.3	51.1	148	89.6	123	115	120	32.8	39.9	783	930.7
1968	3	15	61.5	17.8	59.6	98.9	77	42.8	135	54.4	40.8	32.4	638.2	637.7
1969	53.1		51	94.4	111	104	50.6	55.1	37.6	61	90.2	37	745.4	691.0
1970	6.6	3.3	18.2	37.9	75.7	40.6	85.3	22.4	80.3	60.9	91.1	2.3	524.6	558.4
1971	9.1	25.7	11.1	22.7	30.6	56.9	125	90.2	75.1	67	32.3	59.3	605.1	606.8
1972	40.2		74.9	28.8	84.4	144	77	89.3	71.8	81.8	85.2	48.9	826.6	783.8
1973	29.3	41.7	99.9	95.1	76.6	72.4	101	47.7	113	93.5	58.7	60.9	889.4	904.3
1974	47.5	29	59.7	83	127	63.6	36.8	65.6	65.2	59.9	64.3	16	717.7	756.9
1975	7.4	31.5	70.9	29.3	65.9	62.8	46.2	27.9	99.4	42	75.2	51.1	609.6	563.6
1976	8.4	34.4	81.2	26.4	59.9	50.4	69.3	100	78.2	22	26.7	15.7	573.1	656.5
1977		35.3	54.4	55.2	31.2	31.7	41.2	81.1	103	58.6	74	21.2	587.4	534.1
1978	46.2		29	65.6	55.2	69.4	46.2	134	94.8	49	49.6	40.6	679.4	684.6
1979	25	12	37.9	69.6	93.8	52.3	34.2	88	41	164	72.3	62.7	752.3	708.0
1980	54.2		83.2	131	41.5	121	67.5	32.2	71.3	121	52.2	15.4	791.1	857.9
1981	1.2	111	23.8	69.7	101	83.2	30.3	102	220	82.2	16.4	7.3	848.3	892.0
1982	10.1		31.9	49.7	77.3	72.6	42.8	46.8	107	57.8	137	132	764.8	519.7
1983	29	63.8	40.8	63.7	121	66.7	30	94.5	66.9	120	34	4.5	735.3	965.4
1984		17	12	130	134	46	62	64.5	42	46	61	23	637.7	592.0
1985	1.8	16	32	22.1	116	74	61.5	57.5	82.8	64.2	75.3	7	610.6	611.9
1986	30.8	15.4	22	27.9	109	72.9	104	111	148	57.7	13	3	714.5	781.0
1987			13.3	105	49.5	140	62	39.4	87	100	68	22	686.5	612.2
1988	40.6	5	34.7	129	67.7	11.9	22.7	55.8	74.8	91.8	89.5	27.4	650.4	624.0
1989	32.5	1.3	65.4	24.6	83.6	108	12.7	18.2	69.4	70.6	97.7	14.4	598.5	603.2
1990	47.6	27.5	54.6	91.8	54.7	31.8	45	28.1	55	121	72.5	38.7	667.9	669.2
1991	1.4	15.9	85	99.3	96.3	15.7	80.4	10.9	76.6	96.8	50.3	33.1	661.7	689.5
1992	11	12.7	67.9	26.5	80.4	25.3	106	80.6	97	58.2	96.5	25.4	687.9	649.0
1993	49.2			57.9	111	70.9	84.2	93.3	104	86.9	84.1	34.4	775.2	779.3
1994	30	4.7	16.4	33.6	93.4	47.2	91.4	71.7	93.6	27.2	94.1	21.7	625	627.7
1995	96	0.6	22.9	59.5	60.9	69.2	98.6	61.9	53.9	184	55.1	0.8	763.3	823.3
1996	40.7	64.9	4.7	98.7	79	53.2	123	97.2	184	87	49.8	60.5	942.3	888.3
1997	18.7	78.8	24.6	42.5	85.3	63.5	73.3	66.4	147	9.4	47.6	0.6	658	719.8
1998	51	7.2	83.4	45.8	56	79.3	94.9	62.3	94.2	58.3	48.2	34.8	715.4	680.6
1999	34.2	11.2	1.9	40.2	46.5	55.6	75.6	43.2	154	90.9	90.4	52.9	697	636.3
2000	23.2	37.9	40	86.1	101	119	104	62.7	102	40.7	77.3	21.4	814.9	859.9
2001		65.9	5.7	22.1	82.3	53.2	33.1	89.7	120	124	78	30.2	704.2	694.7
2002	0.9	22.1	39.7	71.9	107	140	56	34.2	65.7	91.7	25.9	9.8	665.8	737.4
2003		17	33.2	33.6	98.5	53.4	38.3	72.8	142	126	109	95.4	819	650.5
2004	7.1	1.6	50.9	91.1	113	79	72.4	117	136	78.8	68.4	44.1	859.9	951.3
2005	37.3	12.3	9.7	139	44.1	94.3	64.2	47.9	172	89.1	105	18.6	833	822.4

Summaries:
Mean= 671.6
Maximum= 965.4
Minimum= 447.0

Monthly Total Snowfall Depths (cm) for CLOYNE ONT HYDRO 616166 2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	35.1	59.2	41.8	21.8							15.8	25.3	199	
1951	39.1	46.5	35.9								59.8	80.3	261.6	162.6
1952	50.8	22.8	22.6								1.3	16.6	114.1	236.3
1953	29	17.8	1.3	1.8							20.1	36.4	106.4	67.8
1954	57.4	47.9	39.4	2.5							13.3	82.9	243.4	203.7
1955	20	33.8	59.7								5.1	14.9	133.5	209.7
1956	30.8	44.6	37.6								33	47.2	193.2	133.0
1957	50.4	12.2	14	2.5							7.6	27.4	114.1	159.3
1958	57.5	67.3	20.2	7.6							18.1	38.5	209.2	187.6
1959	41.4	58.9	21.1	2.5						2.5	32	62.2	220.6	183.0
1960	47.8	103	14.8	5.1								31.3	201.8	264.9
1961	3.3	14.1	29.1	21.1	7.6						2.5	12.5	90.2	106.5
1962	24.6	61.2	28.3	7.1						9.6	11	27.9	169.7	145.8
1963	41.5	26.9	21.6	5.1	10.2						10.1	24.9	140.3	144.2
1964	44.1	18.5	34.3	3.3						2.5	17.9	55.3	175.9	137.7
1965	51.4	43.9	30							7.2	31.8	39.5	203.8	205.7
1966	57.2	20.6	20.4								10.1	24	132.3	169.5
1967	54.8	29.2	7.6								24.1	16.6	132.3	125.7
1968	54.7	15.2	34.3								41.7	82.5	228.4	144.9
1969	23.8	34.9	2.5	6.6						1.3	15.2	25.1	109.4	193.3
1970	39.3	48.3	25.5	28.4							7	115	263.7	181.8
1971	48.8	93.3	54.6								36.8	31.3	264.8	318.7
1972	43.2	66.2	31.7								10.2	77.7	229	209.2
1973	12.7	12.8	8.9	15.2							2.5	74.9	127	137.5
1974	28.1	17.9	53.2	5.1							6.3	54.6	165.2	181.7
1975	43.6	39.9	20.5	33.6							14.5	48.3	200.4	198.5
1976	91.5	65.1	44.2		6.4					19.1	15.3	43.4	285	289.1
1977	56.8	21.9	26.7	5.6	7.6						27.1	143	288.7	177.3
1978	101	19.4	17.2	2							17.6	83.1	240.7	309.7
1979	110	32.4	7.5	28.5						25	9.5	24	237	304.1
1980	19.5	24.5	26							1	10	50.5	131.5	104.5
1981	15.5	28	37							11.7	7.4	49.3	149	152.7
1982	80	32.9	43.3	0.7							12.9	17.4	187.3	213.6
1983	38.1	20.8	19.7	21.5							68.5	73.3	241.8	130.4
1984	30.5	48	17								3	38	136.5	237.3
1985	85.7	29	36	10							25.3	56	242	201.7
1986	31.6	30.5	29	1.9							15	30	138	174.3
1987	47.2	27.8	32.3	3						1	42	38	191.2	156.3
1988	41.9	62	4.7	4.6							11.3	27.2	151.7	193.2
1989	59.6	36.1	42.3	7.2						0.7	22.4	34.9	203.2	184.4
1990	46.2	44.1	5.4	10.9							21.4	46.3	174.3	163.9
1991	58.6	24.7	18.5	10.5						3.3	9.7	52.8	178.1	183.3
1992	40.7	55.5	36.1	24.1					0.2	11.2	42.1	75.2	285.1	230.3
1993	60.9	31.9	38.5	15.2						3.3	12.2	39.4	201.4	267.1
1994	59.6	32.1	23.7	3.2	2.8						9.1	42	172.5	173.0
1995	46.4	21.5	4	2.3						3.6	90.3	55	223.1	128.9
1996	65.5	26.9	25.3	18						0.5	36.3	31.8	204.3	281.5
1997	56.4	30.4	50.6	4.7						35	29.3	29.9	236.3	245.2
1998	76.9	7.6	45.4								7	18.5	155.4	189.1
1999	90.4	18.9	56.3								1.7	36.4	203.7	191.1
2000	30.1	45.3	13.4	14.5							15.2	126	244.1	141.4
2001	62.7	28.1	23.3	1.2						1.2	4.6	60.9	182	257.7
2002	50.1	24.4	46.8	13.9	3					3.1	52.7	14.2	208.2	206.8
2003	56.1	57	18.8	15.6						0.7	20.7	40.4	209.3	215.1
2004	58.1	36.9	12.8	10.7							14.1	77.1	209.7	179.6
2005	34.7	37.9	10	2.9	0.5						17	73.9	176.9	177.2

Mean= 190.3
Maximum= 318.7
Minimum= 67.8

Monthly Total Rainfall Depth (mm) for MADOC 6154779

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	59.5		6.1	68	49.5	124	37.7	90	39.6	64.5	90.6	6.6	635.7	
1951	43.6	35.8	86	111	41.3	90.9	116	89.9	118	59.4	52.5	25.4	870.6	889.1
1952	25.8	19.1	42.4	73	97.6	33	51.5	57.3	68.5	42.9	73.2	68.9	653.2	589.0
1953	33.8	4.6	89.3	91.9	84.8	87	82.5	105	156	18.5	36.9	35.1	825.2	895.5
1954	20.1	21.6	54.9	105	45.5	49.5	31.5	59.6	119	53.9	65	30.8	656.2	632.6
1955	9.9	16.6	66.8	41.6	79.8	71.5	63.1	118	104	277	25	17.9	890.9	944.1
1956	15	7.3	5.5	108	125	102	52.2	114	85	26.7	31.3	18.6	690.2	683.6
1957	36.3	15.8	14.2	62.5	80.5	101	107	35	103	58	76.5	82.5	773.1	663.2
1958	6.9	9.4	3.1	37.2	72.1	49.5	55.3	67.4	82.1	46.3	59.1	5.1	493.5	588.3
1959	27.9	8.9	35.7	60	47.4	46	71.9	61	60.9	87.3	52.2	57.7	616.9	571.2
1960	11.7	35.1	14.4	115	96.7	84.9	80	61.2	19.3	61.5	78.7	1.8	660.1	689.7
1961	27.9	34.1	41.1	83.6	132	78.1	83.1	110	54.4	23	59.1	61.1	788.1	747.8
1962	29.6	9.4	0.8	47.8	115	73.2	70.6	40.4	80	114	49.3	26.9	656.6	701.0
1963	0.5	6.9	50.9	49.8	70.2	27.8	39.9	139	63.7	27.9	124	11.9	612.9	552.8
1964	57.1		38.6	62.9	68.6	22.4	107	90.4	25.5	74.5	56.1	86.1	689.3	682.9
1965	14.7	77.3		38.7	27.9	40.9	83.9	153	77.7	130	71.6	42.7	759	786.3
1966		56.1	56.1	23.3	49.8	65	12.1	87.5	83.5	56.8	165	84.8	740	604.5
1967	3		5.3	49.3	73.1	149	73.1	58.9	105	123	72.6	39.5	752.2	889.5
1968	27.5	25.7	39.3	32.5	59.8	164	34.7	73.2	69.6	56.2	79.5	16.7	678.4	694.6
1969	51.8		26.4	86.3	115	96.7	98.6	54.6	37.2	52.1	74.2	33.5	726	714.9
1970	9.1	14	27.6	45.1	71.2	76.2	109	8.9	71.6	71.6	74.8	10.2	589.5	612.0
1971	3.3	38.2	1.3	22.5	36.7	63.1	87.9	74.8	113	75.2	30.5	53.1	599.3	601.0
1972	21.2	9.4	59.2	25.3	102	120	44.3	90.2	111	86	70.3	62.9	801	752.2
1973	31.2	24.9	83.5	80.9	76.8	66.3	43	52.2	98.1	72.1	73.1	63	765.1	762.2
1974	30	15	57.5	57.4	88.3	75.3	70.8	69.8	61.5	50.5	74.8	28.2	679.1	712.2
1975	26.6	26.5	79.8	49.6	56.4	94.8	42.1	87.3	85.2	47.2	58.2	27.3	681	698.5
1976	22.5	32.6	83.2	64.3	80.4	96.4	65.6	31.6	77.7	70.5	20.3	17.2	662.3	710.3
1977		14.5	47.9	52.1	39.1	61.3	33.8	153	138	64.1	123	42.9	770	641.3
1978	60.6		46.9	65.8	55.8	39.9	45.1	73.6	74.1	45.5	57.1	37.8	602.2	673.2
1979	42	16.8	40.5	66.6	62.7	63.2	20.7	93.6	47.9	86.7	71.6	74.1	686.4	635.6
1980	31	0.4	104	105	58.3	78.4	75.2	41.6	43	103	38.4	49.2	727.9	785.6
1981	0.4	110	19.4	60.8	74.4	129	90.2	95	156	81.6	49.4	11	878	904.4
1982	12.4		19.4	58.4	82.6	67.6	55.8	71.8	84.6	40	121	84.5	698.3	553.0
1983	32	44.6	36.4	41.6	59.6	35.1	3.1	74.8	60.3	105	83.9	60.3	636.5	698.0
1984	0.8	49.6	30.9	117	99.9	73.8	51.4	134	65.2	18.8	71.8	27.2	740	785.6
1985		41	64.2	89.6	69.2	69.6	65	146	74.2	73.9	113	14	820	791.7
1986	27.6	13.4	30.9	47.2	71.7	138	42.6	116	205	59.5	40.7	91.3	883.6	878.9
1987	14	5	70.4	82.5	45.6	83	63.4	80.4	87.4	84.5	88.4	40.5	745.1	748.2
1988	29.4	18.2	40	69.4	52.2	31.9	57.2	79	115	84.8	70	27.4	674.9	706.0
1989	29.3	0.4	31.6	44	98.6	140	57.7	54.4	98.2	80.8	127	10	771.9	732.4
1990	35.1	36.8	30.1	100	77.8	92.3	77.8	73.6	42.8	127	52.5	101	846.2	830.3
1991	5.8	12.3	93.1	102	82.7	29.1	55.9	54.3	90.1	82.6	46.2	28.8	682.5	761.4
1992	39.5	13.4	51.4	79	83.1	32.1	75	99.5	138	63.8	110	22.4	806.9	749.8
1993	54.9		25.8	56.9	59.8	125	38.1	75.6	98.1	85.2	102	30.5	751.4	751.8
1994	15.8		17	66.7	85.6	104	37.3	72.5	39.6	32.7	93.3	30.5	594.7	603.7
1995	70.6	4.7	23.2	54.3	59.8	10.7	92.9	142	85.8	189	90.7	7.9	832.1	856.8
1996	54.4	41.5	4	95.2	89.2	99.4	59.2	33.8	223	73.5	47.3	65.2	886.1	871.8
1997	28	31.4	42.1	29.6	58.2	154	47.9	130	137	44	59.1	14.7	775.9	814.7
1998	72.9	27.4	66.6	35.6	77.1	199	72.9	108	74.8	40.4	50	48	872.5	848.5
1999	42	17	26.2	31.4	53.2	66.4	77	36.4	132	85.2	120	38.2	725	664.8
2000	24.6	18.2	33.6	79.2	150	207	71	115	67.4	32	101	27	926.1	956.2
2001	4	45	11	24.8	52	54.6	7.2	70.2	91.2	104	99	45.8	608.4	592.0
2002	4.2	27	43.8	91.8	153	148	46.4	45.2	60.4	69.4	38.8	7	735.4	834.0
2003		15	47.2	17.2	127	83.2	56.2	78.2	139	122	121	79.2	883.6	730.8
2004	5		47.8	99.8	138	57.4	178	62.8	103	66.4	103	70	930.2	958.4
2005	31.6	20.8	10.6	96.6	25.4	102	60.8	91.2	122	81.6	123	20	785.6	815.6

Summaries: Mean= 737.2
Maximum= 958.4
Minimum= 552.8

Monthly Total Snowfall Depths (cm) for MADOC 6154779

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	69.5	81.6	54	5.5							17.8	29.3	257.7	
1951	22.9	38.1	22.8								36.8	79.9	200.5	130.9
1952	38.1	28	24.2								5.6	32.8	128.7	207.0
1953	41.2	38.6	5.1	0.5							56.7	42.7	184.8	123.8
1954	58.5	68.1	38.5	3.1							18.3	68.6	255.1	267.6
1955	39.9	26.7	44.7								8.9	42.5	162.7	198.2
1956	31	47.3	44.5	17	4.3						30.6	39	213.7	195.5
1957	58.5	20	20.3	6.7							5.7	21.6	132.8	175.1
1958	57.1	61.4	16	5.1							33	51.4	224	166.9
1959	48.4	90.7	15.7	7.7						0.8	27.4	68	258.7	247.7
1960	62.7	87.2	41.9	4.4								22.9	219.1	291.6
1961	9	12.7	45.8	12.7							6.7	37.3	124.2	103.1
1962	39	100	35.5	3.8						7.7	12.7	74	273.1	230.0
1963	44.7	62.8	33.7	19.1	1.3						1	69.9	232.5	248.3
1964	38.1	35.6	27.5	19.6						2.5	20.3	49	192.6	194.2
1965	89.4	82.8	44.4	3.3							16.6	40	276.5	289.2
1966	85.1	26.5	15	5	0.8						13.9	13.9	160.2	189.0
1967	69.8	59.8	12.7	9.9							21.6	38.5	212.3	180.0
1968	74.9	38.2	26								27.2	59.4	225.7	199.2
1969	20.6	26.9	9.5	11.5						9.2	20.8	36.8	135.3	164.3
1970	44.9	73.1	21.6	17.8							9.4	116	283.1	215.0
1971	69	91	62.8	4.1							36.8	33	296.7	352.3
1972	65.5	93.3	46.4	8.4							20.1	71.3	305	283.4
1973	13.4	27.2	1.1	26.2							3.3	64.8	136	159.3
1974	44.9	28.6	22.7	0.8						7.3	5.7	71.2	181.2	172.4
1975	23.1	52.8	27.4	28.5							10.6	67.7	210.1	208.7
1976	66.1	24.6	44.6	1.7						23.1	24.7	61.4	246.2	238.4
1977	87.9	17.9	44.2	4.7	15.9						17.3	144	331.9	256.7
1978	119	3.6	30.2								9.4	32.4	194.9	314.1
1979	69.9	41.4	4	17.2						7.4	0.6	22	162.5	181.7
1980	24	40.6	27.5							0.4	18.1	60.4	171	115.1
1981	3.6	26.2	9.4							14		41.4	94.6	131.7
1982	43.6	42.8	56	1.8							1.6	11.8	157.6	185.6
1983	10.8	20.8	27.8	28.4							7		94.8	101.2
1984	41.8	48.6	32									54.6	177	129.4
1985	49.6	50.8	32								9	47.4	188.8	187.0
1986	22.1	26.2	22.8								14.6	16	101.7	127.5
1987	31	23.4	6	4							20.6	23.6	108.6	95.0
1988	40.4	71.7	0.8	0.4								17	130.3	157.5
1989	10.5	22.2	24.2								6.8	55.4	119.1	73.9
1990	27.6	29.8	5.8	3							3	54.6	123.8	128.4
1991	52.2	27.6	11.7								5	55.9	152.4	149.1
1992	18.7	31.3	52.3	10.8							20.3	96	229.4	174.0
1993	26	65.7	31.8	20						9.1	1	40.4	194	268.9
1994	54.4	42.1	40.7	15.8							14.1	43.4	210.5	194.4
1995	42.7	27.8	12.7	1.1							58.8	31.3	174.4	141.8
1996	38.1	19.7	26.8	6.4							35.5	30.3	156.8	181.1
1997	90.5	34.1	72.9	6.5						2.6	29.4	17.8	253.8	272.4
1998	62.8	17.5	30.7								5	4	120	158.2
1999	74.5	6	59								6	20.2	165.7	148.5
2000	10.5	44	19	9							8.5	80	171	108.7
2001	46	22	28									19	115	184.5
2002	35	15.6	41	18	1						35	10	155.6	129.6
2003	47	29	27	28							5	14	150	176.0
2004	38	17	9	5							2	48	119	88.0
2005	28	34	7	3							12	49	133	122.0

Mean=	183.9
Maximum=	352.3
Minimum=	73.9

Monthly Total Rainfall Depth (mm) for FRANKFORD MOE 6152555

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	75.5	23.3	44.5	72	48	67	33.7	102	27.4	48.9	90.5	38.7	671.8	
1951	58	44.8	106	128	35	82.3	171	111	97.2	41.8	90.2	39.3	1005.1	1004.3
1952	57.9	31	101	82.6	114	22.5	56	101	55.6	63.1	81.8	65.2	831.8	814.2
1953	54.6	12.4	145	70.7	149	37.5	43.2	53.3	92.6	7.3	34.8	33.1	732.9	812.6
1954	15.1	48.6	63.2	74.1	30.4	68.6	18.5	54.1	82.1	59	98.7	69.7	682.1	581.6
1955	12.5	26.4	65.6	50.4	60.2	23.9	48.6	118	61.5	242	26.2	19.6	755.1	877.5
1956	16.7	13.1	26.1	124	127	20.5	36.2	95.5	79.4	25.4	37.2	31.1	632.5	609.7
1957	36	35.7	20.3	71	67.3	93.8	40.9	28.7	117	34.5	55.6	110	710.8	613.5
1958	2.1	17.1	3.1	48.3	59.5	61.3	59.2	105	92.1	41	40.9	7.9	537.7	654.3
1959	40.1	24.1	47.8	89.2	45.3	32.3	141	19.6	54.9	79.3	48.8	90.8	713.6	622.4
1960	25.9	61.7		56.1	97.5	43.2	43.9	85.4	12	59.7	48.9	5.8	540.1	625.0
1961		61.8	50.8	95.7	108	67.6	86.1	55.1	34.8	24.2	61.2	52.1	697.5	638.8
1962	41.5	6.6	9.6	41	94.5	51.1	33.3	57.8	103	76.8	43.3	23.3	582.1	628.5
1963		5.1	55.9	67.6	89.2	17.5	22.2	92.1	35.6	17.7	99.5	20.1	522.5	469.5
1964	69.8		53.1	104	51	27.6	66.3	127	9	47.9	46.7	53.9	655.7	675.3
1965	24.1	73.3	35.3	49.8	13.8	53.4	72.1	100	64.5	101	133	45.3	766.1	687.9
1966	4.1	58.2	47.1	24.2	33.5	74.2	39.6	55.9	84.8	37.2	147	52.3	658.2	637.1
1967	23.3	21.1	2.8	55.9	85	75	48	51	120	109	78.3	34.9	703.7	790.4
1968	41.6	22.3	23.2	16.2	118	127	48.2	67.3	80.9	64.1	89.3	36.1	734.5	722.0
1969	64.4		40.4	71.2	108	86.2	98.9	28.7	24.2	42.2	102	54.3	721	689.6
1970	5.1	26.4	47.5	52.4	79.1	45.4	116	20.3	74.1	101	100	25.2	692.8	723.6
1971	15.6	74.6	1.8	40.9	33.3	60.5	39.6	56.6	105	56.9	29.2	60.1	574.3	610.0
1972	13.8	19.3	80.3	30.9	106	140	73.7	98.2	96	69.6	53.6	74.4	856	817.1
1973	50.4	32	100	101	63	70.2	24	45.6	58.5	74.2	81.2	55	755.2	746.9
1974	34	35.1	62.8	64.3	98	81.6	50.4	62.8	58.5	42.5	70.7	36.1	696.8	726.2
1975	38.6	30.6	93.1	48.3	50.4	86.1	49.1	57.5	79.9	42.2	47.9	34	657.7	682.6
1976	19.2	47.6	99.7	63.5	82.5	94.1	60.7	38.8	83.2	67.6	19.5	19.5	695.9	738.8
1977		20	70.8	63.5	28.9	39.1	39.1	164	123	65.7	109	57.4	780.7	653.1
1978	79.7		57.8	67	61.8	18.2	32.6	84.3	60.4	41.6	64.8	46.6	614.8	669.8
1979	4.8	16.9	39.7	154	66.7	26.1	34.7	80.4	64	84.2	81.9	16.9	670.2	682.9
1980	11.2	5.5	65.4	101	31.2	124	86	48	97.8	108	54.7	56.5	789.6	776.9
1981		133	24.4	84	92.7	50.5	102	103	164	113	45.3	5.3	917.3	977.8
1982	11	3.1	57.1	64.2	85	98.2	53.5	87.8	84.5	46.8	88.6	66.9	746.7	641.8
1983	53.2	57.6	36.4	94.7	122	36.1	27	117	60.5	154	80.8	85.7	925.3	914.0
1984	2	42	22	142	102	75	69.6	191	50	16.6	69.7	53.5	834.5	878.7
1985		54	63	7.5	112	66	43.5	82.4	56.4	85.2	141	46	757.1	693.2
1986	51	15	51.5	68.3	101	92.4	37.3	108	197	92.1	31	100	944.8	1000.6
1987	3.2	12	98.9	82.3	23.9	72.3	59.2	77.2	89.9	65.3	133	44.4	761.9	715.2
1988	49.9	20.8	43.5	59.9	40.5	53.7	80.5	49.7	69.7	140	74.2	24.5	707.3	785.6
1989	37.7	3	18.4	49.5	108	95.8	14	95.2	80.9	103	148	14	767.8	704.2
1990	33	33.5	16.4	103	117	71.9	85.2	57.3	43.5	117	43.1	62	782.9	839.8
1991	6	6	88.5	133	69.2	41.5	39.4	69.3	86.6	81.9	43.2	32.9	697.5	726.5
1992	42	15.2	59.7	91.1	87	47.9	98.2	88.4	107	58.8	108	12.4	814.8	771.4
1993	59.1		2.5	57.3	58.6	104	52.6	81.6	153	100	83.8	35.4	787.9	789.1
1994	15.2		33.7	79	84.3	72.1	46.2	80.4	46.7	28.8	92.2	42.3	620.9	605.6
1995	82.4	7.2	30.7	65.2	72.7	7.8	82.3	114	63.2	181	92	9	807.6	841.0
1996	74.4	64.8	7.9	112	71.6	58.3	62.9	24.8	223	63.8	57.4	87.2	907.9	864.5
1997	36.9	49.2	59.9	30.6	71.9	107	53.2	102	141	43.7	56.6	15.5	766.4	840.0
1998	90.7	26.3	95	44.3	80.3	161	50.9	92.6	51.8	35.8	43	39.5	811.6	800.8
1999	35.4	28.5	29.2	41.9	40.5	56	99.3	48.9	73.3	67.1	98.9	45.9	664.9	602.6
2000	31	20.2	29.5	94.5	86.2	174	113	106	80.6	35.4	82.8	33	886.2	915.2
2001	6.1	43.2	24.5	10.4	44.5	70.7	10.5	62.3	87.5	82.5	67	43.4	552.6	558.0
2002	6.8	30.7	62	101	119	87.7	112	42.3	55.8	65.7	39.6	16.4	738.5	793.4
2003		37.7	48.9	27.8	126	96.3	78.5	35.7	116	88.4	116	73.3	845.5	711.3
2004	5.5	7.5	46	108	99.7	50	221	34.4	110	55	85.7	104	926.7	926.4
2005	27.4	40.7	17.6	95.4	21.2	50.8	48.2	96	86.5	87.2	92	23.5	686.5	760.7

Summaries:		
	Mean=	738.9
	Maximum=	1004.3
	Minimum=	469.5

Monthly Total Snowfall Depths (cm) for FRANKFORD MOE 6152555

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	42.4	50.5	33	4.8							18.4	32.6	181.7	
1951	24.6	19	12.5	0.2							29.1	79.2	164.6	107.3
1952	35	29.7	6.7									37.1	108.5	179.7
1953	32.9	24.4									10	21.9	89.2	94.4
1954	80	20.5	23.1	0.3							3.1	21.2	148.2	155.8
1955	32.9	20.8	46.8	0.3							4.2	31.2	136.2	125.1
1956	24	31.3	29.7	9.1							25.4	29.3	148.8	129.5
1957	46	14.5	15.9	6.2							0.9	9.4	92.9	137.3
1958	32.3	80.7	16.2	0.2							23.4	47.1	199.9	139.7
1959	42.1	45	19.2	2.4							13.8	34.8	157.3	179.2
1960	36.2	28.4	12.7									41.3	118.6	125.9
1961	20.2	7.6	25.4								7.6	23.3	84.1	94.5
1962	27.9	58.6	8.9	3.8						10.2	3.6	45.9	158.9	140.3
1963	28	20.2	5.6	5.1							5.1	40.4	104.4	108.4
1964	22.7	33	15.2	12.7							2.5	33	119.1	129.1
1965	73.7	48	34.9	9.4							6.4	8.6	181	201.5
1966	48.7	15.2	1.6	5.1	1.3							20.3	92.2	86.9
1967	48.2	33	15.2								12.7	24.7	133.8	116.7
1968	41.1	17.5	12.7								20.3	58.9	150.5	108.7
1969	25.8	12.7	2.5							10.2	16.5	21.5	89.2	130.4
1970	32.9	46.9	5.8	6.4							1.3	49.7	143	130.0
1971	44.5	70.3	44.4	2.3							21.7	33	216.2	212.5
1972	49.4	53.3	35.6	7.6						1.6	10.9	59.4	217.8	202.2
1973	8.9	21.7	6.4								0.8	48.4	86.2	107.3
1974	43.2	26.7	22.8								2.5	42.6	137.8	141.9
1975	28.2	32	14.3	16.7							2.4	59.7	153.3	136.3
1976	42.7	19.1	34.5	7.1						4.6	13.4	59.4	180.8	170.1
1977	67.8	13.4	29.8	3.4	5						13.6	102	235.4	192.2
1978	69.7	10.1	16	2.7							5	21	124.5	214.1
1979	50	5										11	66	81.0
1980	8.7	39.6	16.6								2.5	12.5	79.9	75.9
1981	18	9	3								0.5	34.5	65	45.0
1982	27	23	12									12	74	97.0
1983	7.2	12.5	11.9	9.5							17	38.5	96.6	53.1
1984	32	54.5	13								0.5	26.3	126.3	155.0
1985	54.7	50	22	0.5							2.5	62.8	192.5	154.0
1986	22	32.4	39	22							12	7	134.4	180.7
1987	43.4	24.6	5.6	8							3	12.8	97.4	100.6
1988	17.2	63.8	5.2									24.6	110.8	102.0
1989	6.6	31.4	32.2	0.6							11.2	26.6	108.6	95.4
1990	26.4	31.4	1.8	0.6								19.4	79.6	98.0
1991	43.7	25	5								10.9	38	122.6	93.1
1992	17.3	27.1	45.5	7.7							2.5	85.9	186	146.5
1993	23.4	58.8	29.1	8.5						2	2	36	159.8	210.2
1994	52.4	26.7	21.1	7.3							8.7	22.7	138.9	145.5
1995	32.4	24.9	4.5	1.8							31.4	29.9	124.9	95.0
1996	26.1	9.9	14.8	2.3							17.2	28.4	98.7	114.4
1997	74.1	24.6	44.6	2.7						3.2	16	12.3	177.5	194.8
1998	41.4	16.2	21.3								3.9	10.8	93.6	107.2
1999	93.6	1.9	28.6							5.6	1.4	17	148.1	144.4
2000	13.4	28	9	5.3							7.3	62.6	125.6	74.1
2001	42.5	32.5	23.2	0.1								33	131.3	168.2
2002	35.4	18.9	27.1	7.8	0.2						15.6	10.6	115.6	122.4
2003	37.6	33.8	17.5	18.7							1.9	15.2	124.7	133.8
2004	52.7	25.1	8.9	0.9							0.3	34.9	122.8	104.7
2005	27.6	32.8	11.3	5.2							9.1	40.5	126.5	112.1

Mean=	130.9
Maximum=	214.1
Minimum=	45.0

Monthly Total Rainfall Depth (mm) for BELLEVILLE 6150689

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	71.7		6.3	71.4	49.5	98.3	36.4	87.4	36	64.3	100	23.6	645.3	
1951	45.3	37	72.3	124	50.1	74	123	151	78.8	53.6	57.2	39.3	906.3	932.7
1952	22.7	31.6	47.9	104	111	23.3	60.8	83.6	81	70.4	84.4	57.9	778.6	732.8
1953	39.4	6.9	97.1	53.5	130	39.5	64.4	67.8	106	11.7	44.4	30.8	691.3	758.6
1954	18.3	33.5	55.1	86.2	49.7	68.9	28.2	93.8	116	69.8	93	51.9	764.4	694.7
1955	15.8	12.8	64	46.6	64.5	32.4	72.9	126	63.5	297	28.9	15.2	839.5	940.4
1956	14.7	13.7	37.6	113	144	22.1	47.6	84.8	69.4	32	29	27.8	635.4	623.0
1957	31.8	37.4	16	70.5	73.8	105	65.2	31	131	35.6	70.6	113	780.6	654.1
1958	7.7	29.3	2.9	55.6	68.1	49.8	42.8	99.6	83.2	46.3	47.7	6.6	539.6	668.9
1959	39.8	28	41.6	82.8	46.1	48.3	162	39.2	55.6	89.5	48.8	72.7	754.9	687.2
1960	15.5	66.3	2.9	113	85.3	56.8	49.6	170	18.2	63	50.5	1.8	692.7	762.1
1961	0.5	56.1	29.9	87.5	90.7	86	49.3	53.7	28.1	29.7	67.8	41	620.3	563.8
1962	34.2	8.6		49.5	96.7	62.8	43.8	66.5	107	84.1	47.1	37	636.9	662.0
1963	1.8	6.6	50.6	59.7	88.7	29.2	57.3	139	37.4	13.5	102	10.2	595.9	567.9
1964	40.4	1.3	42.2	90	56.9	26.4	45.8	98.3	8.2	47.7	46.2	45.1	548.5	569.4
1965	18	83.4	1.6	47.4	30.5	48.3	84.1	90.2	63.1	78.8	110	41.8	696.9	636.7
1966	8.1	53.1	33.8	16.8	27.6	68.4	39.5	75	95.1	39.8	139	62.5	658.6	609.0
1967	14.6	8.1	1.8	58	67.8	58.8	58	25.2	117	90.2	74.9	34.5	609	701.0
1968	28.4	25.4	27.1	16.3	128	107	29	58.3	102	68.9	91	26.9	708.1	699.8
1969	64.7		38.9	68.9	114	86.9	72.9	51.8	29.2	39.2	82.9	43.4	692.5	684.4
1970	4.3	31.3	35.5	61.8	83.8	55.2	101	13.2	53.3	106	95.9	25.5	666.4	671.7
1971	8.9	55.4	2.3	36.6	32.2	58.7	37.9	52.6	61.7	54.8	21.9	56.1	479.1	522.5
1972	11.5	22.7	35.3	32.2	102	94.9	42.8	87.6	100	85.7	71	66.1	752.1	692.7
1973	37.5	32.6	88.1	85.1	76.8	52.7	41.5	50.7	89	71.9	73.7	66.1	765.7	763.0
1974	36.3	19.6	60.7	60.3	88.3	59.8	68.5	67.8	55.7	50.3	75.5	29.7	672.5	707.1
1975	32.1	34.6	84.2	52.1	56.4	75.3	40.6	84.9	77.2	47	58.9	28.7	672	689.6
1976	27.2	42.5	87.8	67.4	80.4	76.8	63.4	30.8	70.5	70.3	20.4	18.1	655.6	704.7
1977		18.9	50.6	54.7	39.1	48.6	32.7	149	125	63.9	124	45.2	751.4	621.0
1978	73		49.6	69.1	60.7	21.5	31.4	89.4	76.4	49.8	66.3	51.2	638.4	690.1
1979	58.7	18.3	42.3	82.8	51.5	20.7	22.5	50.4	78.9	89	92.2	65.3	672.6	632.6
1980	40.6	7	98	110	37.8	122	112	107	44.6	120	58.4	39.9	898.1	956.5
1981	0.4	115	14.8	66.2	130	93.3	54.3	85.8	144	96.5	34.7	27.4	862.7	898.6
1982	21.8	3.5	67	60.9	136	94	35.3	82.5	85.6	61.8	95.9	66.3	811.1	710.5
1983	43.6	54.8	43	69.2	103	30.4	35.3	104	45.8	136	91.5	99.8	856.4	827.3
1984	3.8	41.2	15.8	163	88.4	76.6	49.7	117	45.5	112	65.4	33.7	812	904.3
1985	5.2	59.6	78.5	47.8	111	50	36	76.5	81.5	70.1	149	15.6	781.3	715.3
1986	34.4	21.8	46.6	52.8	95.1	84.9	56.3	107	186	59.4	41.1	96.1	880.7	908.9
1987	3.5	15.1	69	70.7	19	67.6	60.1	72.9	84.2	48.1	116	28.6	654.9	647.4
1988	29.8	23.5	44	54.8	31.8	43.9	40.5	37.1	48.1	91.1	60.3	19.4	524.3	589.2
1989	35.3	4.2	27	28.9	77.6	83.7	22.4	67.3	60.6	101	128	15.6	651.4	587.7
1990	19.5	41.2	42.9	111	107	79.8	59.1	60	45.5	94.9	42.3	118	821.1	804.5
1991	5.3	8.8	93	94.8	61.5	23.7	26.7	89.1	79.9	58.7	42.9	30.3	614.7	701.8
1992	47.5	17.4	54.3	83.2	83.1	25.4	72.3	96.7	125	63.7	111	23.6	803.3	741.8
1993	66.3		27.2	59.7	59.8	98.9	36.9	73.7	89	84.8	103	32.2	731.2	730.9
1994	19		18	70	85.6	82.3	36.1	70.3	36	32.6	94.3	32.1	576.3	585.1
1995	85	6.2	24.5	57.2	59.8	8.5	89.9	138	77.8	189	91.6	8.3	835.5	862.3
1996	65.5	54	4.2	100	89.2	78.8	57.1	32.8	203	73.3	47.8	68.5	873.7	857.8
1997	33.8	40.8	44.4	31.1	58.2	122	46.4	126	125	43.9	59.7	15.4	746.5	787.9
1998	87.9	35.8	70.4	37.4	77.1	158	70.3	84	63.1	31.1	34.4	33.5	782.9	790.2
1999	35.6	24.9	28.9	30.2	35.9	51.1	93.6	46.1	95.5	80.8	111	45.6	678.9	590.5
2000	28.2	19.1	25.3	90.3	82	161	110	84.5	93	30.6	90.4	24.8	839.6	880.6
2001	3.8	37.2	22.2	10.6	44.6	51.4	8.8	69.6	82.8	81.5	74.5	36.6	523.6	527.7
2002	4.9	22.8	47.5	104	123	88.4	84.1	43.5	51	83.5	37.7	13.6	704.3	763.8
2003		25	39.3	27.7	115	91	82.7	45.6	105	101	131	69.8	833.1	683.6
2004	4.2	5.4	38.4	105	116	45.5	254	38.8	120	67.4	103	92.4	989.8	995.5
2005	28.8	42.3	16.6	105	22.9	55.4	85.4	91.6	83.9	111	120	25.8	788.3	838.3

Summaries:		
	Mean=	722.4
	Maximum=	995.5
	Minimum=	522.5

Monthly Total Snowfall Depths (cm) for BELLEVILLE 6150689

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	63	60.8	48.4	5.1							22.1	44.8	244.2	
1951	34.8	20.3	40.2	0.3							29.1	92.8	217.5	162.5
1952	51.2	36.1	20.9									22.6	130.8	230.1
1953	21	30.1	1.3	0.3							20.6	20.1	93.4	75.3
1954	51.5	35.4	41	1.3							11.9	42.1	183.2	169.9
1955	33.5	30.3	56.2	1.8							4.6	27.3	153.7	175.8
1956	29.7	40.5	39.6	14							38.3	24.9	187	155.7
1957	44.6	14	17.9	8.1							2.3	12	98.9	147.8
1958	39	76.6	12.2								24.5	53.6	205.9	142.1
1959	64.9	63.2	20.6	4.1							22.7	57.5	233	230.9
1960	59.2	56.6	41.2								0.5	56.4	213.9	237.2
1961	25.3	11.7	48.5	20.5							7.1	44.5	157.6	162.9
1962	31.7	75.1	33	1.8						2.5	5.1	38.3	187.5	195.7
1963	50.4	20.9	19.3	16.8	0.3						3.3	45.6	156.6	151.1
1964	14	22.1	18.9	12							3	25.9	95.9	115.9
1965	72.2	35.6	45.1	3.8							9.2	12.8	178.7	185.6
1966	63.6	21.6	8.6	7.6	1.3						2.8	20.5	126	124.7
1967	57.2	25.2	15	1							10.5	21.1	130	121.7
1968	31.3	10	13							0.3	21.3	54.5	130.4	86.2
1969	23.4	16.5	4.8	2.8						6.9	15	29	98.4	130.2
1970	20.4	33.9	18.6	5.1						0.3	5.3	62.4	146	122.3
1971	35.2	57.4	46.3	1.3							19.7	26.4	186.3	207.9
1972	34.8	59.9	45.6	7.8							16	63.3	227.4	194.2
1973	12.1	20.3	1	24.3							2.6	57.5	117.8	137.0
1974	40.6	21.3	20.2	0.8						2.8	4.6	63.2	153.5	145.8
1975	20.9	39.3	24.6	26.5							8.4	60.1	179.8	179.1
1976	59.7	18.3	40	1.6						8.9	19.6	54.4	202.5	197.0
1977	79.5	13.4	39.7	4.4	10.6						13.7	128	289	221.6
1978	108	2.7	27.1								5.2	25.4	168.3	279.5
1979	81.8	24.5		25.2							1	8.8	141.3	162.1
1980	11.4	23.3	23.9								16.6	37.9	113.1	68.4
1981	36.9	14.8	9.6								1.8	48	111.1	115.8
1982	56.2	30.9	18.6	2							7.4	13.6	128.7	157.5
1983	5.8	6.8	30.2	20.5							17.4	88.4	169.1	84.3
1984	36.1	36.1	19.6		0.7						2	30.4	124.9	198.3
1985	49.8	61.2	15.2	7							10.6	73.6	217.4	165.6
1986	18.6	29.2	37	1							11.6	14.2	111.6	170.0
1987	56	18.4	13.6	10.2							6.6	30.6	135.4	124.0
1988	13.8	73.8	4.6	0.6							0.2	17.6	110.6	130.0
1989	9.6	30.8	25.8	4.7							18.2	19	108.1	88.7
1990	29.6	34.4	8.6	5.2							2.4	39	119.2	115.0
1991	35.8	16.2	12.6								10	49.6	124.2	106.0
1992	16.9	23.3	46.8	10							16.1	85.2	198.3	156.6
1993	23.6	48.8	28.5	18.6						3.5	0.8	35.8	159.6	224.3
1994	49.3	31.4	36.5	14.7							11.2	38.5	181.6	168.5
1995	38.7	20.6	11.4	1							46.5	27.9	146.1	121.4
1996	34.7	14.7	24.1	6							28.3	26.7	134.5	153.9
1997	82	25.4	65.2	6						1	23.4	15.6	218.6	234.6
1998	57.1	13	27.5								5.2	9	111.8	136.6
1999	70	1.9	45							1.1	1.7	16.6	136.3	132.2
2000	16.7	40.7	13.4	7.3							16.9	50.4	145.4	96.4
2001	44	34.9	18.6									47.2	144.7	164.8
2002	39.3	29.3	28.5	14.9							24.9	10.2	147.1	159.2
2003	41.4	35	23.1	36							6.8	13.7	156	170.6
2004	51.3	26.6	4.4	2.4							0.6	32.9	118.2	105.2
2005	30.6	32.5	5.4	1							14	37.1	120.6	103.0

Mean=	154.5
Maximum=	279.5
Minimum=	68.4

Monthly Total Rainfall Depth (mm) for MOUNTAINVIEW 615EMR7

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	66.5	17.6	33.2	60.8	48.4	47.3	59.2	77.6	34.3	80	104	38.1	667.2	
1951	33.8	56.1	91.6	126	48.3	50	37.4	73.9	96	18.5	108	63.7	802.5	773.7
1952	21.1	32.5	58	104	109	22.7	73.7	73.8	87.4	63.6	96.3	61.7	803.9	817.5
1953	36.4	7.1	117	53.6	128	38.4	77.9	60	114	10.5	50.9	33	726.8	800.9
1954	17	34.5	66.6	86.6	48.8	67	34.2	82.9	125	63.1	107	55	786.8	709.6
1955	14.7	13.2	77.4	46.7	63.3	31.6	88.2	111	68.4	268	33	16.2	832.2	944.5
1956	13.7	14.1	45.5	113	142	21.5	57.8	74.9	74.8	37	41.8	41.2	676.7	643.5
1957	55.2	39.9	18	59.2	75.1	102	79.2	27.6	141	44.7	80.7	120	842.9	724.9
1958	7.2	30.1	3.4	55.8	66.9	48.6	52.1	146	104	48	46.5	5.4	614.4	762.8
1959	13.9	13.9	24.9	93.6	80.4	27.4	119	23.1	70.6	102	47.5	75.3	691.1	620.7
1960	15.4	51.2		87.8	61.8	84.6	46.3	87.2	16.5	87.6	46.4		584.8	661.2
1961		65.1	11.6	58	122	75.5	36.2	31.9	28.2	34.4	95.1	50.3	607.8	509.3
1962	65.6	14.8	21	60.3	63.7	58.5	61.6	31.4	93.2	85.3	10.6	28.6	594.6	700.8
1963			61.2	59.8	90.3	33.9	30.9	72.5	40.1	12.2	86.7	23.5	511.1	440.1
1964	70.1	19	82.9	80.1	45	39.8	46.5	58.7	13.6	35.4	54.4	62.7	608.2	601.3
1965	33	60.1	16.9	37.5	31.5	56.2	49	86.6	58	67.7	102	42	640.5	613.6
1966	18.3	40.2	32.6	28.3	32.9	40.4	22.9	62.7	112	42	135	72.1	640.1	576.3
1967	1.8		3.6	67.4	66.6	98.3	68.4	22.4	116	94.3	92.4	39.4	670.6	745.9
1968	27.2	22.1	22.7	18	132	99.9	20	56.2	94.9	75.7	111	36.4	716.6	700.5
1969	37.5	12.7	43.6	76.1	127	103	61.1	36.2	22.1	44.6	83.3	36.3	683.4	711.3
1970		22.4	40.6	55.9	55.7	71.7	116	22.4	77.4	66.6	108	39.5	675.5	648.3
1971	22	67.4	7.5	37.3	44.4	46.5	72.8	58.8	36	38.4	37.8	59.7	528.6	578.6
1972	36.6	25.1	85.6	43.5	80.6	93	86.3	62.3	63.6	67.8	104	103	851.9	741.9
1973	40.6	25.5	111	117	65.7	20.4	28	24.2	55.1	66.7	66.4	77.2	697.7	761.2
1974	45.5	47.3	62.8	47.7	96.1	52.8	44.7	48	52.5	54.4	76.9	15.6	644.3	695.4
1975	42.1	56.9	96.1	39.7	74.1	107	76.9	53.5	128	53.3	103	32.2	863.1	820.1
1976	12.8	32.9	72.1	84.3	109	156	95.4	51.8	105	85.7	16	14	834.2	940.2
1977		25	59.9	61.8	21.1	32.6	42.5	145	126	70.6	144	25.9	753.8	614.5
1978	57.6		50.3	58.2	67.1	25.8	49.8	79.4	113	42.7	82.6	49.1	675.5	713.8
1979		16.3	41.6	83.6	53.9	23.7	63.1	64.5	129	93.8	92.2	67.1	728.3	701.2
1980	44.6		63.8	111	35.5	90	198	111	60.8	111	77.3	47.3	949.8	985.0
1981		104	16.9	68.6	67.4	85.6	74.4	90.4	140	68.1	44.8	25.3	786	840.0
1982	46.1		45.1	34.1	60.8	141	84.4	80.6	81.5	66.3	115	71.5	826.6	710.0
1983	60.6	74.2	59.3	83.5	101	26.1	53.6	48.9	41.3	78.5	118	102	846.3	813.5
1984	5.7	62.6	8.3	146	100	40.1	69.6	83.7	42.6	17.7	68.2	43.2	687.6	796.3
1985		53.4	69.6	35.5	49.4	56.9	45.6	62.1	75.2	74.3	161	27.5	710.4	633.4
1986	16	6.5	25.4	72.2	93	86.9	33.8	138	184	72.8	48.2	112	888.9	917.1
1987	6.2	25.6	56.8	81.2	27.5	68	46.6	56.6	69.4	59	124	34.8	655.9	657.1
1988	25.4	25	49.2	58.2	36.2	47.2	47.3	51.4	47.4	108	62.8	21.2	579.1	654.1
1989	31.6	5.6	26.2	26.8	106	89	13.4	79.2	63.6	118	125	17.6	702.6	643.4
1990	29.8	57.4	54.2	126	139	105	66.2	55	51.6	121	47.3	127	978.1	947.8
1991	12.2	16.8	99	96.2	60.6	33	33.2	47.2	86.8	66.8	47.6	41.6	641	726.1
1992	56	24.2	72.8	91.4	87.2	30.4	77.2	116	97.4	62.4	120	27.6	862.8	804.2
1993	70.4		12.6	63.2	67.2	110	33.4	57.4	97.4	99.8	120	53.3	784.9	759.0
1994	20	0.4	27.2	81.8	87.8	74.2	71.6	119	33.4	32.6	105	46	698.5	721.3
1995	68	7.8	36.2	57	57.5	6.2	125	138	58.2	176	95.8	6.4	831.1	880.9
1996	68	58	10.6	99.4	98.4	97.8	68.6	60.4	197	67.2	62	71.8	959.4	927.6
1997	24.4	38.2	43.8	33.4	71.6	101	35	87	124	51.2	74	17.4	700.8	743.4
1998	96.4	48	58.8	40.4	75.9	175	95.6	103	68.4	38	51.4	40.4	890.9	890.9
1999	36.8	20.4	38.8	24.6	51.3	53.6	173	53.2	84.2	80.8	113	41	770.9	708.5
2000	36	21.6	36.8	108	79.6	146	122	93.2	95.4	29.6	98.8	18	884.4	922.2
2001	10	41	34	14	43.2	45.8	13.6	24.4	99	88.4	78.8	41	533.2	530.2
2002	16.2	23	49.8	104	144	103	91.2	33	77.6	81.2	58.8	15.6	798	842.8
2003	1.8	36	49	22	115	53.4	114	54.4	80.6	102	149	63.8	842	702.6
2004	6.2	7.6	39.6	109	106	51.8	173	51.6	137	65	100	95.8	943	959.6
2005	30.8	41.2	16.2	119	18	57.6	73	105	95.4	93	106	16.8	772	845.0

Summaries: Mean= 742.5
Maximum= 985.0
Minimum= 440.1

Monthly Total Snowfall Depths (cm) for MOUNTAINVIEW 615EMR7

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	67.1	48.3	32.4	6.1							31.4	45.8	231.1	
1951	44.9	32	17.7	0.2							0.9	16.9	112.6	172.0
1952	54.6	27	15									18.1	114.7	114.4
1953	22.4	22.6	1	0.2							23.2	16.1	85.5	64.3
1954	54.4	26.4	29.4	0.8							13.5	33.7	158.2	150.3
1955	35.6	22.6	40.4	1.2							5.1	21.9	126.8	147.0
1956	29.3	30.4	28.4	9							58.5	24.4	180	124.1
1957	45	8.9	18.9	9.3							2.5	9.8	94.4	165.0
1958	41.3	57.3	8.7								64.2	48.1	219.6	119.6
1959	45.8	35.9	12.4								39.3	17.2	150.6	206.4
1960	33.9	40.7	30								3.1	38.5	146.2	161.1
1961	8.5	4.6	20	15								34.4	82.5	89.7
1962	66.2	32.1	9.5	5.2							3.1	28.5	144.6	147.4
1963	76.6	26	13.9	10.6							9.5	34.4	171	158.7
1964	7.2	17.3	5.7	8.7								15.2	54.1	82.8
1965	44.1	40.9	29.3	6.8							8.6	20.7	150.4	136.3
1966	60	16.2	5.3	2.1								15.8	99.4	112.9
1967	47.2	42.7	15.7								12.7	21.5	139.8	121.4
1968	44.6	13.6	12.7								24.1	50.8	145.8	105.1
1969	30.3	13.3								9.5	21.1	30.6	104.8	128.0
1970	60.3	21.1	8.9	1.4							15.6	52.3	159.6	143.4
1971	30.9	61.3	35.6								25.9	13.4	167.1	195.7
1972	31.7	40.4	26.4	7							26.9	41.2	173.6	144.8
1973	8.6	11.9	5.7	2.4							2.2	37.3	68.1	96.7
1974	34.3	8.5	22.1								6.3	35.9	107.1	104.4
1975	27.8	23.6	15.5	21								44.7	132.6	130.1
1976	52.7	21.1	36.7	0.7							22.7	55	188.9	155.9
1977	126	13.3	31	1.4							13.5	111	295.2	249.4
1978	60.4	13.2	14.9								15.6	18.7	122.8	213.0
1979	101	17.6	0.6	37.2							8.8	6.2	171	190.7
1980	6.6	20.8	30								7	23.5	87.9	72.4
1981	30	46.8	12.2								2	25.2	116.2	119.5
1982	59.8	28.5	14.9	2.5								9.2	114.9	132.9
1983	6.8	8.1	11.8	8.3							16.3	58.1	109.4	44.2
1984	59.8	28.5	13.4									29.9	131.6	176.1
1985	68.2	39.6	11.2								9.5	95.2	223.7	148.9
1986	31.2	19.9	21.1								10	5.2	87.4	176.9
1987	51.8	5	11.2	8.2							9.4	32.8	118.4	91.4
1988	21	67.8	7.2	0.2								24	120.2	138.4
1989	11.6	56.4	32.4	3.2							26	49.4	179	127.6
1990	22	29.4	7.6	1.4							1.4	34.4	96.2	135.8
1991	40	25.2	5.2								13.8	32.2	116.4	106.2
1992	20	27.4	37.4	6.4							11.6	60.2	163	137.2
1993	29.4	55	28.2	12.6						7	4.2	36.4	172.8	204.0
1994	57.2	44.8	29	12							17.4	20.2	180.6	183.6
1995	32.8	20.2	4.4	2.6							37.8	35.4	133.2	97.6
1996	22.2	11.6	21	0.2							11.2	21	87.2	128.2
1997	76.2	14.1	48.2	0.8							25.6	17.6	182.5	171.5
1998	40.4	5	36.4								5.4	14.6	101.8	125.0
1999	95.6	2	50.2									13.2	161	167.8
2000	17.7	25.4	15.2	9.2							31.7	71.7	170.9	80.7
2001	54.2	41.4	26	0.6								78.8	201	225.6
2002	32.2	26.2	25.6	8.4							17	21.4	130.8	171.2
2003	121	37.2	14.2	31.4							0.6	21.4	226.2	242.2
2004	66.6	16.8	8.6	1.2							0.4	40.4	134	115.2
2005	37.6	35.6	5.4	2							24.6	60.2	165.4	121.4

Mean=	141.3
Maximum=	249.4
Minimum=	44.2

Monthly Total Rainfall Depth (mm) for TRENTON A 6158875

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
76.9	22.5	37.3	72	48.3	72.5	35.1	104	28.7	54.4	103	36.7	690.6	
58.9	43.2	89	128	35.2	89.1	178	113	102	46.5	102	37.2	1022.3	1022.6
58.9	29.9	84.7	82.6	115	24.4	58.3	102	58.3	70.1	92.9	62	839.1	823.4
55.6	11.9	121	70.7	150	40.6	44.8	53.8	97.3	8.1	39.4	31.4	724.6	808.7
15.2	46.7	53	74.1	30.5	74.2	19.3	54.7	86.3	65.8	112	66.1	697.8	590.6
12.6	25.4	55.1	50.4	60.6	25.9	50.6	119	64.7	270	29.7	18.7	782.5	912.4
17	12.7	21.8	124	128	22	37.7	96.6	83.3	28.1	42.3	29.5	643	619.6
36.6	34.3	17	71	67.7	102	42.6	29	123	38.4	63.1	104	728.7	633.4
2.1	16.5	2.6	48.3	59.8	66.5	61.7	106	96.7	45.8	46.5	7.6	560.4	673.1
40.7	23.2	40.1	89.2	45.5	35	147	19.9	57.7	88.3	55.6	56.6	699.1	640.7
15.2	45.9	3.6	90.9	89.9	72.5	37.8	84.7	11.5	72.5	54.7	5.3	584.5	636.7
0.5	53.9	45.2	67.6	87.7	67.1	82	50	19.6	27.3	70.7	55.9	627.5	560.9
25.9	17.4	2.8	46.1	108	65.8	34.7	72.3	112	95.8	36.3	22.1	639.3	707.4
2.8	12.2	55.8	64.2	85.8	10.2	44.5	118	23.3	7.9	112	12.7	548.9	483.1
51.6	2.5	55.8	91.3	41.4	24.4	53.8	108	10.7	45	41.4	48.3	573.9	609.2
25.9	70.6	6.1	53.9	33.5	48.9	97	98.4	53.2	112	104	41.2	744.6	689.2
7.1	43.8	49.7	16.1	29.7	46.2	29.3	77.5	102	32.2	135	69	637.2	578.8
9.7	4.5	3.1	61.9	67.7	87.8	67.9	30.4	111	98.3	86.6	37.1	666.2	746.3
27.5	26.7	27.7	21.5	128	97.8	26.7	52.5	64.7	71.4	95.9	33	673.1	668.2
74.4	5.6	41.4	69.1	109	93.4	103	54.6	28.5	44	86.2	42.2	751.7	751.9
5.1	22.3	38.6	43.2	81.3	64.6	82.3	15	60	96.2	104	23.9	636.6	637.0
13.2	55.3	1.6	33.1	29.6	54	34.4	36.9	62	65.5	29	68	482.6	513.5
18.8	30.2	37.4	40	96.4	134	46.8	87.6	98.5	77.7	77.2	70.6	815.3	764.4
32.7	30.3	99.4	105	77.5	86.8	38.6	30	95.2	74.7	93.8	49.7	814.1	818.0
45.1	22.1	63.7	78.9	111	72.5	61.3	65.4	61.5	54.3	82.5	34.3	752.6	779.3
39.1	29.5	78.2	48.3	50.6	93.2	51.1	58.2	84	47	54.2	32.3	665.7	696.0
19.5	45.8	83.5	63.5	82.9	102	63	39.3	87.3	75.3	22.2	18.5	702.8	748.6
	19.3	59.4	63.5	29	42.4	40.6	166	129	73	124	54.5	800.7	662.9
80.9		48.5	67	62.1	19.6	33.8	85.3	74.6	58.3	77.7	53.8	661.6	708.6
48	23.8	50.6	84.2	46.7	27	30.8	54.1	67.9	91	99.9	65.1	689.1	655.6
38.5	5.5	93.6	114	40.3	123	129	80.5	57.4	109	53	39.2	882.3	955.8
0.2	106	16.8	67.5	84.6	65.7	86.3	95.4	139	96.2	42.8	17.8	818.3	849.9
39.8	3.6	56.2	61.2	79.3	123	38	93.7	81.7	51.1	96.7	62.9	787.7	688.2
40.5	54.3	52.3	63.2	101	42.5	29.4	96.4	43.2	143	88.1	111	864.7	825.4
6.9	50.9	24.2	161	89.3	134	44	81	44.6	28.6	73.6	37.4	775.8	863.6
2	55.2	63.1	30	103	47.2	49	92.4	58.7	80	159	18.2	758.1	691.6
34.2	22.1	53.2	55.5	104	67.3	45.2	119	206	59.3	48.2	94.4	909.2	943.0
5.6	4.5	77.3	83.4	20.2	88.3	33.4	73.5	80.5	48.2	111	35.8	661.5	657.5
29.1	25.4	42.1	58.8	32.7	50.4	39	59.1	44.6	98.4	67.7	19.4	566.7	626.4
35.4	5	22	29.1	86.2	84.2	20	51.8	75	109	142	18.6	678.8	604.8
28	44.3	44.8	110	118	87	68.6	78.2	39.4	96.7	46.8	120	881.4	875.6
6.6	10	93.2	90.3	60	23.1	51.8	75.4	72.2	78	45.8	32.3	638.7	727.4
48.8	20.4	56.5	81.2	76	27.4	78.2	72.2	115	58.8	114	26.8	775.4	712.6
73		26	72.4	51	101	43.2	48	96.6	89.4	104	42.8	747.6	741.4
21	0.6	28.2	79	84.8	78.1	48	81.2	49.2	32	104	40.2	646.7	648.9
83.7	6.9	25.8	65.2	73.2	8.4	85.6	115	66.3	201	105	8.6	845	875.3
75.5	62.4	6.6	112	72.1	63	65.6	25	235	70.8	65.2	82.8	935.3	901.6
37.4	47.4	50.2	30.6	72.3	116	55.3	103	148	48.5	64.4	14.8	786.9	856.7
92.2	25.3	79.8	44.3	80.8	175	52.9	93.6	54.3	39.8	48.7	37.6	824.1	817.2
36	27.4	24.5	41.9	40.7	60.7	103	49.4	77.1	74.6	112	43.6	691.5	621.6
31.4	19.5	24.7	94.5	86.6	188	118	107	84.8	39.3	93.8	31.3	919.1	949.4
6.2	41.7	20.6	10.4	44.6	76.6	11	63.1	92	91.6	76	41.2	575	582.9
6.9	29.6	52	101	120	95	116	42.8	58.6	72.8	45	15.4	755.1	811.9
	36.3	41	27.8	127	104	81.6	36	122	98.4	132	69.5	876	734.5
5.6	7.2	38.8	108	100	54.2	230	34.8	116	61.2	97.2	98.8	951.8	957.3
27.8	39.2	14.8	95.4	21.2	55	50.2	97	90.8	96.9	104	22.3	715	784.3

Summaries:
Mean= 735.4
Maximum= 1022.6
Minimum= 483.1

Monthly Total Snowfall Depths (cm) for TRENTON A 6158875

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Water Year
1950	51.6	58.6	47.5	8.1							27.7	38.2	231.7	
1951	29.7	21.9	17.9	0.3							43.7	93.1	206.6	135.7
1952	42.4	34.5	9.8									43.7	130.4	223.5
1953	39.9	28.3									15	25.7	108.9	111.9
1954	97.3	23.7	33.1	0.5							4.6	24.9	184.1	195.3
1955	40.1	24.1	67.5	0.5							6.6	36.7	175.5	161.7
1956	29.2	36.4	42.8	15.5							38.4	34.3	196.6	167.2
1957	55.9	16.7	23.2	10.4							1.4	10.8	118.4	178.9
1958	39.6	93.6	23.3	0.3							35.2	55	247	169.0
1959	51.4	52.2	27.7	4.1							20.7	53.6	209.7	225.6
1960	63.9	67.3	41.4	0.3							0.5	67.3	240.7	247.2
1961	30.7	11.7	38.1	16.3							8.6	53.9	159.3	164.6
1962	37.4	55.9	18.3	6.2						6.6	3.6	53.5	181.5	186.9
1963	47.9	28.8	22.4	4.6	4.6						1.8	53.8	163.9	165.4
1964	20.7	28.5	24.2	10.5						0.8	4.3	36.3	125.3	140.3
1965	77.6	55.7	38.2	3							12.5	13.2	200.2	215.1
1966	75.1	25.2	9.4	7.8	1.3						8.2	24.6	151.6	144.5
1967	60.4	45.4	17.7	1.5							20.7	29	174.7	157.8
1968	59.2	19	20.1							0.3	20.3	50.6	169.5	148.3
1969	26	19.2	4.9	3.3						5.9	19	36.5	114.8	130.2
1970	29	38.6	13.8	8.1							9.9	58.2	157.6	145.0
1971	46	66.5	64	2.8							23.2	25.5	228	247.4
1972	50.6	60.8	45.4	8.4						0.8	18.2	69.7	253.9	214.7
1973	12.8	25.5	1.5	15.3							3.6	41.7	100.4	143.0
1974	34.5	20.6	30	1.6						1	2.5	50	140.2	133.0
1975	34.5	37.1	20.8	28.5							3.6	70	194.5	173.4
1976	52.3	22.3	49.6	11.9						2.3	20.1	69.7	228.2	212.0
1977	82.3	15.7	42.7	5.8	5						20.5	120	292.5	241.3
1978	84.8	11.5	23	4.6							9.7	30.8	164.4	264.4
1979	74.6	37.1	1.1	13.7						0.3	0.2	16.8	143.8	167.3
1980	15.1	41	30.9								16.1	48.3	151.4	104.0
1981	50.7	24.4	19.2	0.2							2.2	48.5	145.2	158.9
1982	58.2	34.8	17.1	4.4							10.8	20.7	146	165.2
1983	10.2	11.5	21	14.6							24.2	58.8	140.3	88.8
1984	53.2	56.2	17.2								1.8	35	163.4	209.6
1985	59.2	57	27.8	4							11.6	103	262.5	184.8
1986	27.1	33.2	36.4	0.4							12.2	15.2	124.5	211.7
1987	62.2	17.8	17.6	11							6.6	26	141.2	136.0
1988	31	71.1	6							0.2		31.3	139.6	140.9
1989	14.8	36.6	38.9	10.2							21.4	35	156.9	131.8
1990	40.2	34.6	8.4	4.2							2.8	28	118.2	143.8
1991	54.4	27.2	17.4								17.2	41.6	157.8	129.8
1992	26	30.4	34.5	5							12	64.5	172.4	154.7
1993	30	60.7	24.2	13.6						2	3.2	35.5	169.2	207.0
1994	55.4	38.8	30.4	12.5							13	26.6	176.7	175.8
1995	39.5	29	6.4	3							47.3	35	160.2	117.5
1996	31.8	11.7	21.1	4							26	33.4	128	150.9
1997	90.1	28.6	64.1	4.6						1.6	24.2	14.4	227.6	248.4
1998	50.4	18.8	30.8								5.8	12.6	118.4	138.6
1999	114	2.2	41							2.8	2.2	20.1	182.2	178.4
2000	16.3	32.4	12.8	9							11	73.6	155.1	92.8
2001	51.7	37.7	33.5	0.2								39	162.1	207.7
2002	43.2	21.8	39	13.2	0.2						23.2	12.4	153	156.4
2003	45.7	39.2	25.4	32							2.8	18	163.1	177.9
2004	64.2	29	13	1.6							0.4	41	149.2	128.6
2005	33.5	38	16.4	8.8							13.8	47.4	157.9	138.1
													Mean=	168.9
													Maximum=	264.4
													Minimum=	88.8

OCTOBER 2009

REPORT ON

ROBLIN LAKE GROUNDWATER EVALUATION, AMELIASBURGH, PRINCE EDWARD COUNTY, ONTARIO

Submitted to:
Quinte Conservation
2061 Old Highway 2
RR#2
Belleville, ON K8N 4Z2

REPORT

Report Number: 09-1127-0065

Distribution:

2 copies - Quinte Conservation
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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by Quinte Conservation to complete an evaluation of the groundwater contribution to Roblin Lake in the Township of Ameliasburgh, Ontario. Quinte Conservation has undertaken an investigation to better understand the water movement through the Ameliasburgh subcatchment. The scope of work for the groundwater evaluation was set out in Golder's proposal (P9-1127-0028, dated March 18, 2009) and included:

- Preparation of a conceptual geologic and hydrogeologic model;
- Preparation of a numerical model and simulations of groundwater flow; and,
- Preparation of maps and a report.

2.0 REGIONAL SETTING

2.1 Physiography

Roblin Lake is situated in the Hamlet of Ameliasburgh in Prince Edward County, approximately 13 km southwest of Belleville (see Figure 1). Lake Ontario and the Bay of Quinte are located 10 km southwest and 7 km north of the lake, respectively.

The regional topography is shown in Figure 2, and indicates that Roblin Lake is located within a topographic depression on the top of an east-west trending escarpment that drops off steeply approximately 500 m north of the lake. Roblin Lake is situated in the broader St. Lawrence Lowlands Physiographic Region, and in particular in the Prince Edward physiographic region (Chapman and Putnam, 1984), which is generally characterized by flat topography and shallow soil over limestone bedrock.

2.2 Surficial Geology

Surficial geology for the Roblin Lake area is shown in Figure 3. The area in the immediate vicinity of Roblin Lake generally has a thin veneer of drift deposits over Paleozoic bedrock. To the north of the lake, at the base of the escarpment, surficial geology includes coarse-textured glaciolacustrine deposits (i.e., sand and gravel), fine-textured glaciolacustrine deposits (i.e., silt and clay), local sandy silt to silty sand till deposits, and organic deposits.

2.3 Bedrock Geology

The bedrock geology for the Roblin Lake area is shown in Figure 4. The escarpment on which Roblin Lake is situated consists of the Middle Ordovician-aged nodular limestone and shale of the Lindsay Formation. The Lindsay Formation is underlain by the Verulam Formation, consisting of interbedded limestone and shale. The Lindsay Formation is not present in the lower-lying areas north of the escarpment, where the Verulam Formation is the uppermost bedrock unit.

2.4 Hydrogeology

Beyond the Hamlet of Ameliasburgh, which is served by a municipal supply from Roblin Lake, water supply in the area surrounding Roblin Lake is drawn from water wells. The locations of the water wells contained within the MOE Water Well Information System (WWIS) are shown on Figure 2.

3.0 BATHYMETRIC SURVEY

To assist in the development of the conceptual hydrostratigraphic model and numerical groundwater model, a bathymetry survey of Roblin Lake was carried out by Golder on May 21, 2009. The Garmin GPSMAP188 real-time GPS / sonar depth sounder was used for navigation, positioning, and water depth measurement during the bathymetry survey. The GPSMAP188 provided a real-time display of position, speed, heading, and water depth and was also linked to a portable laptop computer in order to record the navigation and bathymetric data acquired during the survey. The 200 kHz (narrow beam) sonar setting was used to acquire the bathymetric data.

The survey was carried out along a series of tracklines spaced approximately 15 m apart in a pattern which oriented the survey lines roughly perpendicular to shore. The tracklines were displayed on the GPSMAP188 with real-time GPS position also displayed on-screen. These tracklines were navigated as closely as possible by the helmsman and navigator in an aluminum boat.

Bathymetry data were recorded simultaneously with the GPS navigation data on a portable computer. All bathymetric data were acquired in WGS84 latitude and longitude then converted into the UTM NAD83 co-ordinate system. The raw bathymetric survey data expressed as elevation were then graphed as a function of distance along the survey trackline and also posted in plan view. A small number of spurious depth sounder readings were removed from the raw data set based on examination of these graphs and the plot plan. The bathymetric depths were later converted into elevation using a reference lake water level of 110.54 m above sea level (masl) as provided by Quinte Conservation.

The edited bathymetry survey tracklines and data points are presented on Figure 5. These data were gridded using a minimum curvature algorithm with a 4 m grid cell size. The gridded data was masked to the approximate shoreline which existed at the time of the survey and then colour contoured.

As shown, the lake bottom slopes gently downward to the west over the eastern half of the lake, and has a much steeper slope along the west and south sides. The maximum depth of the lake is approximately 15 m near the west edge of the lake, in the area of the municipal water intake.

4.0 CONCEPTUAL MODEL DEVELOPMENT

4.1 Method

A conceptual model describes the essential features of a hydrogeological system. Data from a variety of sources were considered in developing the conceptual model. Mapping data included Natural Resources Values Information System (NRVIS) maps from the Ontario Ministry of Natural Resources, Ontario Geological Survey (OGS) maps from Ontario Ministry of Northern Development and Mines, and the data obtained during the bathymetric survey described in Section 3.0. Subsurface information was obtained from the MOE WWIS. Data provided by Quinte Conservation (Quinte Conservation Data) were also applied; these included water level and well depth measurements, eastings and northings for six private wells and a Provincial Groundwater Monitoring Network (PGMN) well near Roblin Lake. Geology information for these wells was not available.

Based on a preliminary scoping of the data, an 11 km by 11 km study area was chosen, centred on Roblin Lake. Within this area, water well records were extracted from the WWIS, combined with available data from other sources, and examined to determine subsurface geological and hydrogeological conditions.

The hydrogeological information contained in the WWIS represents water level data collected during different years, different seasons and from different formations depending on the depth of the well. The static water levels may not be representative of actual static conditions as they are likely measured shortly after completion of the drilling of the well. On an individual basis, the information cannot be relied upon to be representative of actual current conditions; however, when multiple wells are considered together, trends in water levels can be observed and outliers can be fairly easily identified. It is recognized that the information in the WWIS should be used with an acknowledgement of its limitations. The simulation of steady state (versus transient) conditions in the numerical model and professional judgement were applied in this study to account for the uncertainty inherent in the WWIS data.

All contouring completed for development of the conceptual model was completed on a 100 m uniform grid, using the default kriging option within Surfer© by Golden Software Inc. Kriging is a commonly utilized geo-statistical technique used to interpolate unknown values (elevation, head, etc.) at a given geographical point based on nearby known values.

Based on the available information, and on the results of the data review and processing, a "layer cake" hydrostratigraphic model was postulated. Lateral boundaries to the groundwater flow system were postulated at groundwater divides (i.e., vertical flow paths), on paths of known horizontal groundwater flow direction (i.e., horizontal flow paths), or along lines of constant groundwater elevation. Areas with distinct recharge characteristics were postulated based on topography, surficial geology and underlying hydrostratigraphy. Areas of groundwater discharge were postulated based on the locations of the watercourses, lakes, and wetlands, and on topography.

4.2 Results

4.2.1 Hydrostratigraphy

Figures 6 to 9 show geological and hydrogeological information from the WWIS and Quinte Conservation Data projected onto regional cross-sections. It is noted that the wells located within 1 km of the cross-section lines shown on Figure 2 were projected onto the cross-sections. As a result, the ground surface for some wells on the cross-sections may not coincide with the ground surface profile shown.

Based on the information in the WWIS and mapped geology, the following four hydrostratigraphic units, in order of increasing depth, were postulated for the hydrogeological system under investigation:

1) Clay overburden (typically 0 to 8 m thickness);
2) Sand overburden (typically 0 to 10 m thickness);
3) Weathered limestone bedrock (estimated at 10 m thickness); and,
4) Un-weathered limestone bedrock.

The top of the model was set equal to ground surface elevation taken from the NRVIS digital elevation model.

Clay was assumed to be present everywhere where clay was mapped at surface (i.e., where unit 8 is mapped on Figure 3), while sand was assumed to be present everywhere where sand and till were mapped at surface (i.e., where units 5 and 9 are mapped on Figure 3). Organic deposits were not considered to be a significant hydrostratigraphic unit and were not included in the conceptual model. The thickness of each overburden layer (i.e., clay or sand) was interpolated onto the 100 m grid from the thickness of the unit recorded in the WWIS.

Initial hydraulic conductivity values were assigned based on available field data, typical ranges (shown in Table 1 below) and professional experience with hydrostratigraphic units. Local adjustments were considered during the model calibration exercise.

Table 1: Typical Hydraulic Conductivity Ranges (Freeze and Cherry, 1979)

Material	Range of Hydraulic Conductivity (m/s)
Un-weathered Clay[1]	1×10^{-13} to 1×10^{-9}
Clean Sand	1×10^{-6} to 1×10^{-2}
Limestone and Dolostone	1×10^{-9} to 1×10^{-6}

Notes: [1] Weathering of clay may increase the hydraulic conductivity by at least one order of magnitude.

The hydraulic conductivity of the sand unit was assumed to be in the middle of the typical range (i.e., approximately 1×10^{-4} m/s; see Table 1), while the hydraulic conductivity of the clay unit was assumed to be near the high end of the typical range (i.e., approximately 1×10^{-9} m/s; see Table 1) to account for weathering of this surficial deposit.

The limestone bedrock surface was determined by subtracting the overburden thickness from the interpolated ground surface elevation. The upper 10 m of limestone bedrock were assumed to be weathered and of higher hydraulic conductivity than the remainder of the limestone bedrock. The hydraulic conductivity of the unweathered limestone bedrock was assumed approximately equal to the value inferred from a rising-head test conducted by Quinte Conservation at a local water well with a depth of 30 m (i.e., around $5x10^{-7}$ m/s). The hydraulic conductivity of the weathered limestone bedrock hydrostratigraphic unit is identified as an uncertainty in the conceptual model.

4.2.2 Groundwater Recharge, Discharge and Flow Direction

Figure 10 shows contours of groundwater elevation as inferred from all wells in the WWIS and the Quinte Conservation Data. The groundwater elevation contours generally follow the topographic contours, with the highest elevations measured along the escarpment on which Roblin Lake is situated, and groundwater flowing north toward the low-lying area at the base of the escarpment and south along the topographic slope south of the lake. Four of the Quinte Conservation Data wells were shallow dug wells; no water level data for dug wells was available from the WWIS. The limited amount of water level data from shallow wells dug into the weathered bedrock near Roblin Lake is identified to be an uncertainty in the conceptual model.

It was assumed that groundwater flow beneath and surrounding Roblin Lake is recharged at uplands and discharges at lowlands including wetlands, and streams. The recharge rate was assumed controlled by the surficial and bedrock geology, and the following recharge zones were postulated:

1) Higher recharge through sand and bedrock exposed at the ground surface; and,
2) Lower recharge through clay at the ground surface.

5.0 GROUNDWATER FLOW MODELLING

A numerical model was developed to simulate the 3-D distribution of hydraulic head in the study area, using MODFLOW (McDonald and Harbaugh, 1988). A calibrated flow model was developed through the establishment of a finite difference grid, distribution of hydraulic conductivity, and distribution of boundary conditions, with adjustments, as necessary, to match the output of the model to observed conditions (in this case the observed static water levels in the WWIS and the Quinte Conservation Data). Visual MODFLOW Version 4.2 was used as a pre- and post-processor for MODFLOW.

5.1 Method

5.1.1 Finite Difference Grid

The finite difference grid divides the model domain into rows (separated by lines of constant northing), columns (separated by lines of constant easting), and layers (vertically through the model).

The row and column widths were made a uniform size of 100 m, chosen to allow for an appropriate distribution of hydraulic conductivities and boundary conditions, while maintaining a manageable overall grid size. The model domain was divided into nine layers of grid blocks, with individual grid block thicknesses chosen to best match the "layer cake" hydrostratigraphic model. Layer thicknesses ranged from 0.5 m to 50 m (in the unweathered limestone bedrock only). The outline of the model domain is shown in Figure 11.

5.1.2 Boundary Conditions

Boundary conditions were assigned to the outside of the model to match the boundaries of the flow system as postulated in the conceptual model.

Groundwater recharge was simulated using constant flux boundary conditions applied to the top surface of the model. Zones of constant recharge rate were assigned so as to correspond with the distinct recharge areas postulated in the conceptual model. Adjustments of the rates assigned to these zones, modification of the outlines of these zones, and addition of new zones were all considered during model calibration.

Constant head boundary conditions were applied to the upper grid block layer within the footprint of Roblin Lake to hold the groundwater elevation at the lake bottom surface at 110.54 masl. The latter value is the measured lake elevation provided by Quinte Conservation. The use of constant head boundary conditions instead of drains at Roblin Lake allows for the possibility of both discharge and recharge of groundwater.

Natural groundwater discharge was simulated with drain boundary conditions assigned in the uppermost grid block layer in the areas postulated to be groundwater discharge areas. The drain elevation was set equal to the elevation of the grid block top. Based on McDonald and Harbaugh (1988), the drain conductance was set according to the equation:

$$C = 2K_z \frac{A}{dz}$$

where C is the vertical conductance, K_z is the vertical hydraulic conductivity, A is the plan-view cross-sectional area of the grid block, and dz is the grid block height in the vertical direction.

5.1.3 Hydraulic Conductivity

Hydraulic conductivity was assigned to the individual grid blocks based on their location within the assumed hydrostratigraphic model and the values postulated in the conceptual model. For the numerical model it was assumed that the overburden and bedrock formations were anisotropic, with the bedrock (K_h=100K_v) more anisotropic than the overburden (K_h=10K_v) due to the layered nature of the bedrock. The simulated hydraulic conductivity zones are shown in Figure 11.

5.1.4 Model Calibration

In general terms, model calibration is the exercise of adjusting model properties and boundary conditions (generally referred to as "parameters"), within reasonable bounds, so as to best match the model output to the observed conditions. In the case of steady-state groundwater flow modelling, the model output is limited to groundwater elevations and groundwater discharge rates, and both of these would ideally be considered during model calibration. In this case, however, since no groundwater discharge information (i.e., baseflow inferred from stream-flow data as measured in a gauging station) was available for the watercourses within the model domain, only the groundwater elevations were considered in the model calibration.

For comparison to the observed values, simulated groundwater elevations at each measurement point were interpolated from the simulated groundwater elevations in the surrounding grid blocks. The match between the observed and simulated groundwater elevations was assessed from plots of simulated versus observed groundwater elevations, and from calibration statistics: maximum over-prediction, maximum under-prediction, residual mean, absolute residual mean, root mean square (RMS), normalized RMS, and correlation coefficient.

The strategy employed for model calibration was to first adjust the hydraulic conductivities of the hydrostratigraphic layers and the rates of the recharge zones as inferred from the conceptual model in order to best match the simulated to observed groundwater elevations on a regional scale (i.e., throughout the model). Starting values and reasonable ranges for these parameters were inferred from the available data and from tabulated values (i.e., published typical values and from Golder's experience with similar formations).

Once the regional calibration was obtained, local adjustments to the shape and number of recharge zones were considered to obtain the best possible match to the observed groundwater elevations in close proximity to the lake. Local adjustments to the hydraulic conductivities were also considered, if justifiable. The "best calibrated model" was identified by this process, and its input parameters and output are discussed in the following sections.

5.2 Results

The model input parameters leading to the best calibrated model are summarized in Table 2 below:

Table 2: Numerical Model Input Parameters

Model Parameter		Value
Horizontal Hydraulic Conductivity (m/s)	Clay[1]	$1x10^{-8}$
	Sand[1]	$5x10^{-4}$
	Weathered Limestone[2]	$3x10^{-6}$
	Un-weathered Limestone[2]	$5x10^{-7}$
	Roblin Lake Weathered/Fractured Bedrock Zone[1]	$7x10^{-5}$
Recharge (mm/year)	Clay	5
	Sand	50
	Weathered Limestone	15
	Roblin Lake Weathered/Fractured Bedrock Zone	70

Notes: [1] In overburden and the Roblin Lake weathered/fractured bedrock zone, the hydraulic conductivity in the vertical direction is ten times less than in the horizontal direction
[2] In the weathered and un-weathered limestone the hydraulic conductivity in the vertical direction is one hundred times less than in the horizontal direction

The Roblin Lake Weathered/Fractured Bedrock Zone (see Figure 11) is an area 500 to 1200 m wide around Roblin Lake where the hydraulic conductivity of the upper 3 m of weathered bedrock and the recharge rate were increased to better match the observed groundwater elevations in the dug wells (from the Quinte Conservation Data) and in the WWIS wells near the lake. This was considered a reasonable adjustment based on anecdotal information indicating that the upper bedrock around the lake is significantly weathered and fractured, and that many local wells (including four of the Quinte Conservation Data wells) are dug into the upper bedrock.

The results of the calibration indicate a reasonable agreement between the simulated groundwater elevations and the observed groundwater elevations from the WWIS wells and the Quinte Conservation Data, considering the temporal variations inherent in the WWIS wells.

The calibration statistics for the Quinte Conservation Data set and the entire data set including Quinte Conservation Data and WWIS wells are summarized in Table 3 below:

Table 3: Numerical Model Calibration Statistics

	Quinte Conservation Data	WWIS and Quinte Conservation Data
Count	6	134
Maximum Over-prediction (m)	1.93	22.65
Maximum Under-prediction (m)	-1.47	-9.98

	Quinte Conservation Data	WWIS and Quinte Conservation Data
Residual Mean (m)	0.24	2.35
Absolute Residual Mean (m)	0.83	4.44
RMS	1.06	6.05
Normalized RMS (%)	12.8	11.9
Correlation Coefficient	0.95	0.92

The PGMN well was not used in the calibration of the Quinte Conservation Data set because it is completed in a much deeper unit than the other Quinte Conservation Data wells (at 57 m below ground surface).

5.3 Groundwater Contribution to Roblin Lake

Contours of simulated water table elevation from the best calibrated model are illustrated on Figure 11 and generally match the observed groundwater contours (Figure 10), with the highest groundwater elevations along the top of the escarpment and a steep decrease in the water table along the slope of the escarpment.

The groundwater contribution to Roblin Lake was estimated as the rate of transfer of water to the cells underlying the lake from the surrounding cells. Over the area of the lake, an estimated 215 m^3/d of groundwater discharges to the lake, and an estimated 20 m^3/d of water recharges from the lake to the groundwater. The majority of the groundwater discharge to the lake occurs on the south side of the lake, where groundwater hydraulic heads are higher.

6.0 DATA GAPS

Data gaps identified in this study are:

1) The hydraulic conductivity of the weathered limestone bedrock hydrostratigraphic unit and the Roblin Lake weathered/fractured bedrock zone. This information could be supplied by one or more pumping tests or rising-head tests conducted at nearby wells completed in these units.

2) The limited amount of water level data from shallow wells dug into the weathered bedrock near Roblin Lake. This information could be supplied by groundwater monitoring wells installed in the area.

Resolution of the identified data gaps would result in a more accurate estimate of the groundwater contribution to Roblin Lake.

7.0 CONCLUSIONS

Golder Associates Ltd. (Golder) was retained by Quinte Conservation to complete an evaluation of the groundwater contribution to Roblin Lake in the Township of Ameliasburgh, Ontario. Quinte Conservation has undertaken an investigation to better understand the water movement through the Ameliasburgh subcatchment.

Roblin Lake is located within a topographic depression on the top of an east-west trending escarpment that drops off steeply approximately 500 m north of the lake. A bathymetric survey determined that the lake bottom slopes gently downward to the west over the eastern half of the lake, and has a much steeper slope along the west and south sides. The maximum depth of the lake is approximately 15 m near the west edge of the lake, in the area of the municipal water intake.

The conceptual hydrostratigraphic model included four units: clay overburden and sand overburden in the low-lying areas at the base of the escarpment, and weathered limestone bedrock underlain by unweathered limestone bedrock. The groundwater elevation contours generally follow the topographic contours, with the highest elevations measured along the escarpment on which Roblin Lake is situated and groundwater flowing north toward the low-lying area at the base of the escarpment and south along the topographic slope south of the lake.

During the 3-D numerical groundwater flow modelling process, an area of fractured/weathered bedrock around Roblin Lake having increased hydraulic conductivity and groundwater recharge was considered to match the groundwater levels measured in shallow dug wells in the area. The results of numerical modelling indicate that over the area of the lake, there is an estimated 215 m^3/d of groundwater discharge to the lake, and an estimated 20 m^3/d of water recharge from the lake to the groundwater. The majority of the groundwater discharge to the lake occurs on the south side of the lake, where groundwater hydraulic heads are higher.

8.0 LIMITATIONS AND USE OF REPORT

This report was prepared for the use of the Quinte Conservation. The report, which specifically includes all tables, figures and appendices, is based on data and information collected by Golder Associates Ltd. and is based solely on the conditions of the properties at the time of the work, supplemented by data obtained by Golder Associates Ltd. as described in this report.

Golder Associates Ltd. has relied in good faith on this information and does not accept responsibility for any deficiency, misstatements, or inaccuracies contained in the information as a result of omissions, misinterpretation or fraudulent acts of the persons contacted or omissions in the reviewed documentation.

The assessment of bathymetric conditions at this site has been made using the results of physical measurement from a limited number of monitoring locations. The conditions between measurement locations have been inferred based on conditions observed at the measurement locations. Conditions may vary from the measured locations.

The services performed as described in this report were conducted in a manner consistent with that level of care and skill normally exercised by other members of the engineering and geoscience professions currently practising under similar conditions, subject to the time limits and financial and physical constraints applicable to the services.

Any use which a third party makes of this report, or any reliance on, or decisions to be made based of it, are the responsibilities of such third parties. Golder Associates Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this report.

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Report Signature Page

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STEPHEN R. WILSON
PRACTISING MEMBER
0122
ONTARIO

LEB/SRW/am

n:\active\2009\1127 - geosciences\09-1127-0065 quinte ameliasburgh groundwater evaluation\report\09-1127-0065 report.docx

REFERENCES

Chapman, L.J., and Putnam, D.F., 1984. The Physiography of Southern Ontario. Ontario Geological Survey, Special Volume 2, 270p, Accompanied by Map P.2715 (coloured), scale 1:600,000.

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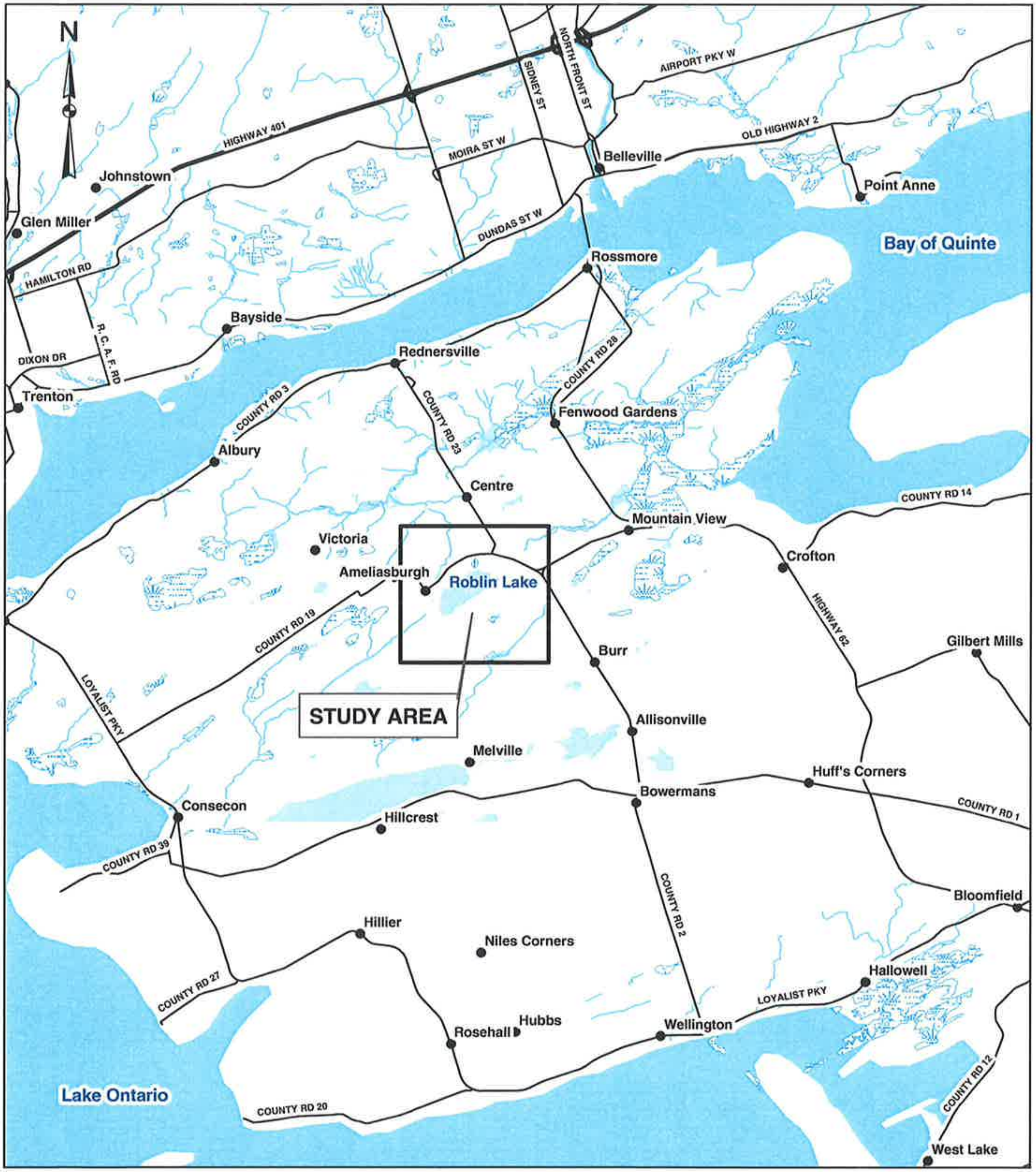

NOTE

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REFERENCE

Digital base map data supplied by DMTI Spatial Inc. CANMAP, 2008

Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 18

4 0 4

1:150,000 KILOMETRES

Golder Associates Ottawa, Ontario	DATE 18 AUG. 2009 DESIGN LB GIS AB CHECK LEB 7 Oct. 09 REVIEW [signature] 8 Oct-09	TITLE **KEY PLAN**
PROJECT No. 09-1127-0065 SCALE AS SHOWN REV. 0		PROJECT ROBLIN LAKE GROUNDWATER EVALUATION — **FIGURE: 1**

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LEGEND

- Water Well (MOE WWIS)
- Private Water Well (Quinte Conservation Data)
- Water Control Structure
- Municipal Water Intake
- Topographic Contour (masl)
- Roadway
- Waterbody
- Wetland
- River or Stream
- Woodlands
- Cross-Section Location in Plan
  *Refer to Figures 6 to 9 for Cross-Sections

NOTE

This figure is to be read in conjunction with the accompanying Golder Associates Ltd. report No. 09-1127-0065

REFERENCE

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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 18

1,000 0 1,000
SCALE 1:50,000 METRES

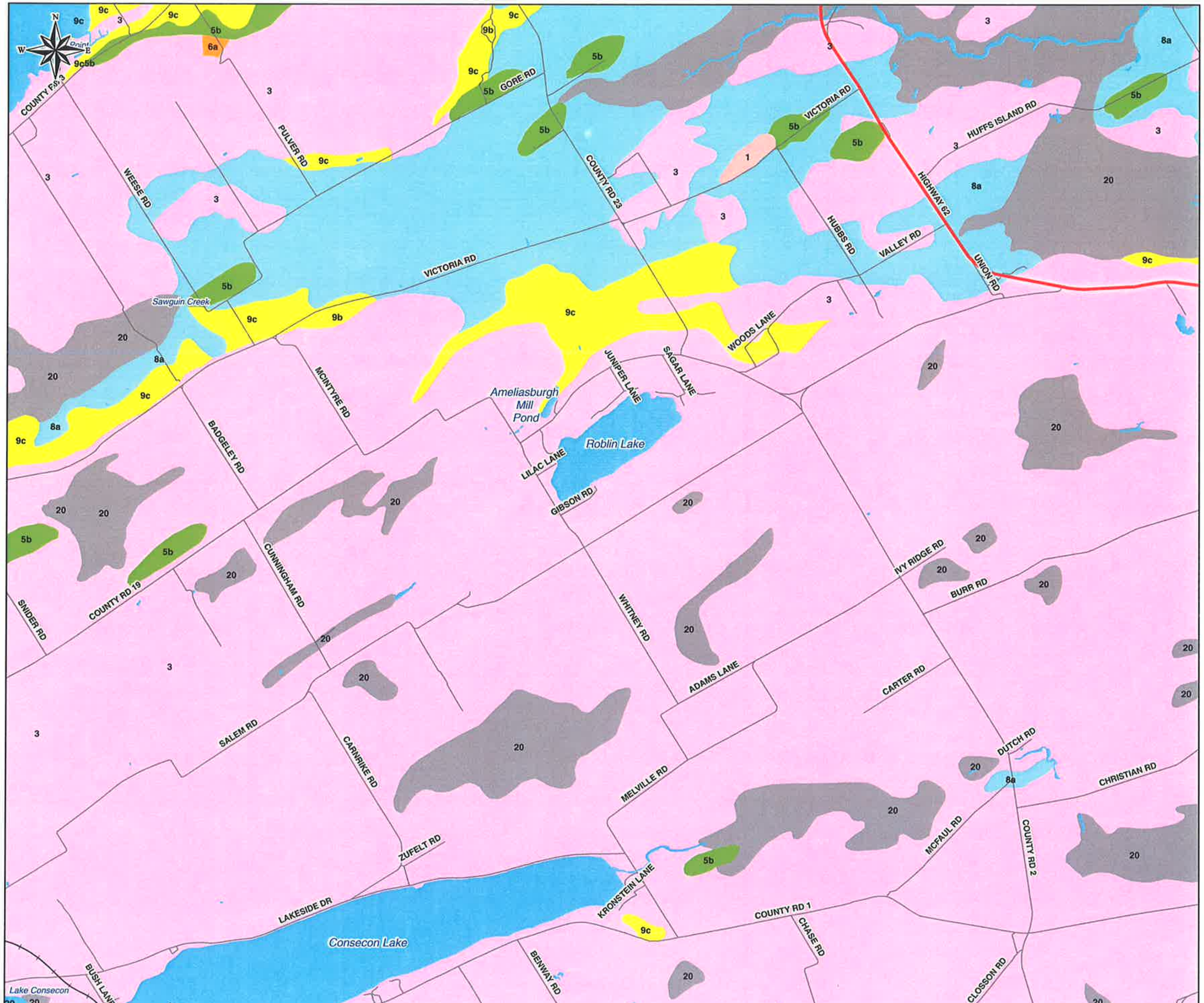
PROJECT
ROBLIN LAKE GROUNDWATER EVALUATION

TITLE
SITE PLAN

Golder Associates
Ottawa, Ontario

PROJECT No. 09-1127-0065			SCALE AS SHOWN	REV. 0
DESIGN	LB	18 AUG. 2009		
GIS	AB	18 AUG. 2009		
CHECK	LEB	7 Oct 09		
REVIEW				

FIGURE: 2



LEGEND

- **21** **Man-made deposit**: till, sewage, lagoon, landfill, urban development
- **20** **Organic deposits**: peat, muck, marl
- **19** **Modern alluvial deposits**: clay, silt, sand, gravel, may contain organic remains
- **18** **Colluvial deposits**: boulders, scree, talus, undifferentiated landslide materials
- **17** **Eolian deposits**: fine to very fine sand and silt
- **16** **Coarse-textured marine deposits**: sand, gravel, minor silt and clay
  - 16a: Deltaic deposits
  - 16b: Littoral deposits
  - 16c: Foreshore and basinal deposits
- **15** **Fine-textured marine deposits**: silt and clay, minor sand and gravel
- **14** **Coarse-textured lacustrine deposits**: sand, gravel, minor silt and clay
  - 14a: Deltaic deposits
  - 14b: Littoral deposits
  - 14c: Foreshore and basinal deposits
- **13** **Fine-textured lacustrine deposits**: silt and clay, minor sand and gravel
- **12** **Older alluvial deposits**: clay, silt, sand, gravel, may contain organic remains
- **11** **Coarse-textured glaciomarine deposits**: sand, gravel, minor silt and clay
  - 11a: Deltaic deposits
  - 11b: Littoral deposits
  - 11c: Foreshore and basinal deposits
- **10** **Fine-textured glaciomarine deposits**: silt and clay, minor sand and gravel
  - 10a: Massive-well laminated
  - 10b: Interbedded silt and clay and gritty, pebbly flow till and rainout deposits
- **9** **Coarse-textured glaciolacustrine deposits**: sand, gravel, minor silt and clay
  - 9a: Deltaic deposits
  - 9b: Littoral deposits
  - 9c: Foreshore and basinal deposits
- **8** **Fine-textured glaciolacustrine deposits**: silt and clay, minor sand and gravel
  - 8a: Massive to well laminated
  - 8b: Interbedded silt and clay and gritty, pebbly flow till and rainout deposits
- **7** **Glaciofluvial deposits**: river deposits and delta topset facies
  - 7a: Sandy deposits
  - 7b: Gravelly deposits
- **6** **Ice-contact stratified deposits**: sand and gravel, minor silt, clay and till
  - 6a: In moraines, kames, eskers and crevasse fills
  - 6b: In subaquatic fans
- **5a** **Till**: Silty sand to sand-textured till on Precambrian terrain
  - 5a: Shield-derived silty to sandy till
- **5b** Stone-poor, sandy silt to silty sand-textured till on Paleozoic terrain
- **5c** Stony, sandy silt to silty sand-textured till on Paleozoic terrain
- **5d** Clay to silt-textured till (derived from glaciolacustrine deposits or shale)
- **5e** Undifferentiated older till may include stratified deposits
- **4** **Bedrock-drift complex in Paleozoic terrain**
  - 4a: Primary till cover
  - 4b: Primary stratified drift cover
- **3** **Paleozoic bedrock**
- **2** **Bedrock-drift complex in Precambrian terrain**
  - 2a: Primary till cover
  - 2b: Primary stratified drift cover
- **1** **Precambrian bedrock**

NOTE

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REFERENCE

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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 18

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SCALE: 1:45,000 METRES

PROJECT

ROBLIN LAKE GROUNDWATER EVALUATION

TITLE

SURFICIAL GEOLOGY

Golder Associates
Ottawa, Ontario

PROJECT No. 09-1127-0065			SCALE AS SHOWN	REV. 0
DESIGN	LB	20 AUG 2009		
GIS	BT	20 AUG 2009		
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REVIEW	[illegible]	8 oct 09		

FIGURE: 3

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LEGEND

- Road
- Railroads
- Lindsay Formation
- Verulam Formation
- Precambrian
- Waterbody

NOTE

This figure is to be read in conjunction with the accompanying Golder Associates Ltd. report No. 09-1127-0065

REFERENCE

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SCALE: 1:45,000 METRES

PROJECT

ROBLIN LAKE GROUNDWATER EVALUATION

TITLE

BEDROCK GEOLOGY

Golder Associates
Ottawa, Ontario

PROJECT No. 09-1127-0065			SCALE AS SHOWN	REV. 0
DESIGN	LB	16 JUNE 2009	**FIGURE: 4**	
GIS	BT	16 JUNE 2009		
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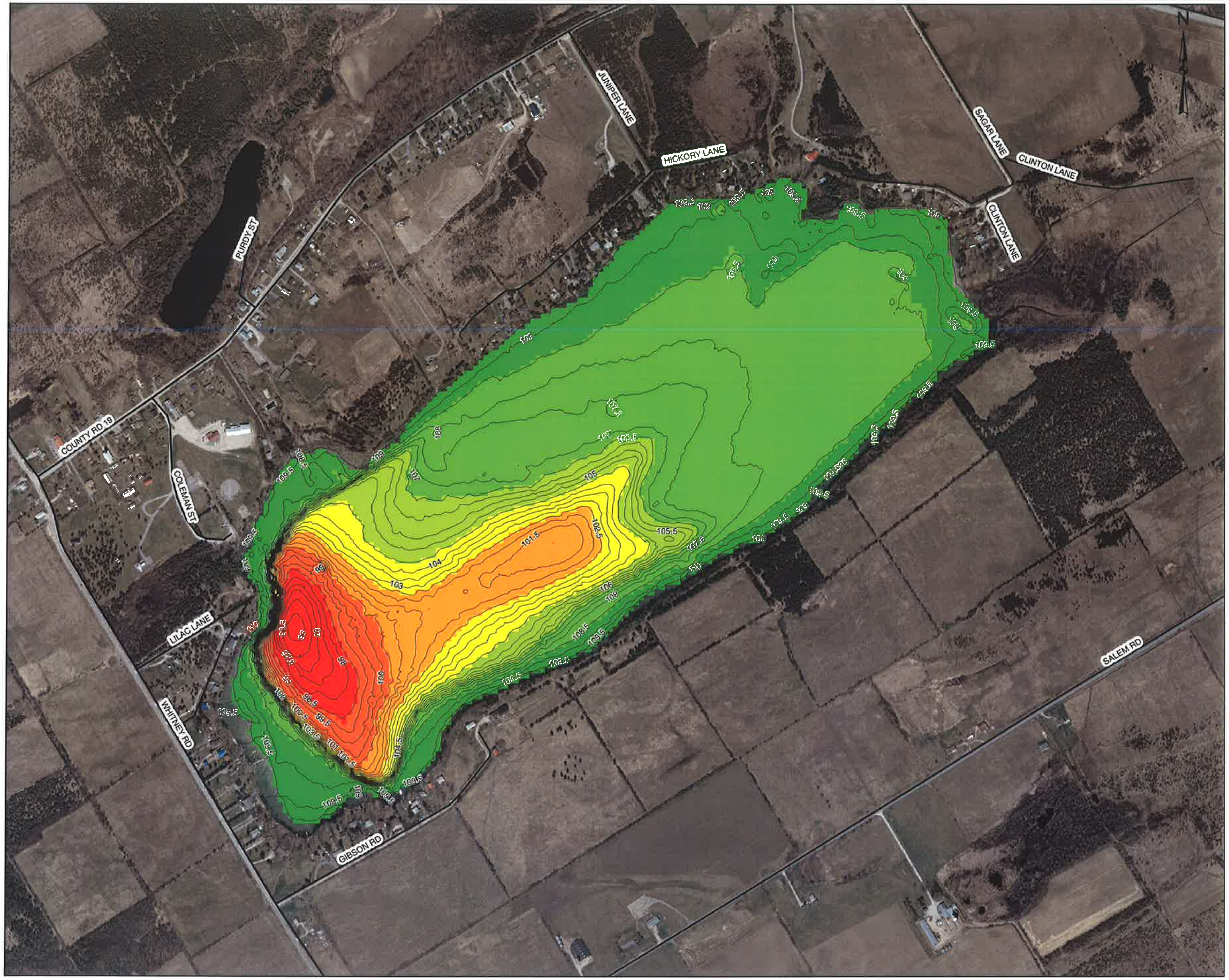

LEGEND

Roblin Lake Bottom Elevation Contour (masl)

Roadway

Lake Bottom Depth
(Metres below water surface)

- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14.7

NOTE

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REFERENCE

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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 18

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SCALE 1:7,500 METRES

PROJECT

ROBLIN LAKE GROUNDWATER EVALUATION

TITLE

BATHYMETRIC SURVEY RESULTS

Golder Associates
Ottawa, Ontario

PROJECT No.09-1127-0065			SCALE AS SHOWN	REV. 0
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GIS	AB	18 AUG. 2009		
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REVIEW				

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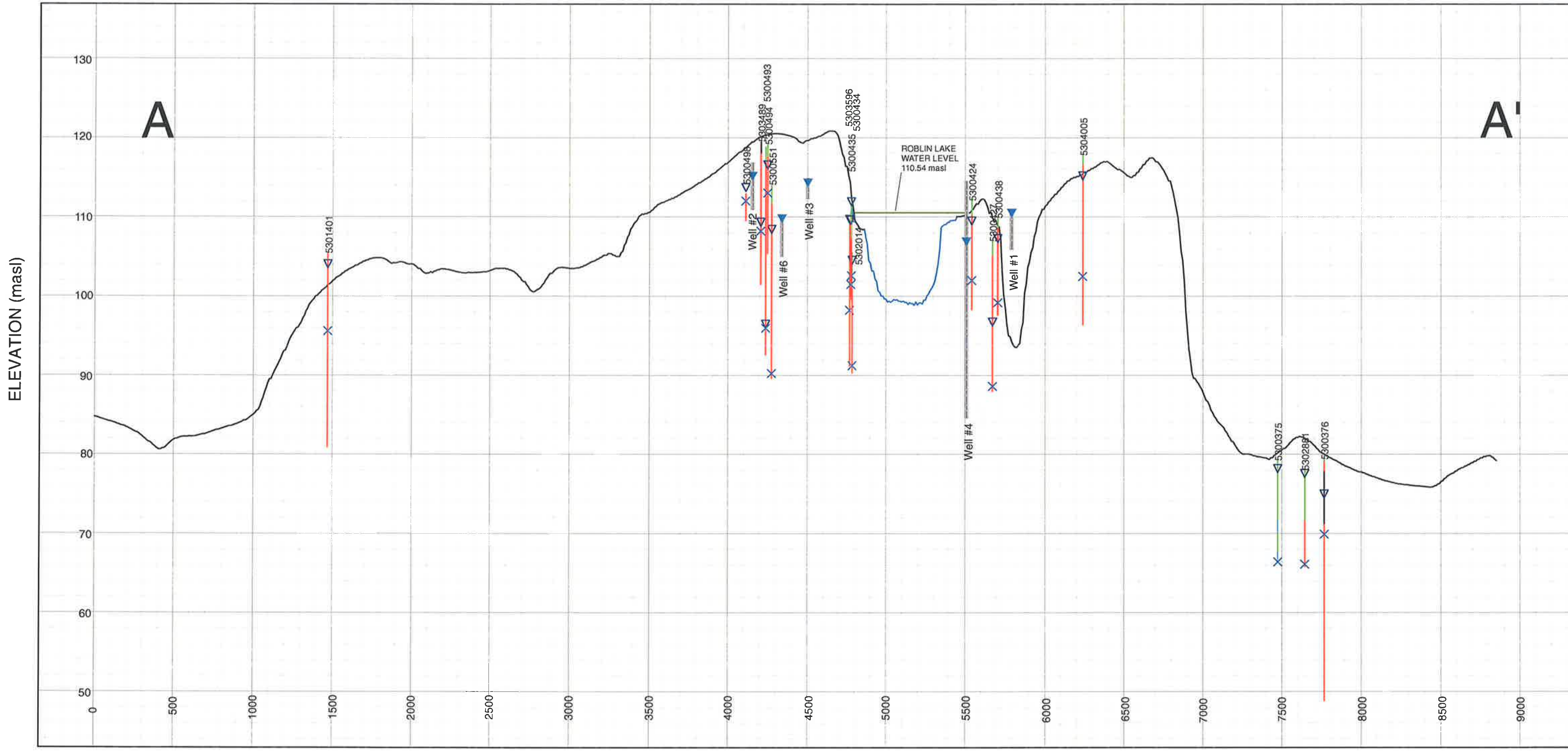

DISTANCE ALONG SECTION LINE (METRES)

500 250 0 500 1,000

SCALE 1:25,000 METRES

LEGEND

Well Driller's Description of Materials

- Overburden
- Clay
- Hardpan
- Sand/Gravel
- Limestone
- Shale
- Sandstone
- Precambrian

- 5301401 Water Well Record in WWIS
- x Record of Water Found in WWIS
- Static Water Level in WWIS
- Static Water Level - Quinte Conservation Data
- Private Water Well- Quinte Conservation Data (No Geology information Available)
- Ground Surface Profile (masl)
- Roblin Lake Bathymetric Surface (masl)

REFERENCE

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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 18

NOTE

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PROJECT

ROBLIN LAKE GROUNDWATER EVALUATION

TITLE

CROSS SECTION A - A'

Golder Associates
Ottawa, Ontario

PROJECT No. 09-1127-00658			SCALE AS SHOWN	REV. 0
DESIGN	BT	21 AUG 2009	FIGURE: 6	
GIS	BT	21 AUG 2009		
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REVIEW				

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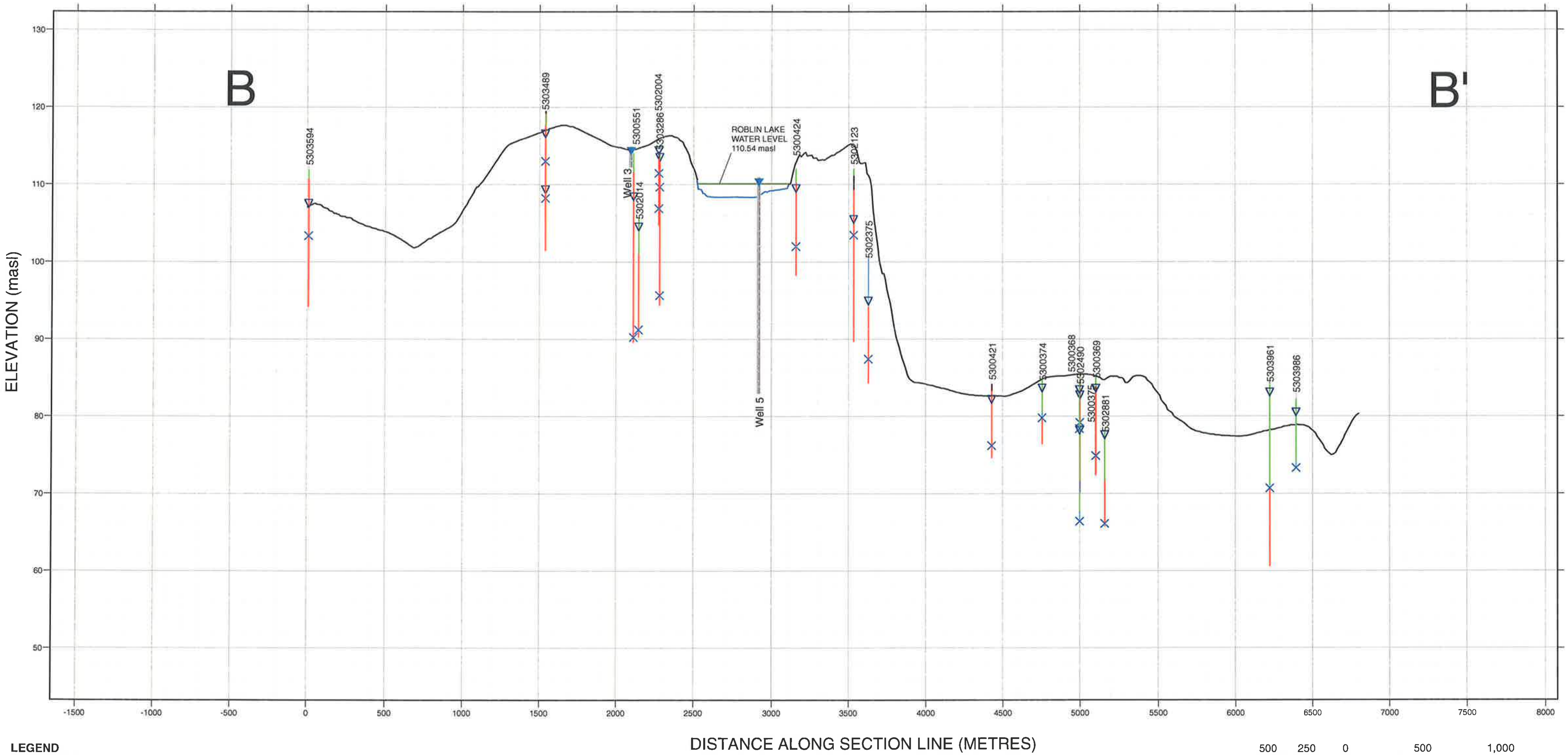

LEGEND

Well Driller's Description of Materials

- Overburden
- Clay
- Hardpan
- Sand/Gravel
- Limestone
- Shale
- Sandstone
- Precambrian

5303594 Water Well Record in WWIS
x Record of Water Found in WWIS
▽ Static Water Level in WWIS
▼ Static Water Level - Quinte Conservation Data
Private Water Well- Quinte Conservation Data (No Geology Information Available)
Ground Surface Profile (masl)
Roblin Lake Bathymetric Surface (masl)

500 250 0 500 1,000
SCALE 1:25,000 METRES

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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 18

NOTE

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PROJECT
ROBLIN LAKE GROUNDWATER EVALUATION

TITLE
CROSS SECTION B - B'

Golder Associates
Ottawa, Ontario

PROJECT No. 09-1127-00658			SCALE AS SHOWN	REV. 0
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GIS	BT	21 AUG 2009		
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REVIEW	[signature]	8 Oct 09		

FIGURE: 7

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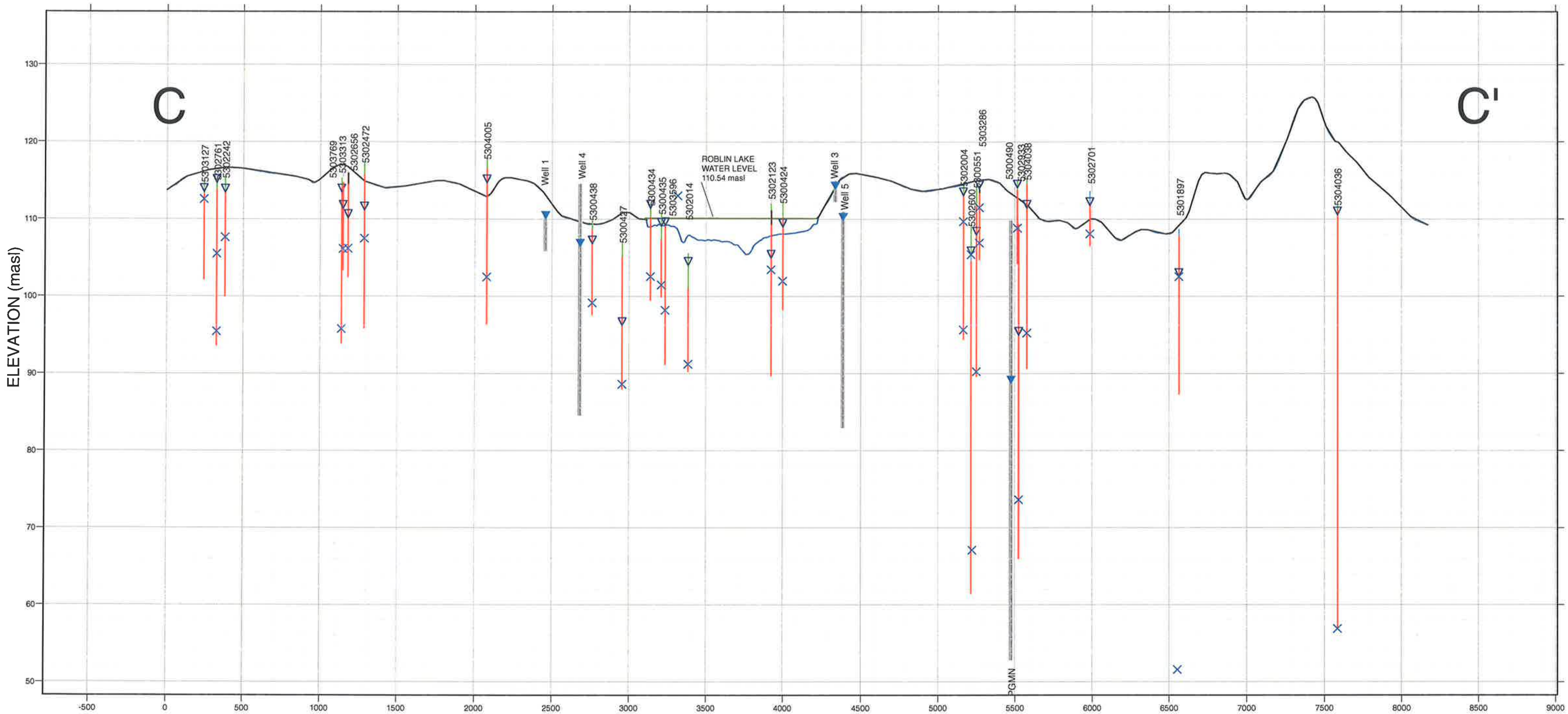

LEGEND

Well Driller's Description of Materials

- Overburden
- Clay
- Hardpan
- Sand/Gravel
- Limestone
- Shale
- Sandstone
- Precambrian

- 5303127 Water Well Record in WWIS
- x Record of Water Found in WWIS
- Static Water Level in WWIS
- Static Water Level - Quinte Conservation Data
- Private Water Well- Quinte Conservation Data (No Geology Information Available)
- Ground Surface Profile (masl)
- Roblin Lake Bathymetric Surface (masl)

500 250 0 500 1,000

SCALE 1:25,000 METRES

REFERENCE

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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 18

NOTE

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PROJECT

ROBLIN LAKE GROUNDWATER EVALUATION

TITLE

CROSS SECTION C - C'

Golder Associates
Ottawa, Ontario

PROJECT No. 09-1127-00658			SCALE AS SHOWN	REV. 0
DESIGN	BT	21 AUG 2009		
GIS	BT	21 AUG 2009		
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REVIEW		8 Oct 09		

FIGURE: 8

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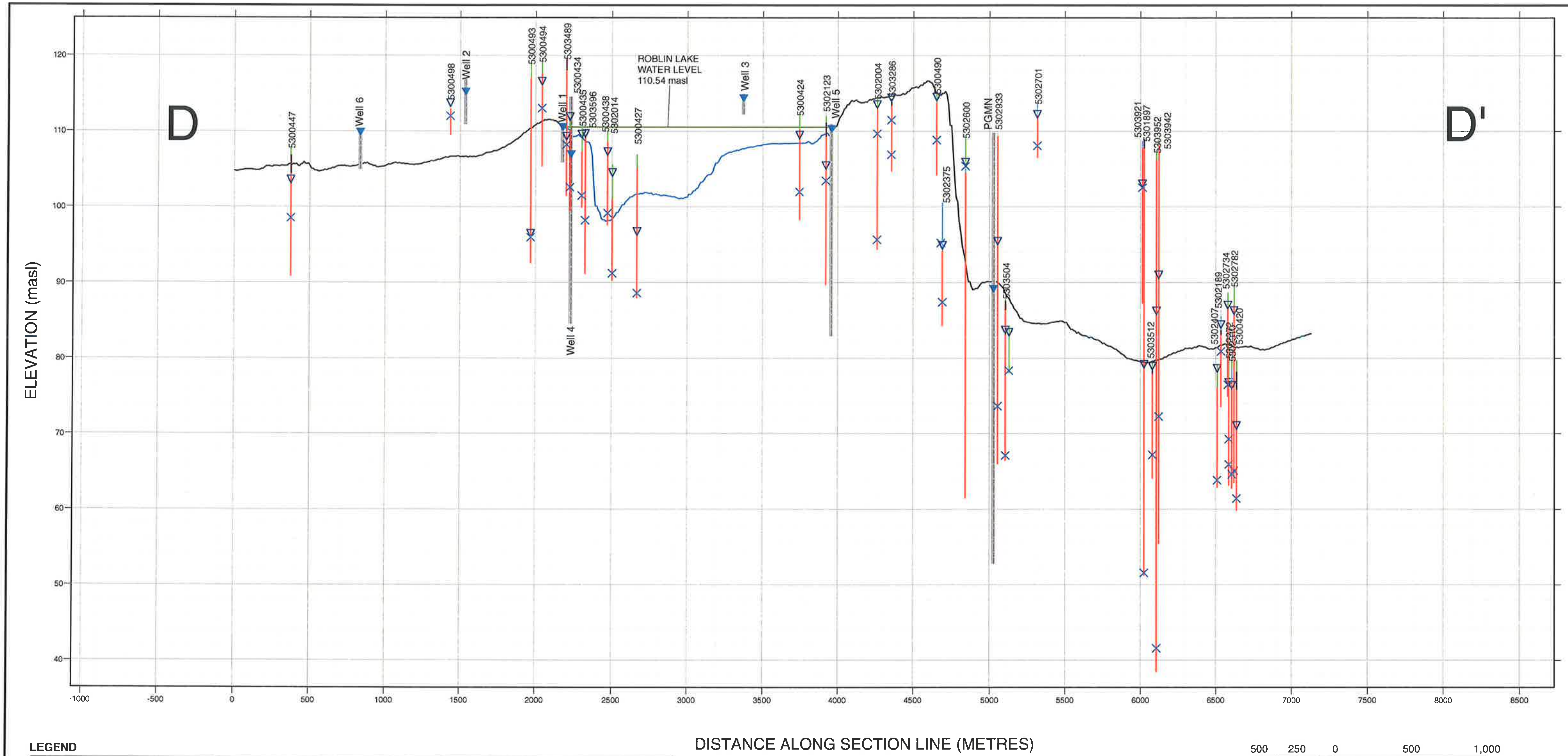

LEGEND

Well Driller's Description of Materials

- Overburden
- Clay
- Hardpan
- Sand/Gravel
- Limestone
- Shale
- Sandstone
- Precambrian

- 5300447 Water Well Record in WWIS
- x Record of Water Found in WWIS
- ▽ Static Water Level in WWIS
- ▼ Static Water Level - Quinte Conservation Data
- Private Water Well- Quinte Conservation Data (No Geology Information Available)
- Ground Surface Profile (masl)
- Roblin Lake Bathymetric Surface (masl)

500 250 0 500 1,000

SCALE 1:25,000 METRES

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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 18

NOTE

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PROJECT

ROBLIN LAKE GROUNDWATER EVALUATION

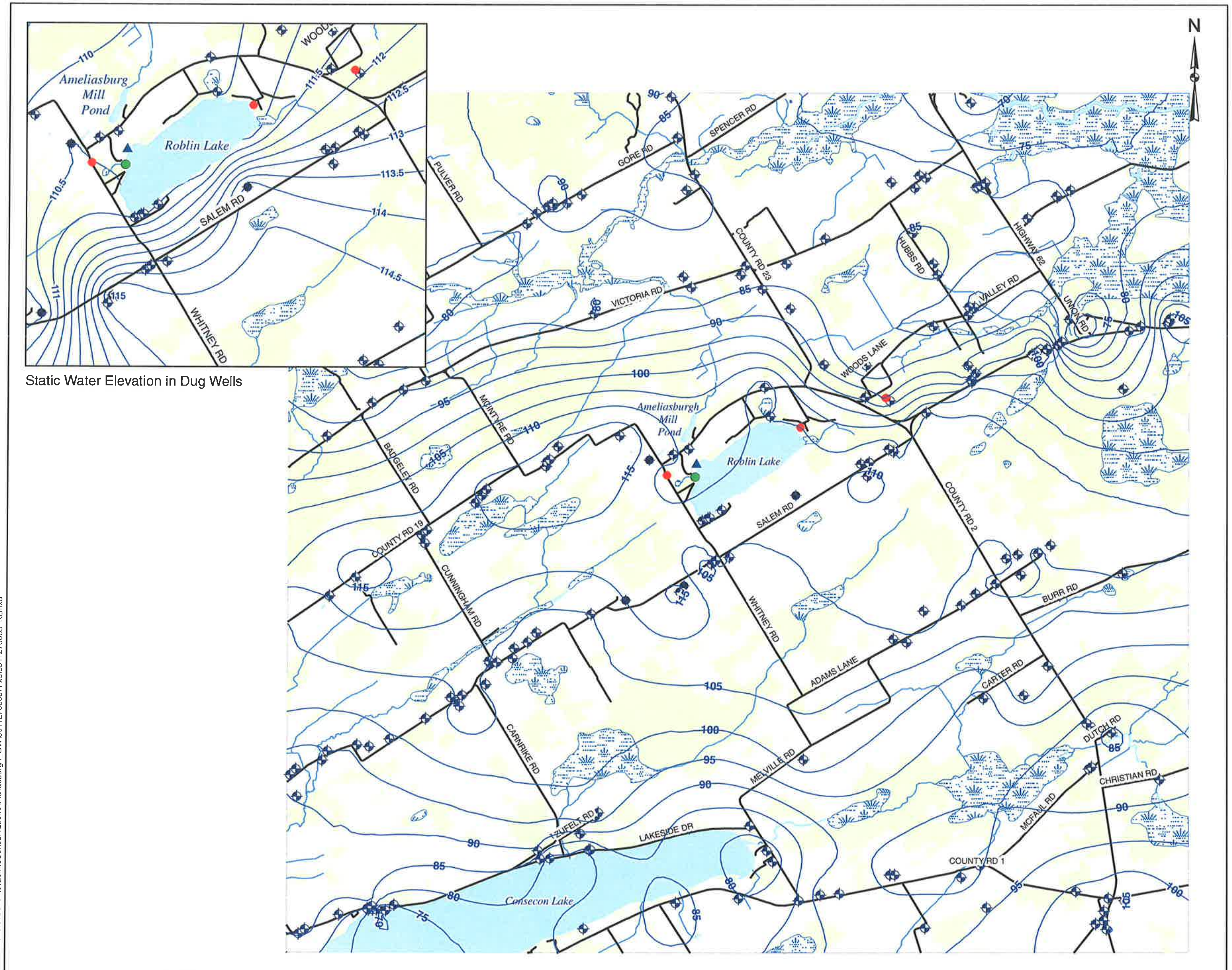
TITLE

CROSS SECTION D - D'

Golder Associates
Ottawa, Ontario

PROJECT No. 09-1127-00658			SCALE AS SHOWN	REV. 0
DESIGN	BT	21 AUG 2009		
GIS	BT	21 AUG 2009		
CHECK	LEB	7 Oct 09		
REVIEW				

FIGURE: 9



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LEGEND

- Private Water Well (Drilled)
- Private Water Well (Dug)
- Water Well (MOE WWIS)
- Municipal Water Intake
- Water Control Structure
- Static Groundwater Elevation (masl)
- Roadway
- River or Stream
- Waterbody
- Wetland
- Woodlands

NOTE

This figure is to be read in conjunction with the accompanying Golder Associates Ltd. report No. 09-1127-0065

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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 18

1,000 0 1,000
SCALE 1:50,000 METRES

PROJECT

ROBLIN LAKE GROUNDWATER EVALUATION

TITLE

STATIC GROUNDWATER ELEVATIONS

Golder Associates
Ottawa, Ontario

PROJECT No. 09-1127-0065		SCALE AS SHOWN	REV. 0
DESIGN	LB	18 AUG. 2009	
GIS	AB	18 AUG. 2009	
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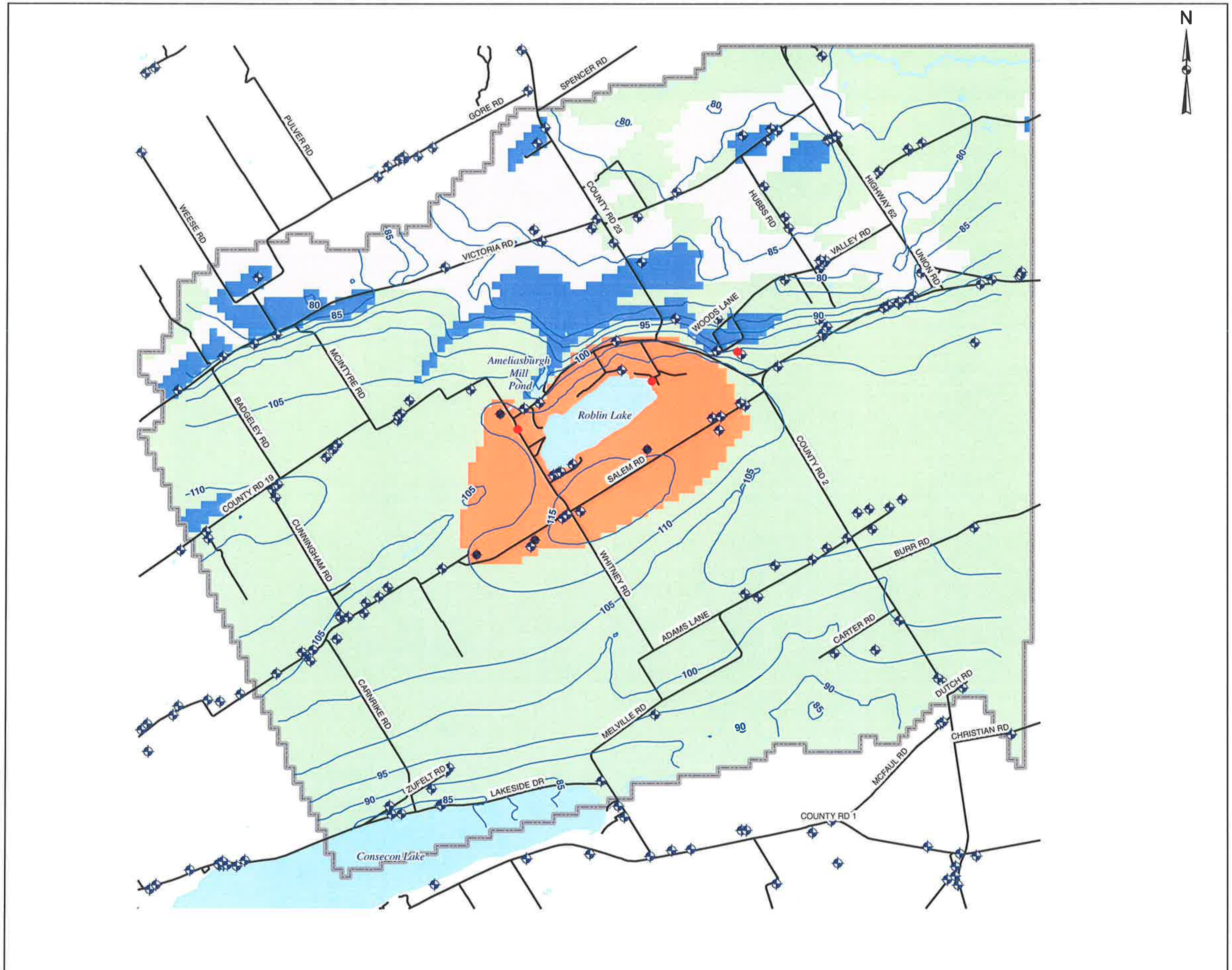
REVIEW	[illegible]	20 Oct 09	

FIGURE: 10



LEGEND

- Private Water Well (Drilled)
- Private Water Well (Dug)
- Water Well (MOE WWIS)
- Simulated Groundwater Elevation (masl)
- Roadway
- Model Domain
- Waterbody

Simulated Hydraulic Conductivity and Recharge Zones

- Roblin Lake Weathered / Fractured Bedrock Zone
- Weathered Limestone
- Sand
- Clay

NOTE

This figure is to be read in conjunction with the accompanying Golder Associates Ltd. report No. 09-1127-0065

REFERENCE

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Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 18

1,000 0 1,000
SCALE 1:50,000 METRES

PROJECT
ROBLIN LAKE GROUNDWATER EVALUATION

TITLE
SIMULATED GROUNDWATER ELEVATIONS

Golder Associates
Ottawa, Ontario

PROJECT No. 09-1127-0065			SCALE AS SHOWN	REV. 0
DESIGN	LB	18 AUG. 2009		
GIS	AB	18 AUG. 2009		
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REVIEW	KMA	20 Oct 09		

FIGURE: 11

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APPENDIX C

Quinte Conservation Watershed Hydrology Model

Version 1.5

Updated February 24, 2010

APPENDIX C

Quinte Conservation Watershed Hydrology Model

Introduction

This appendix summarizes the existing conditions hydrology model for the Quinte Conservation watersheds, and its use in the Tier 2 Surface Water Risk Assessment discussed in the main report. The Quinte Conservation Watershed Hydrology Model (QCWHM) was formulated using the GAWSER (Guelph All-Weather Sequential-Events Runoff model) program (Version 6.9.11), and was set-up using the same procedures that are outlined in detail elsewhere (e.g. Schroeter & Associates, 1996, 2000, 2003, 2005; Schroeter & Boyd, 1998). The widespread application of GAWSER in more than 50 Ontario streams has been reported by Schroeter et al. (2000b, 2003).

The purpose of the work described herein was to utilize the current hydrological model of the Quinte Conservation watersheds (as it was last formulated in 2000) to provide water balance assessments for the Source Water Protection (SWP) Tier 2 Surface Water Risk Assessment noted in Chapter 2 of the main report without developing any new procedures within the current model, and using readily-available data. The idea was basically to take the current QCWHM 'off the shelf', and apply it directly (where possible) to the Tier 2 assessments. As such, the descriptions of the model set-up, validation and application have been kept as brief as possible. For more detail, the interested reader should review the documents listed later in this Appendix.

Hydrologic Modelling in the Quinte Conservation Watersheds: A brief history

Since the formation of the Moira River Conservation Authority (MRCA), and its associated agencies, the Napanee Region Conservation Authority (NPCA) and the Prince Edward County Conservation Authority (PECCA) which now form Quinte Conservation (QC), there have been a number of studies carried out to compute hydrologic quantities (e.g. flood flows) for specified locations within the Moira, Salmon, and Napanee River watersheds, and Prince Edward County. These studies were reviewed, in terms of the extent of their input data bases and the runoff estimate techniques used, to assess what information could be utilized in the present analyses.

The *Moira Valley Conservation Report* (Department of Planning and Development, 1950), the *Napanee Valley Conservation Report* (Department of Planning and Development, 1957), and the *Napanee Region Conservation Report 1967: Salmon River Section* (Department of Energy and Resources Management, 1967), supplied good baseline information, the flooding history of the Moira, Salmon and Napanee River watersheds, and excellent stream bed profile plots.

Sibul et al. (1974), and Ostry and Singer (1981) presented excellent detailed reviews of the surface and ground water resources in the Moira River watershed. These reports provided good information regarding the surficial geology of the region, and estimates of lake area. EGA Consultants Ltd. (1991 a,b) carried out an extensive review of all the operational dams in the Moira River Watershed, providing an excellent manual for dam operations, as well as elevation-outflow-storage relationships. This study included the development of a simple ‘statistical’ flood forecasting technique to predict monthly and daily streamflow volumes.

Chysler & Lathem (1978a,b; 1981) conducted a series of hydrologic and flood plain mapping studies for the Napanee and Salmon Rivers. Detailed tables of subwatershed areas, lengths and widths, as well as reservoir/pond/lake elevation-outflow-storage relationships, were used directly in the present analysis. Watt and Associates (1991) formulated a simple stochastic forecasting model for the Napanee River, and tested it for a number of spring snowmelt events.

Lazier and Schroeter (1983) carried out an investigation of the flood control performance of the Consecon Lake Dam through the use of computer simulation techniques. A model of the Consecon Creek watershed was formulated using Queen’s HYMO software. It was calibrated using observed daily flow data for three historical events at the Allisonville gauge: May 1974 (rainfall-only), February 1981 (rain on snowmelt), and September 1981 (rainfall-only). The flood control performance of Consecon Lake was assessed using the Timmins Regional Storm, and the February 1981 event.

In November 1998, a joint-venture project was initiated by the Ontario Ministry of Natural Resources (OMNR), the Water Survey of Canada (WSC) under the auspices of the CHIPS (Canadian Hydrometrical Information Prediction System) program, and Quinte Conservation (QC) to hire Schroeter & Associates (2000) to construct a flood forecast model for the Moira, Salmon and Napanee Rivers using the series of programs that form the GRIFFS (Grand River Integrated Flood Forecast System) software. The deterministic hydrologic modelling procedures that form the heart of the GRIFFS software package are supplied by the GAWSER (Guelph All-Weather Sequential-Events Runoff) model. GAWSER has been applied widely in Ontario for planning, design, real-time flood forecasting, water balance and low flow assessments and evaluating the effects of physical changes in the drainage basin. The report, *Moira River Integrated Flood Forecast System (MRIFFS): Final Technical Report*, fully documents the complete set-up of GAWSER for the Moira, Salmon and Napanee River watersheds. It was calibrated and verified with streamflow data from six gauges for five snowmelt/rainfall events, and the results were judged to be satisfactory for flood forecasting purposes. Additional events (e.g. June 2000) were simulated during several training workshops at the QC head office, and in real-time.

This brief history of hydrologic modelling in the Quinte Conservation watersheds is given to let the reader know that as much existing information as possible went into the development of the hydrologic model that is being applied in the main text of this report. Although much of the early modelling was focused on producing flood estimates, the most recent model formulated using the GAWSER package (see Schroeter & Associates, 2000) represents the application of a full hydrologic model for flood forecasting purposes. A full hydrologic model is capable of producing not lonely flood flow estimates, but low flow estimates, water balance assessments, as well as flow duration information. This type of information is necessary in any Source Water Protection (SWP) Tier 1, 2 and 3 analyses.

Model Set-up

This section outlines the steps taken to set-up the Quinte Conservation Watershed Hydrology model (QCWHM) in point form, with adequate references given where more detailed information is available. The validation procedures are noted in the next section. Table and figure numbers are assigned as they are referenced in the text by first occurrence, although most of the relevant tables and figures are given later in this Appendix. Some of the smaller tables are given directly in the text.

Because the focus of the present analyses are two locations identified for Source Water Protection Tier 2 assessments, one in the Moira River watershed, and the other in Prince Edward County, all of the discussion that follows will be deal with those two areas. The Salmon and Napanee River portions of the overall QCWHM have not be altered since the publication of the 2000 MRIFFS report.

1) Figure 1 shows the breakdown for subcatchments for hydrologic modelling purposes in the Moira River portion of the QCWHM, whereas Figure 2 gives the same information for Prince Edward County.

   Typically, subcatchments are chosen to have stream crossings:

   a) at all flow monitoring stations,
   b) at significant points of interest (e.g. damage centres, power generating stations, fish habitat, water takers),
   c) to provide sufficient distributed flow inputs to any floodplain mapping (backwater curve) calculations,
   d) to isolate the drainage areas for each major lake (reservoir) in the system, and
   e) to reflect the spatial variations in soil type, land cover and meteorological inputs.

   Other subcatchments were delineated to improve the modelling results based upon:

   f) according to large changes in the longitudinal slope of major tributary streams within the subcatchment,
   g) the need to have subcatchments shapes such that a single overland flow path length is representative, and
   h) the degree of imperviousness (e.g. can it be classed as rural or urban catchment?).

   The number routing channels and addition points considered in the model is determined as a direct consequence of the subcatchment delineation process. The total drainage area of the Moira River portion of QCWHM is 2743 km^2, and it comprises 34 subcatchment, 28 channel, and 6 reservoirs elements connected by 33 addition nodes. It’s mean subcatchment size was found to be 76.2 km^2, with a range of 2.53 to 315 km^2.

The Prince Edward County portion of the model has a total drainage area of 581 km^2, and it is broken down into 37 subcatchments, 9 channels, 3 reservoirs and 11 addition nodes. It's mean subcatchment size is 15.7 km^2, where the range is 1.35 to 63.7 km^2.

This level of modelling detail, in terms of subcatchment size, is comparable to other GAWSER applications (e.g. Schroeter & Associates, 1998; 1999, 2000, 2003, 2005, and 2006a,b,c).

2) The schematic representations of the models outlined in this appendix, illustrating the linkage between subcatchment, channel and reservoir elements, are given in Figures 3 and 4. After the initial set-up of the Moira River portion of the model, it was decided that further subcatchment delineation for Deer and Madoc Creeks was noted for a Tier 2 assessments. Figure 5 shows the changes in the modelling schematic for the areas around Madoc.

3) To account for the wide variation in runoff generation response attributed to the different land cover features and soil types (e.g. source areas), the subcatchment elements were further subdivided into nine 'hydrologic response units' (HRUs); one impervious and eight pervious. These HRUs are defined below as:

Hydrologic Response Unit (RU)	Description (vegetation/soil type)
1	Impervious surfaces (includes exposed bedrock areas)
2	Open water (direct contribution to lakes)
3	Other Lakes
4	Wetland or other flooded areas
	Low Vegetative Cover (includes pasture and row crops)
5	Thin soil on bedrock, bottom land, muck and peak
6	Clays, clay loams, and loam soils
7	Loamy sand, sands, and sandy loams
	High Vegetative Cover (Forests)
8	Slow infiltration soils (includes clay, silts & others)
9	Fast infiltration soils (includes sands & gravels)

Open areas have low vegetal growth, like pastures, cropped fields, fallow and grasses. They are grouped together because they change from year-to-year. 'Low vegetative cover' is a more stable term for long-term modelling.

For rural subcatchments, the impervious areas include roads and adjoining shoulders, lanes, ditches and stream channels. The total impervious area in a given subcatchment can be determined by measuring the length of the roads and streams from topographic maps, and multiplying by a representative width. In previous applications of GAWSER in southern Ontario, the imperviousness of rural watersheds usually represents about 1.5 to 3% of the area (Schroeter & Associates, 1996, updated 2008). Generally, the subcatchments within 30 to 35 km of Highway 401 (e.g. 145, 150) are agricultural in nature, and hence similar to those applied in previous GAWSER modelling. As such, the values used here (see Table 2) are comparable. However, most subcatchments north of Highway 7 are considered ‘rural forested areas’, and so the total impervious area is much lower, except in areas with ‘exposed bedrock’.

For urban subcatchments, which are few in these watersheds, the impervious area was taken from the urban designated areas on the topographic maps (e.g. the pink areas on the 1:50,000 scale maps), and an appropriate impervious factor of 0.35 applied.

Response Unit 2 represents the surface areas of all lakes (and/ or reservoirs) that are modelled as separate reservoir routing elements. Response Unit 3 and 4 respresent lakes, marshes, swamps and wetland areas that are not modelled as separate reservoiring elements. As such their drainage characteristics (see Table 1) have been set to mimic the hydrologic response of these areas in a ‘lumped’ manner, rather than as separate reservoir routing elements.

Soil type areas were determined from available quaternary geology or county soil maps provided by Ministry of Natural Resources as a GIS layer in the Land Information Ontario database. For the most part, the soils in the Quinte Conservation watersheds consist primarily of thin soil on bedrock, with some pockets of silty clay and sand and gravel.

Low and High vegetative covers were isolated separately from the Land Cover layer, soils were clipped to each area and soil type percentages were calculated

More than 60% of the modelled areas are forested. With the exception of subcatchment 574 (in PEC), 70 of the 71 subcatchments considered here have some lake or wetlands areas within them.

Figures 6 and 7 illustrated the hydrologic response units in the Moira River and Prince Edward County portions of the QCWHM, upon which the subcatchment boundaries are noted.

4) <u>Response unit drainage characteristics</u>. Each previous zone or response unit in GAWSER is considered as two soil layers. The top or first layer has specified thickness up to 300 mm (in the soils examined to date), which typically corresponds to the ‘A’ horizon (e.g. Chapman and Putman, 1984). The thickness of the second layer is usually set in the range of 150 to 1250 mm, depending upon whether the response unit contributes to subsurface or groundwater storage. The second layer generally corresponds to the ‘B’ horizon.

   Rainfall (or snowmelt) falling on a response unit is separated into overland runoff and infiltrated components. The term infiltration is used here to describe the rate of water movement downward through the soil surface. Seepage indicates the water movement downward from the bottom of the first soil layer into the second layer, whereas percolation refers to the downward movement out of the bottom of the second layer of a response unit. Percolated water appears as subsurface flow (e.g. tile drainage) in response units assumed to contribute to this storm flow component, or to groundwater storage in all other response units. The rate of water movement into each soil layer (either from rainfall, snowmelt, or soil-water) depends on the drainage characteristics of each soil layer. The selection of drainage characteristics (parameters) is explained below.

Table 1 gives the hydrologic response unit (HRUs) drainage characteristics that were used directly in the model. The values listed were initially chosen from tables given in Chapter 8 of the *Hydrology of Floods in Canada* (Watt et al., 1989), and were later validated in the numerous applications of GAWSER noted in the reference section. The 2000 MRIFFS report gives a detailed discussion about how the individual response unit drainage characteristics were selected. Table 1A are the final values applied in the Moira River watershed, whereas the values given in Table 1B are for the Prince Edward County watersheds.

5) Subcatchment Characteristics: The procedures for selecting the overland flow routing characteristics (e.g. length, width, main and off-channel sections, and overland flow lag factor) for rural subcatchments are documented in Lesson 7 and 8 of the *GAWSER Training Guide and Reference Manual* (Schroeter & Associates, 2008). In the GAWSER program, the overland flow linear reservoir lag constant (KO) is specified as a function of the base time (TB) of the area/time versus time curve, or

   KO = FTB * TB

   where TB=TMC+TOC, and FTB is the overland flow basetime factor. Generally, FTB has been set at 2, but for swampy, wetlands, lakes or hummocky topography dominated subcatchments, FTB is set between 3 and 5. For urban subcatchments, those with imperviousness greater than 10%, the FTB is set at 1.2.

   Outflows from subsurface and groundwater storage are modelled in GAWSER using a linear reservoir procedure, which requires two recession constants to be specified; KGW for discharge from groundwater storage and KSS for subsurface flow. These constants have been estimated from observed hydrograph data or hydrogeologic studies, when available. Nevertheless, values applied in numerous previous studies were deemed to be acceptable here, and so KSS=5 h, and KGW=384 h for each subcatchment (see *GAWSER Training Guide*, Lesson 5 and 7).

   The drainage areas, lengths and widths, the response unit percentages, cross-section and reference flow rate assignment for the main and off-channels, overland runoff lag factor (FTB), as well as the subsurface and groundwater (baseflow) recession constants for each subcatchment under existing conditions, are summarized in Table 2 (for the Moira River) and Table 3 (for Prince Edward County). The symbols for the column headings have been defined in *GAWSER Training Guide and Reference Manual* (Schroeter & Associates, 2008).

6) Stream Channel Information: Stream channel data are necessary inputs to both the overland flow (runoff) and channel routing calculations in GAWSER. Consequently, representative cross-sections are required inputs to the routing procedures, where the parameters are computed directly by the program using the channel length, bed slope and a characteristic rating curve developed for the section (see Table 4).

A typical off-channel section was used for all rural subcatchments, and taken from previous applications of GAWSER (Schroeter & Associates, 2008; Schroeter & Boyd, 1998). It was not possible to obtain cross-section data for main channels in each subcatchment or all channel routing elements. Therefore, some sections were used ('borrowed') for several elements, with minor adjustments in slope and roughness to account for local conditions. Photographs taken during field tours proved valuable for deciding which cross-sections could be reasonably substituted or 'borrowed'. Where measured cross-section data were not available at all, representative sections were established from regional geomorphical relationships (see Leopold, 1994; Annable 1996) using a procedure outlined in other GAWSER applications (see Schroeter & Associates, 2000, 2003 and 2005) by imposing a simplified trapezoidal cross-section geometry

Channel roughness coefficients (Manning's n) were initially selected from typical values given in hydraulics texts (e.g. Chow, 1959) through a comparison between pictures in the text, and actual sections photographed in the field. Slopes and channel lengths were measured directly from available mapping in the GIS database..

7) <u>Treatment of detention ponds and lakes</u>: Distinct hydraulic features within the Quinte Conservation watersheds were isolated, and considered as reservoir (pond, or Lake) elements. In GAWSER, storage-outflow information for reservoirs (as well as ponds and lakes) can be entered as tables computed by other means (e.g. HEC-2), or using standard equations representing flow through different parts of the control structure (e.g. weir, gates, valves and turbines) and the storage in the reservoir as a function of water level, or a combination of tables (e.g. elevation-storage) and discharge equations. These procedures are described fully in Lesson 6 of the *GAWSER Training Guide* (Schroeter & Associates, 2008).

   As part of the Moira River Forecast Model set-up study (e.g. Schroeter & Associates, 2000), the GAWSER reservoir routing procedures were modified to handle stoplog settings, sluice gate openings or valve settings, which result in different discharge-elevation relationships throughout the simulation. A maximum of six control structure units (e.g. stoplogs, sluice, valve or turbine) can be modelled. The user would specify the time (as fractions of the Julian date, like JD=104.5 would be noon on April 15th), and individual settings (e.g. number of stoplogs out, percent valve opening, or amount of gate opening) for each control structure unit during the simulation. Flows through ‘uncontrolled or emergency spillways’ would be handled in an elevation-discharge-storage table.

   Table 5 summarizes the characteristics of the major ‘controllable’ lakes considered in the QCWHM. For the lakes listed in Table 5, the control structure settings (e.g. number of stoplogs removed) were set at the normal operating ranges according to discussions with Quinte Conservation staff, and those recommended by EGA (1991a). A sample rule curve developed for Lingham Lake on the Black River and applied in the long-term applications outlined herein is illustrated in Figure 8. Similar curves were set-up for the other ‘controllable’ lakes (e.g. Deloro Head Pond, Deerock Lake, and Skootamatta Lake, and Roblin Lake). All other controllable lakes were set at typical control settings for the entire year (e.g. Moira Lake, Stoco Lake, and Consecon Lake).

8) Potential Evaporation Estimates**:** In GAWSER, there are two evapotranspiration models, one using a set daily potential for each month (the climatological approach) developed from available lake evaporation estimates (see Table 6A and 6B), and the Linacre (1977) formula, which uses daily mean air temperatures, elevation and latitude to compute daily potential evaporation rates. The first method is described in Appendix A of the *GAWSER Training Guide and Reference Manual* (Schroeter & Associates, 1996, updated October 2008), but the second approach has seen limited application (see Schroeter et al., 2000b), and has been documented in a few studies (Schroeter & Associates, 2005, 2006a,b,c).

The Linacre (1977) lake evaporation rate formula is expressed as

$$PE = [700\ T_M/(100 - A) + 15\ (T - T_D)]/(80 - T)$$

$$T_M = T + 0.006\ H$$

$$(T - T_D) = 0.0023\ H + 0.37\ T + 0.53\ R + 0.35\ R_{ANN} - 10.9$$

where PE is the daily potential evaporation rate (in mm/day), H is the elevation (in m), T is the mean daily temperature (in C), A is the latitude (in degrees), T_D is the mean dew point temperature, R is the mean daily range of temperature, and R_{ANN} is the annual difference between the mean temperatures of the hottest and coldest months.

In applying the Linacre model to the South Muskoka River watershed, Schroeter & Associates (2005) found that the above formula caused the mean annual actual evapotranspiration amount to be over-estimated. By applying a factor of 0.75 (call this ETFAC) to potential rates determined from the above formula, they found good agreement between the computed values and those published on maps for Ontario (OMNR, 1984). For GAWSER applications in the Long Point Region, Catfish and Kettle Creek, ETFAC was found to be 0.60 (Schroeter & Associates, 2006a,b,c). For the present applications, ETFAC was found to be 0.54.

9) Snowmelt Input Data: Snow accumulation and melt in different land cover units within a watershed are accounted for in GAWSER by defining 'blocks of equivalent accumulation' (BEAs). For the Quinte Conservation watersheds, six EABs were identified and considered: two open field block (ploughed and grass/pasture/grains), one forest block, and three edge blocks (e.g. fence lines, roadway easements with ditches, and forest/field edges). Edge blocks are areas with significant capacity to store snow during blowing snow conditions. Schroeter and Whiteley (1986) and Burkart et al. (1991) give further information about snow accumulation characteristics among differing landscape units in southern Ontario.

The BEAs were estimated from land cover information given in Table 2 and 3 using similar relationships between blocks found in southwestern Ontario (Schroeter & Whiteley, 1986). Notice that more than 60% of the study area is forested (determined from the sum of forest and half the forest edge). The snowmelt model parameters listed in Table 7 were taken directly from MRIFFS report (Schroeter & Associates, 2000).

10) Meteorological Input and Streamflow Comparison Data: For the long-term applications reported in this appendix, 56 year meteorological data sets were prepared using the procedures outlined by Schroeter et al. (2000a), employing information available from the records for Bancroft Auto (AES 616I001), Madoc (6154779), Cloyne Ontario Hydro (6161662), Frankford MOE (6152555), Belleville (6150689), ad Mountainview (615EMR7). Additional information was obtained for these stations: Kaladar (6153935), Ompah (6105760), Picton (6156533), Stirling (6158051), and Trenton A (6158875). These meteorological data sets consisted of daily maximum and minimum air temperatures and snowfall amounts, as well as hourly rainfall depths.

For testing model performance through the comparison of observed and simulated flows, discharge data (both daily and hourly) were available from these federal (Water Survey of Canada, WSC) gauges for the period 1969 to 2008: Moira River near Foxboro (02HL001), Black River near Actinolite (02HL003), Skootamatta River near Actinolite (02HL004), Moira River near Deloro (02HL005), and Consecon Creek at Allisonville (02HE002). For the event model testing, additional information was obtained for some new federal gauges: Moira River at Tweed (02HL007), and the Clare River near Bogart (02HL008).

13) Parameter selection and Adjustments: Previously published values were employed as first estimates for all model parameters. In this case, parameter values were taken directly from Schroeter and Boyd (1998), and Schroeter and Associates (1999, 2000, 2003, 2005).

Once the model was completely set-up, the number of parameters requiring additional adjustment during calibration and performance testing are relatively few. The program adjusts the specified parameters for all response units and subcatchments in a similar manner, as shown here for effective hydraulic conductivity (KEFF).

$$KEFF(i)_{used} = FKEFF * KEFF(i)_{specified}$$

where FKEFF is the effective hydraulic conductivity adjustment factor, the subscript 'used' denotes the value of KEFF actually used in the runoff calculations for response unit (i), and the subscript 'specified' represents the value of the parameter (e.g. KEFF in Table 1) for response unit (i) actually entered in the input files during model set-up.

In previous applications of GAWSER, the most commonly adjusted parameter factors have been the following:

Symbol	Definition
FDS	Maximum depth of depression storage factor
FKEFF	Effective hydraulic conductivity factor (for surface infiltration)
FCS	Maximum seepage rate (movement of water from layer 1 to 2)
FD	Maximum percolation rate (movement of water out of layer 2)
FKO	Overland runoff lag factor
FKMF	Combined refreeze/snowmelt factor
FIMCI	Initial soil-water content adjustment factor for soil layer 1
FIMCII	Initial soil-water content adjustment factor for soil layer 2

FEVAP	Potential evapotranspiration adjustment factor
FNEW	Relative density of new snow factor
FINS	Interception storage adjustment factor

Values of unity for any of the above factors means that the 'as set-up' values specified in the watershed files (see also Table 1 and 2) are used directly in the calculations.

The monthly parameter adjustment factor table (see Table 8A) was originally calibrated in previous applications of GAWSER for the Quinte Conservation watersheds (see Schroeter et al., 2000b), and similar watersheds (see Schroeter & Associates, 2003, 2005). This parameter adjustment table was applied directly in the present study, and is incredibly robust, having been utilized with essentially the same values in more than 40 hydrology studies in the past 18 years (see Schroeter et al., 2003). The parameter adjustment factors are completely defined in the *GAWSER Training Guide and Reference Manual* (Schroeter & Associates, 1996, updated 2008), but are noted above for handy reference. Table 8A was applied directly for the Moira River watersheds, whereas Table 8B was applied for the PEC watersheds.

Each parameter adjustment factor listed in Table 8 represents the value of that factor at the midpoint of each month (the 15^{th} of the month). During actual computations, the GAWSER programs interpolates between the values listed in Table 8 on a daily basis. For example, the value of the effective hydraulic conductivity factor (FKEFF) on March 15^{th} is 0.02, and it's value on April 15^{th} would be 0.10. Hence, the value on March 30^{th} at midnight would be the average of the March 15 and April 15 values, or in this case 0.06. Figure 9 illustrates the daily variations in the effective hydraulic conductivity adjustment factor (FKEFF) throughout a typical simulation year. Similar plots can be made for the other parameter adjustment factors noted in Table 8.

Model Validation

1) Assessment of event modelling results: As noted in the Introduction, the QCWHM was extensively calibrated, verified and validated for five spring freshet events in the MRIFFS Study (Schroeter & Associates, 2000). In that report, the procedures for assessing event modelling results were outlined in detail. In summary, the event modelling results were assessed using these key hydrograph statistics: peak flows, times to peak flows, hydrograph volumes, and the Nash-Sutcliffe (1970) model efficiency (which is something like a correlation coefficient). In those applications, it was shown that the agreement between observed and simulated results was highly influenced by difficulties in estimating the rainfall patterns (both spatially and temporally), initial snow pack conditions, and ice cover conditions affecting flow measurements (e.g. missing hourly values estimated by mean daily flows). Nothwithstanding the complexities in both the flow comparison and the meteorological input data, the modelling results presented in the 2000 MRIFFS report suggested that the formulated models were reasonably good representations of the hydrology in the Moira, Salmon and Napanee River watersheds.

2) Assessment of continuous modelling Results: The assessment of event modelling results was discussed in the previous paragraph. While this information provides some guidance in evaluating the continuous simulation results, they cannot be applied directly because of several key differences in the way meteorological input data are applied in the event and continuous modelling work as summarized below.

   a) In event modelling, most of the available meteorological information was utilized to build an input data set for each individual event. Spatial rainfall and air temperature distributions were considered to develop unique inputs for 15 zones of uniform meteorology (see Figure 10). Snow course data (when available) were used to distribute the initial snowpack conditions, while observed streamflows provided estimates for the initial outflows from each subcatchment.

   b) This level of detail is warranted in event modelling, because the number of events considered (five in the 2000 MRIFFS study) is relatively low compared to the number of events encountered in a continuous simulation period. A typical water year will have some 40 or so rainfall events, with about half producing noticeable changes in stream discharge. For a 30 year period, that's about 1200 to 1500 individual events. Consequently, it is simply not possible with the resources available (both economic and manpower) for this study to work-up the rainfall data with the same level of detail found in the event modelling. Even so, a significant level of effort was expended to estimate the missing hourly rainfall depths in the continuous simulation data set (Schroeter and Boyd, 1998; Schroeter et al., 2000b).

   c) The meteorological inputs for the continuous simulation work utilized data for six main climate stations within and surrounding the study area, namely: Bancroft Auto (AES 616I001), Madoc (6154779), Cloyne Ontario Hydro (6161662), Frankford MOE (6152555), Belleville (6150689), and Mountainview (615EMR7). These meteorological data sets consisted of daily maximum and minimum air temperatures and snowfall amounts, as well as hourly rainfall depths. These stations were selected because they had the longest continuous record of data in the general vicinity of the Quinte Conservation watersheds. Moreover, these stations lie in the prevailing direction (west to east) for weather sequences in the study area, and hence were deemed to be more representative than other available data.

   d) The purpose of the event modelling is to show that the formulated hydrologic model can reasonably reproduce the streamflow response of the study area for historical events. Consequently, the 'goodness of fit' requirements for event modelling are more stringent than for continuous simulation.

   e) The main objective of any continuous simulation exercise is to understand how the hydrologic system in a watershed responds, in terms of frequency of occurrence for selected quantities, to the sequences of climate inputs. For example, in pre-and post development comparisons, we are interested in how often a certain level of response (e.g. hydrograph volume, water level in a detention pond) occurs over the course of a long-term period for each scenario. With this purpose it is not as important to have the absolute correct data (in terms of volumes and timing) for input to the hydrologic model. However, the input data must be sufficiently representative so as to generate meaningful 'statistics' for the system response quantities. In this regard, the model must be able to reproduce the general response of the watershed in terms of major movements of water (e.g. runoff, groundwater recharge, evapotranspiration), in both time and space.

3) In light of the above considerations, the continuous simulation results were compared with observed hydrograph data (here, daily flows), but were assessed primarily in terms of qualitatively matching the volumes at gauged points of interest on an annual and monthly basis. Matching measured and modelled hydrographs on an hourly or daily basis is meaningless, because we know that the meteorological inputs are not entirely representative of those occurring on the watershed, especially for specific events. However, some comparative statistics are given to help assess the model performance with some objective criteria. The most important tools for assessment are water balance tables, visual comparisons of annual and monthly hydrograph plots, and flow duration curves.

4) The hydrologic model was applied for the period November 1, 1969 to October 31, 2005, the period in which all five long-term gauges (e.g. Moira River near Deloro, Black River near Actinolite, Skootamatta River near Actinolite, Moira River near Foxboro, and Consecon Creek at Allisonville) were in operation concurrently. Because the model was applied using the water year concept, the initial snow pack depth and equivalent water contents on November 1, 1969 were assumed to be zero.

   A first check on the results for the 36 year simulation is a rather comprehensive ('one-stop shopping') table, an example of which is given in Table 9 for the Moira River near Foxboro gauge (WSC No. 02HL001). Top part of Table 9 gives the mean monthly water balance, and the middle portion lists a return period extreme flow summary (high and 7-day lows), and the bottom parts provides flow duration information. These water balance quantities represent the areal average for the entire drainage area upstream of the Foxboro gauge.

   The individual quantities for the top part of Table 8 can be expressed in a water balance

   Precip = ET + Runoff + Baseflow + Losses (or net storage)

   where 'Precip' represents the total precipitation (rainfall plus snowfall), ET is the combined evapotranspiration and sublimation total, 'Runoff' is the mean annual runoff, 'Baseflow' is the portion of the infiltrated water that returns to the stream, and 'Losses' signifies the amount of infiltrated water that does not return to the receiving stream. The 'Losses' total also includes water stored in the system, and is often referred to as the 'net storage' term. For instance, the positive totals for 'Losses' during the winter months (e.g. December to March) represents snow on the ground, whereas the negative values during the summer months (e.g. May to August) denotes water pulled from soil-water storage. Water present in all controllable lakes or reservoirs will also influence the value of the 'net storage term'. 'Total Flow' is the sum of the 'Runoff' and 'Baseflow' components. Tables like 9 can be prepared for any point of interest noted in the watershed model (see schematics in Figures 2 and 3) for both measured (when available) and modelled flows. Water balance quantities for other points of interest will in the next section on Model Application.

From Table 9, one can see that the mean annual precipitation for the 1969 to 2005 water year period is about 942 mm. The average annual actual evapotranspiration (ET) plus sublimation total is about 543 mm, a reasonable value for this part of Ontario according to Brown et al. (1974) and OMNR (1984). The mean annual runoff is about 199 mm, of which 69% is generated during the months of March to May. The mean annual total streamflow is 399.6 mm, which 50.3% appears as baseflow. Although not shown in Table 9, the observed mean annual streamflow for the same period is 400.1 mm, which is only 0.1% higher than the simulated value. This level of agreement between the measured and modelled mean annual volumes is considered excellent for continuous simulation work.

5) Table 10 lists the assignment of climate station data to each Zone of Uniform Meteorology for the long-term (continuous) simulations. In some cases, the same data set is used for more than one ZUM. Table 10 also gives the list of stations used in the missing value fill-in work for the primary climate station.

6) Table 11 gives key hydrograph statistics for the observed and simulated monthly flows at each gauge. Notice that the agreement between the modelled and measured mean monthly flows is excellent, at less than $\pm$4%. As indicated by the standard deviations, the variability in observed and simulated monthly flows were in excellent agreement (less than $\pm$6%) for the Black River, Skootamatta and Foxboro gauges. Moreover, the modelled values explained more than 66% the variations in the measured flows for Deloro, Black, Skootamatta and Foxboro gauges as suggested by the high model efficiencies (E^2) noted in the Table. Despite the difficulties noted earlier in securing representative precipitation data, the simulation results for monthly flow volumes are entirely acceptable for the purposes of this study.

   In order to illustrate the overall agreement between the observed and simulated results, three sets of diagrams are given in Figures 11, 12 and 13 for all five gauges considered in the 1969 to 2005 simulations. (Please note, that the year shown is the ending year for a given water year, i.e. 1974 represents the 1973-74 water year.) The first of diagrams noted in Figure 11 give the time-series histogram plots of the mean monthly flow volumes (expressed as a depth in mm). These histogram plots are expressed in depths of water so that the general response pattern can be compared between gauges with vastly different drainage areas. For the most part, the agreement between the measured and modelled histogram plots is very good. Any noted discrepancies between the observed and simulated volumes are primarily attributed to the ice covered conditions affected the measured flows during the winter months, and the meteorological input dataset, and it's lack of representativeness for the different parts of the study area.

   The discrepancies between the measured and modelled flow volumes, noted in the previous paragraph, are more obvious when the second group of diagrams is presented in Figure 12. These plots represent the time-series of monthly flow volumes throughout the whole simulation period (Nov. 1, 1969 to October 31, 2005). In general, the overall trend in the modelled volumes is in agreement with the measured values, especially during the spring freshet (snowmelt) period at each gauge. These results are very encouraging, notwithstanding the complexities cited earlier.

The last general check on model performance for the continuous (or long-term) simulations is given by the flow duration curves exhibited in Figure 13. The flow duration curves are to be interpreted as follows. Suppose in a given flow duration plot that the discharge shown at the 40% duration time is 4 m^3/s. This means that 40% of the time the discharge at this location (or gauge) will be equal to or higher than 4 m^3/s. It also means that the discharge at this location will be less than 4 m^3/s about 60% of the time. Simply put, the flow duration curves are a statistical summary of the flow response at this location. The general agreement between the observed and simulated curves in Figure 13 are good, although the discrepancies noted earlier are more obvious in these plots. When reviewing these plots (Figure 13), remember that the measured and modelled results are not in the same one-to-one correspondence in time as are the diagrams illustrated in Figures 11 and 12. The flow duration curves were created by taking the entire 36-year dataset of daily flows and rank ordering the values from highest to lowest. This exercise is done independently for both the simulated and observed flows for each gauge location. In that regard, the fact that there is any agreement between the measured and modelled results is remarkable.

7) The diagrams illustrated in Figures 11 to 13 were the primary tools used for the qualitative assessment of model performance. However, there were another five graphs created to help with model testing for each gauge considered here. A sample of these five additional graphs are noted in Figure 14 for the Consecon Creek at Allisonville gauge. Figures 14 A and B illustrate three plots based on the mean annual total flow information (see Table 9). The time-series of annual total flow volumes is given in the top part of Figure 14 A, whereas the cumulative mass curve of total annual flow volume is given in the bottom part of Figure 14A. The cumulative mass curves are important diagrams for identifying whether the meteorological input data are reasonably correct for the required simulations. If the meteorological input data are reasonably representative on a mean annual basis for the watershed in question, then the simulated cumulative volumes track close to the 1 to 1 line. Figure 14 B depicts the scatter diagram for the annual total flow volumes, with $\pm$25% boundary or error lines. The objective in assessing model performance with the scatter diagrams is that the points should appear to be randomly distributed, with roughly the same number of points on either side of the 1 to 1. If there are too many points on one side of the 1 to 1 line, then simulation would be biased in a higher or lower direction. The diagrams noted in Figures 14 C are similar to those in Figures 14 A and B, but representing monthly flow volumes.

   If the interested reader wishes to review these other graphs (about 25 in all), they can requested them from Quinte Conservation staff.

8) As noted earlier, the Quinte Conservation Watershed Hydrology Model (QCWHM) was extensively calibrated, verified and validated in the MRIFFS Study (Schroeter & Associates, 2000). For the present work, the model was set-up for March 29 to April 21, 2008 event period to demonstrate it's capability in event model. Table 12 gives the key hydrograph statistics for these simulations, and the measured and modelled hydrographs are presented in

Figure 15. The model efficiencies (E^2) for all 7 gauges are reasonable. The major discrepancies with these simulations were attributed to getting the correct snow pack initial depth and water content, and ice cover influences in the measured flows early in the modelling period (e.g. March 29 to April 1). Overall, the event simulations were comparable to those presented in the 2000 MRIFFS Report.

9) In conclusion, the general agreement between the observed and simulated results for the 1969 to 2005 period with information from five gauges in the Quinte Conservation watersheds has been judged entirely satisfactory for the purposes of this study. In the next section, the validated hydrologic model will be applied to produce quantities for use in the Tier 2 risk assessments.

Model Application

Once the model has been set-up and tested, it can be applied for what ever water management purpose that may be required. In this case, we wish to compute water balance quantities for a number of points of interest under existing conditions, and different meteorological input sequences. For the climate stations listed in Table 10, we have 56 year (1950 to 2005) meteorological data sets consisting of hourly rainfall amounts, and daily maximum and minimum air temperature and snowfall amounts. These datasets were analyzed to determine the 2 year and 10 year drought periods according the 'director's Rules'. For each station listed in Table 10, 2 and 10 year moving average computations were conducted on a water year basis (e.g. November in one year to October in the next), and are summarized in Table 13. This table gives the mean annual precipitation, and the minimum and maximum years in the 56 year record. The table also shows the 2 year and 10 year periods with the lowest average precipitation in the 56 year records for each station noted in Table 9. In addition, results are shown for an average of all 6 stations noted. In general, the year with the lowest annual precipitation was found to be 1961, 1963, 1964, 1982 and 1989. As noted in Table 12, the minimum 2 year period is 1962 to 1963, 1963 to 1964, 1982 to 1983 and 1988 to 1989. The 10 year minimum periods were found to be 1955 to 1964, 1956 to 1965, 1957 to 1966, and 1961 to 1970. It is not possible to have 3 or 4 different periods applied during a single simulation run, and so the 2 year and 10 year drought periods were selected based upon the 6 station average as shown in Table 13.

For the 2 and 10 year drought periods, the model was run for the previous 3 years in order to initialize the drought period simulations. For the average or mean condition runs, the entire 56 year data set was applied to the model. The water balance quantities computed for each meteorological scenario and a selected number of points of interest are summarized in Table 14.

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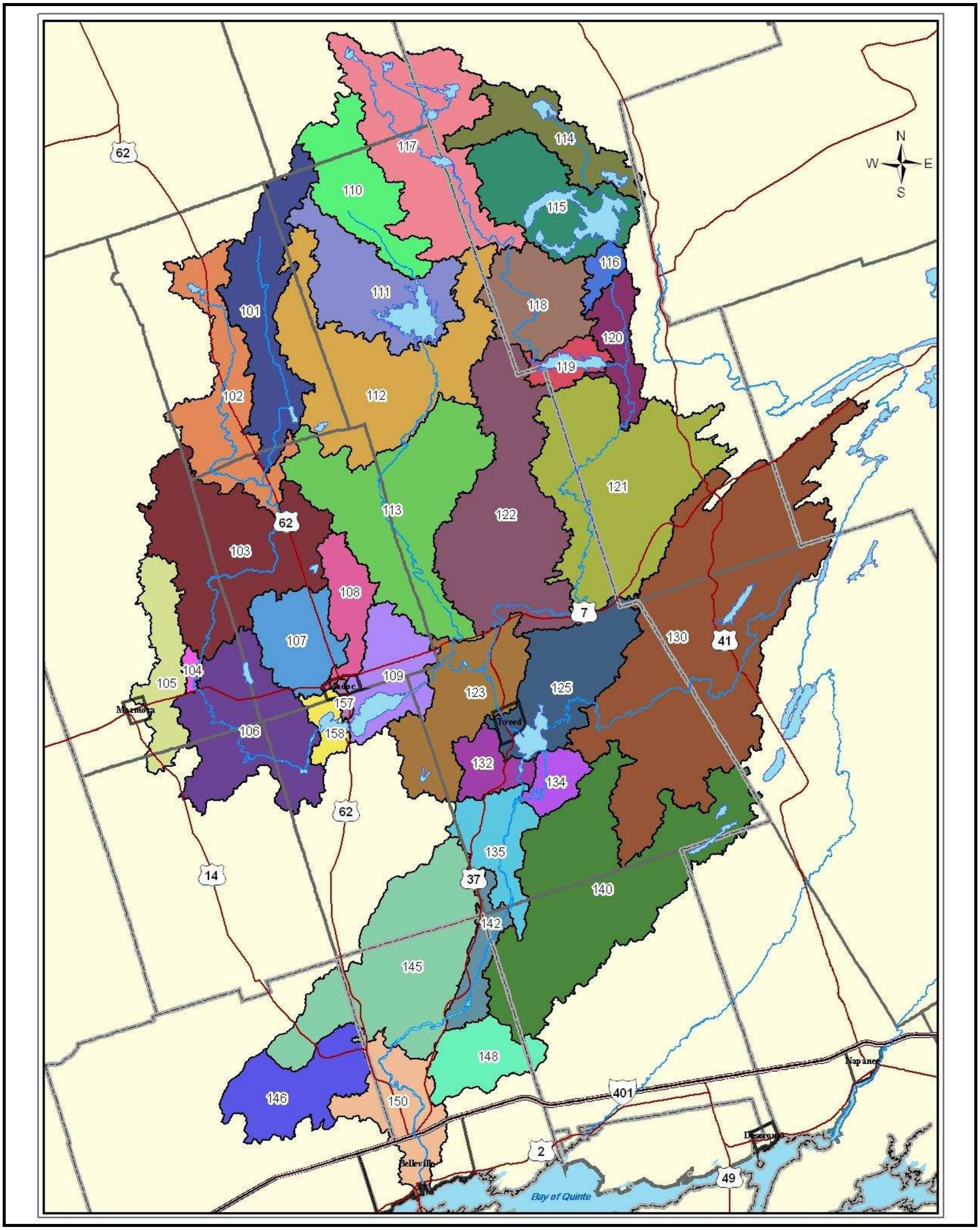


Figure 1 Subcatchment divisions for hydrologic modelling purposes, Moira River

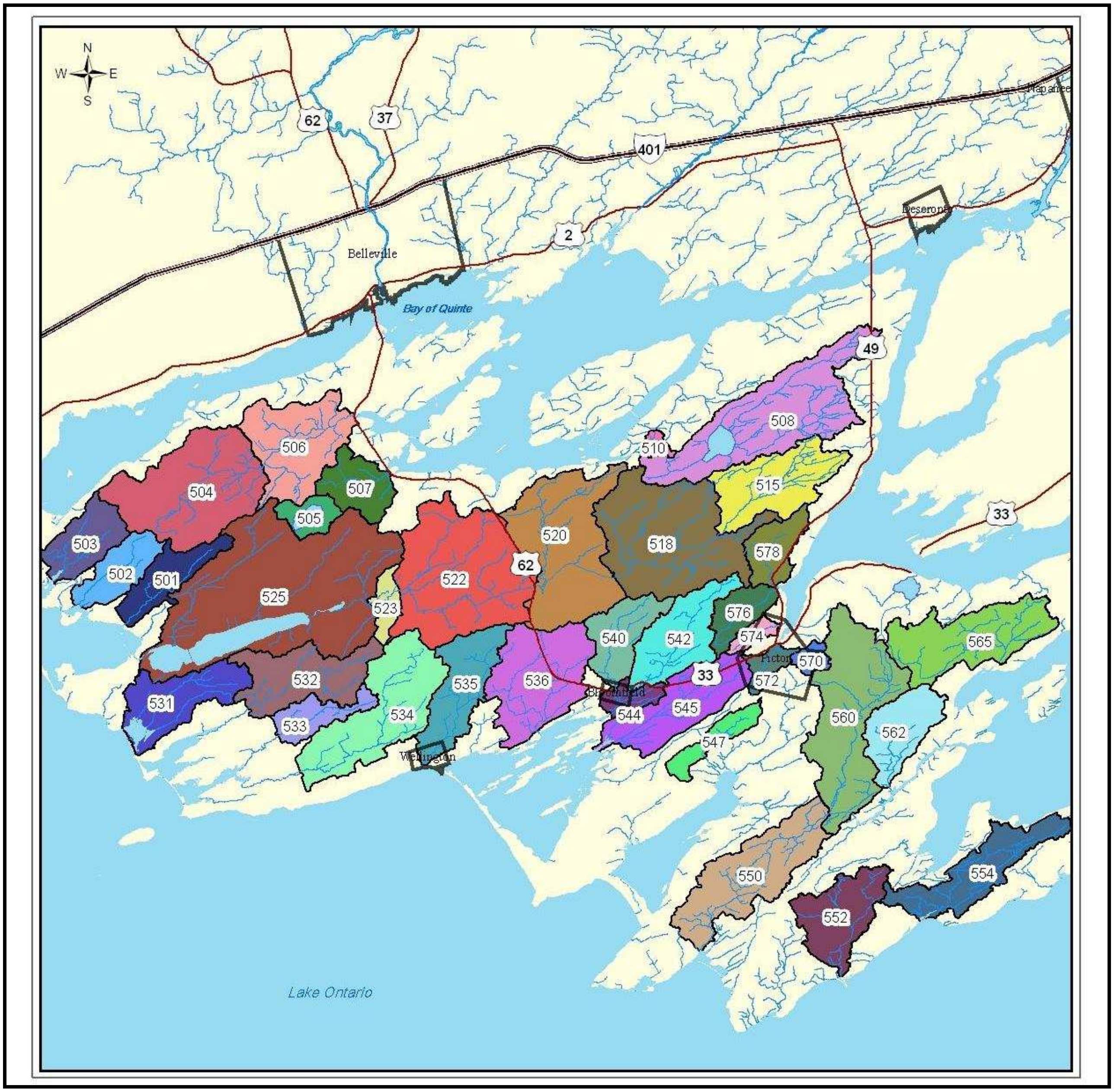


Figure 2 Subcatchment divisions for hydrologic modelling purposes in Prince Edward County

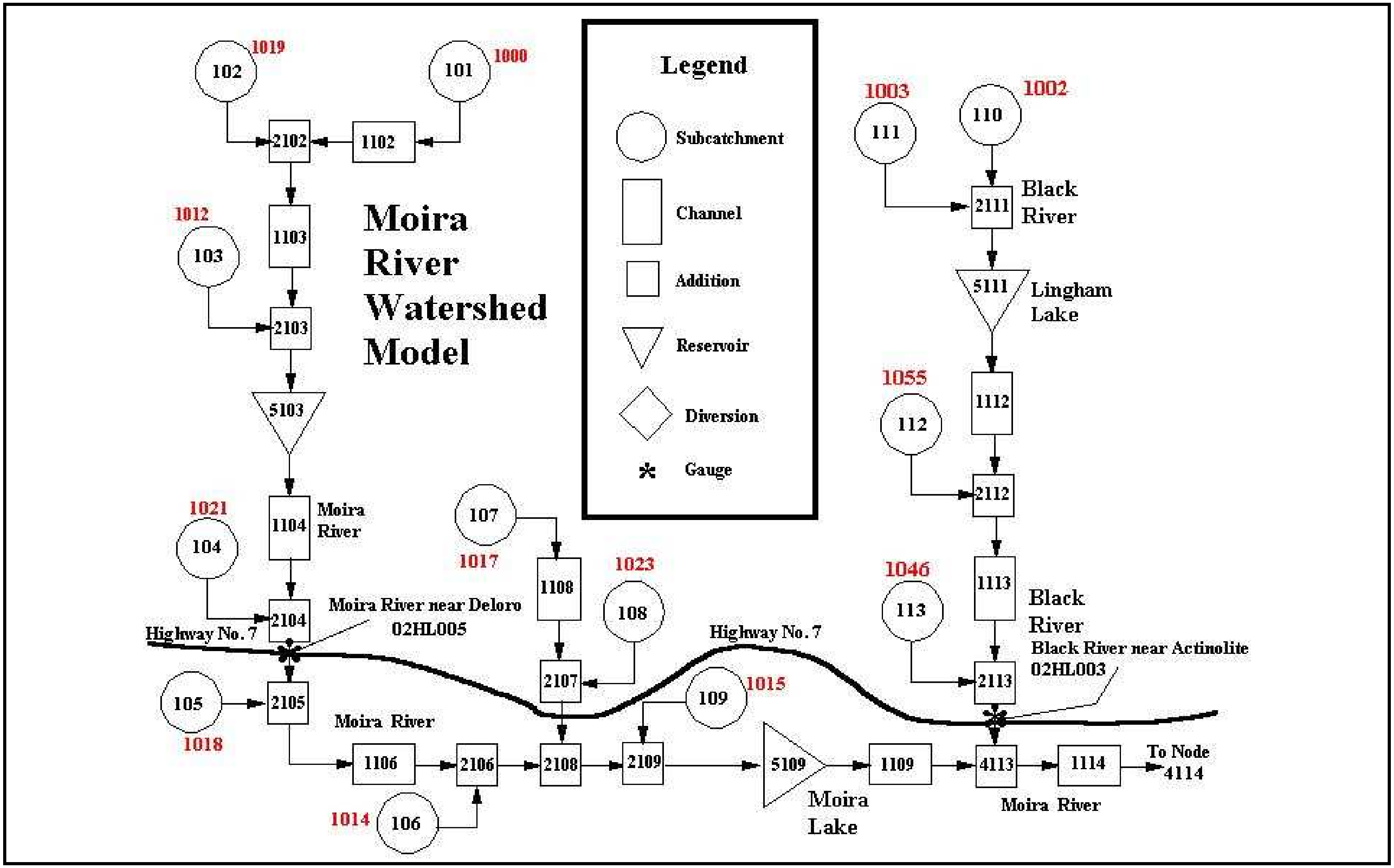


Figure 3 Schematic representation of the Moira River hydrologic model

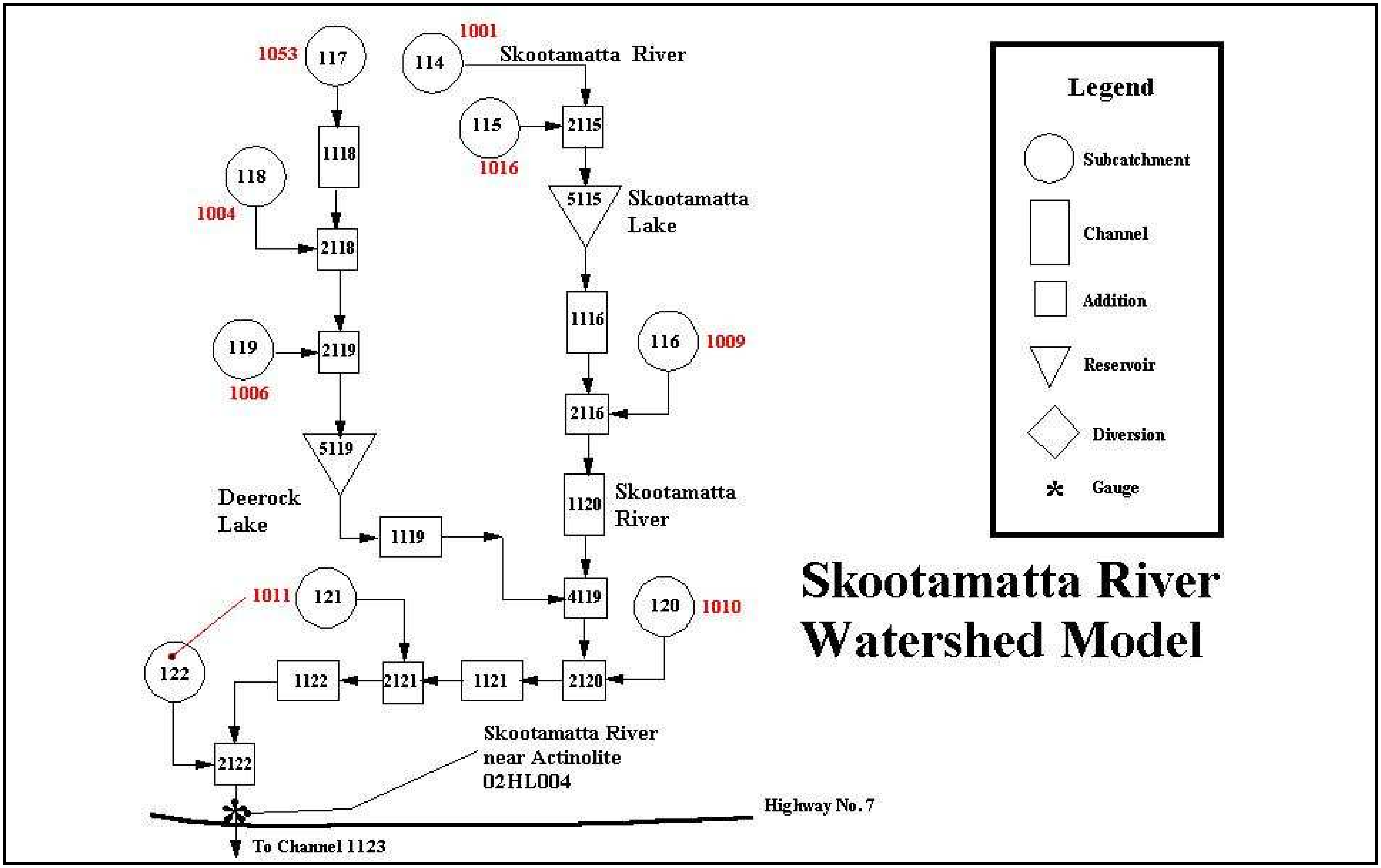


Figure 3 Continued

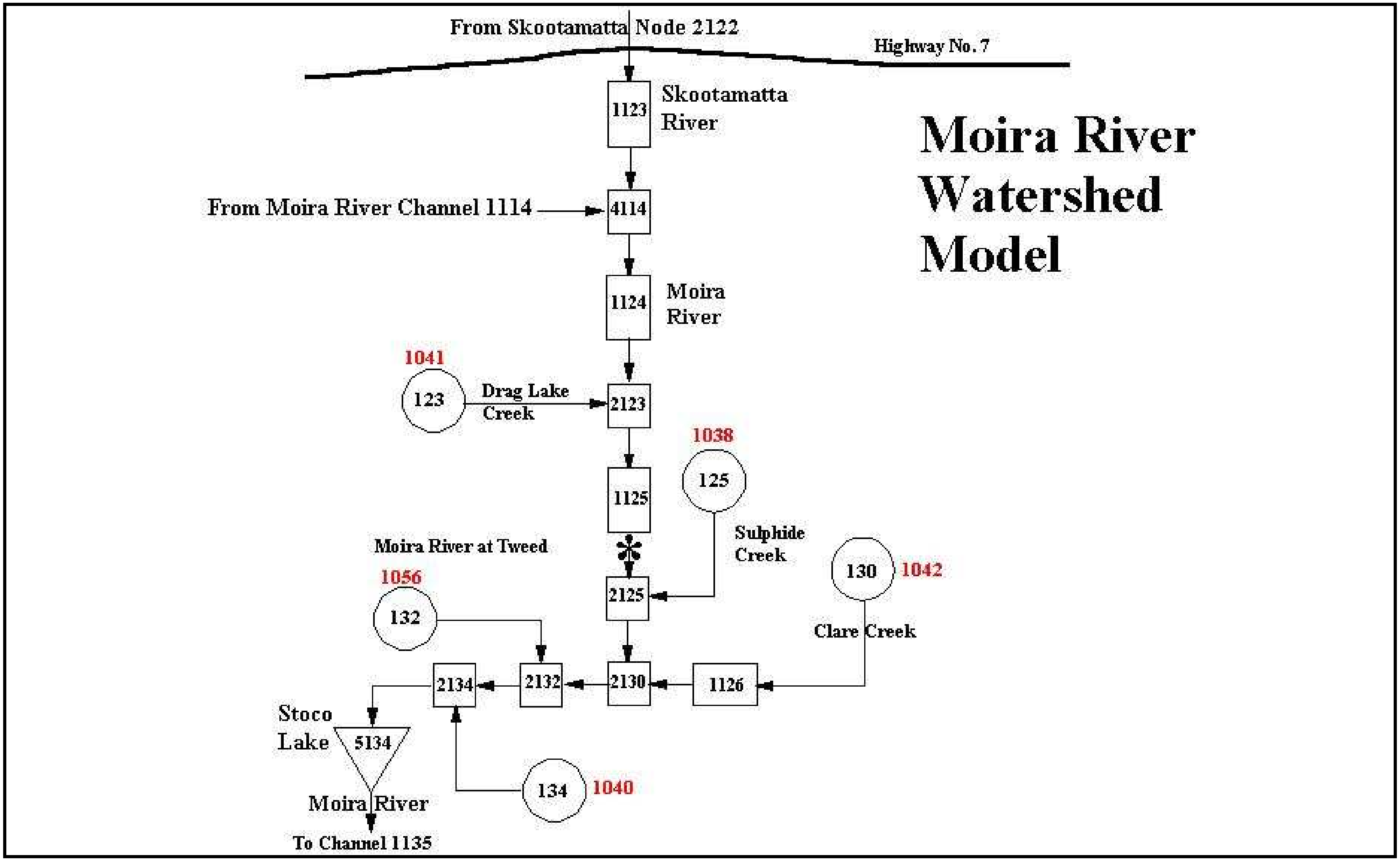


Figure 3 Continued

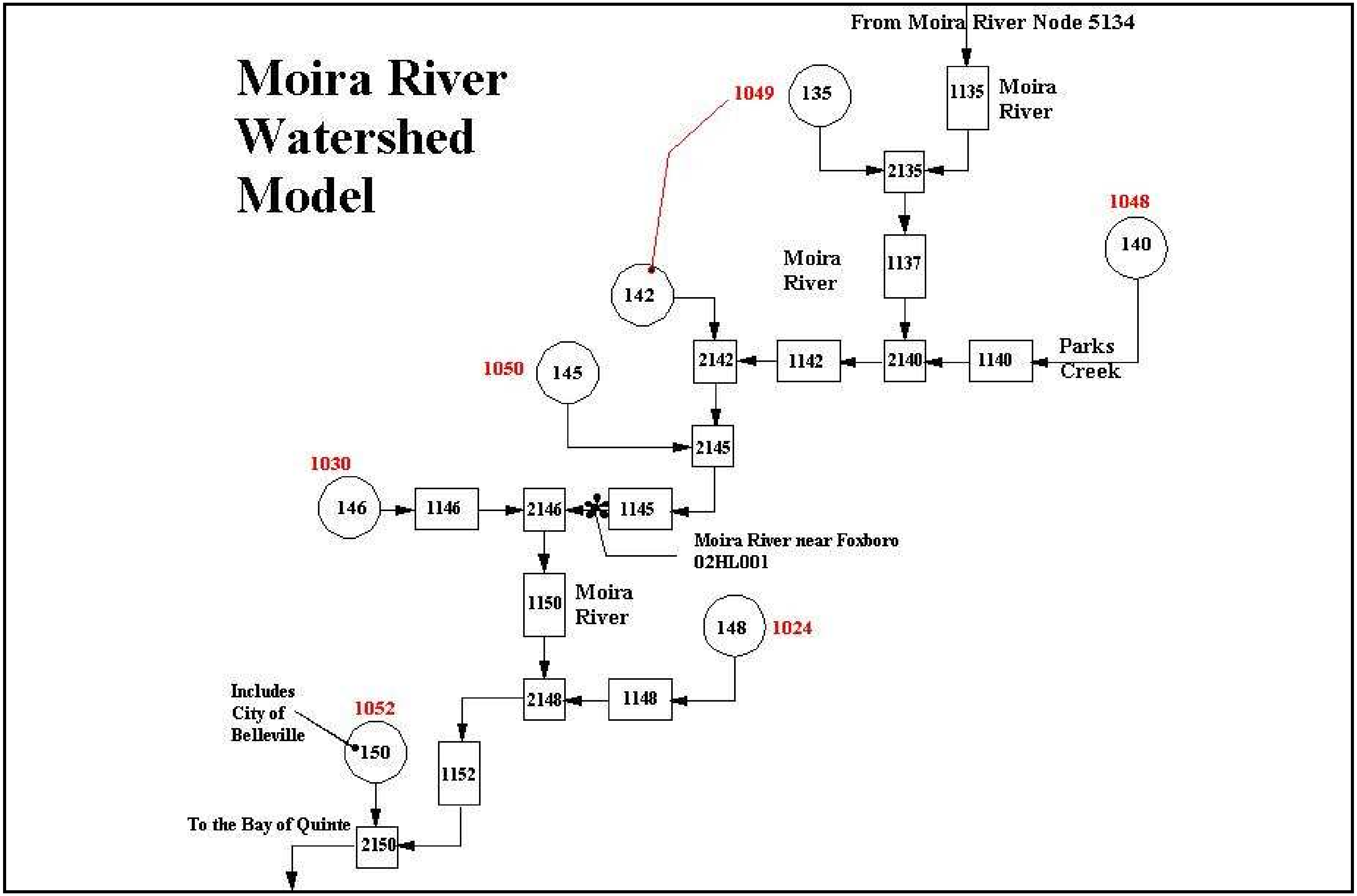


Figure 3 Continued

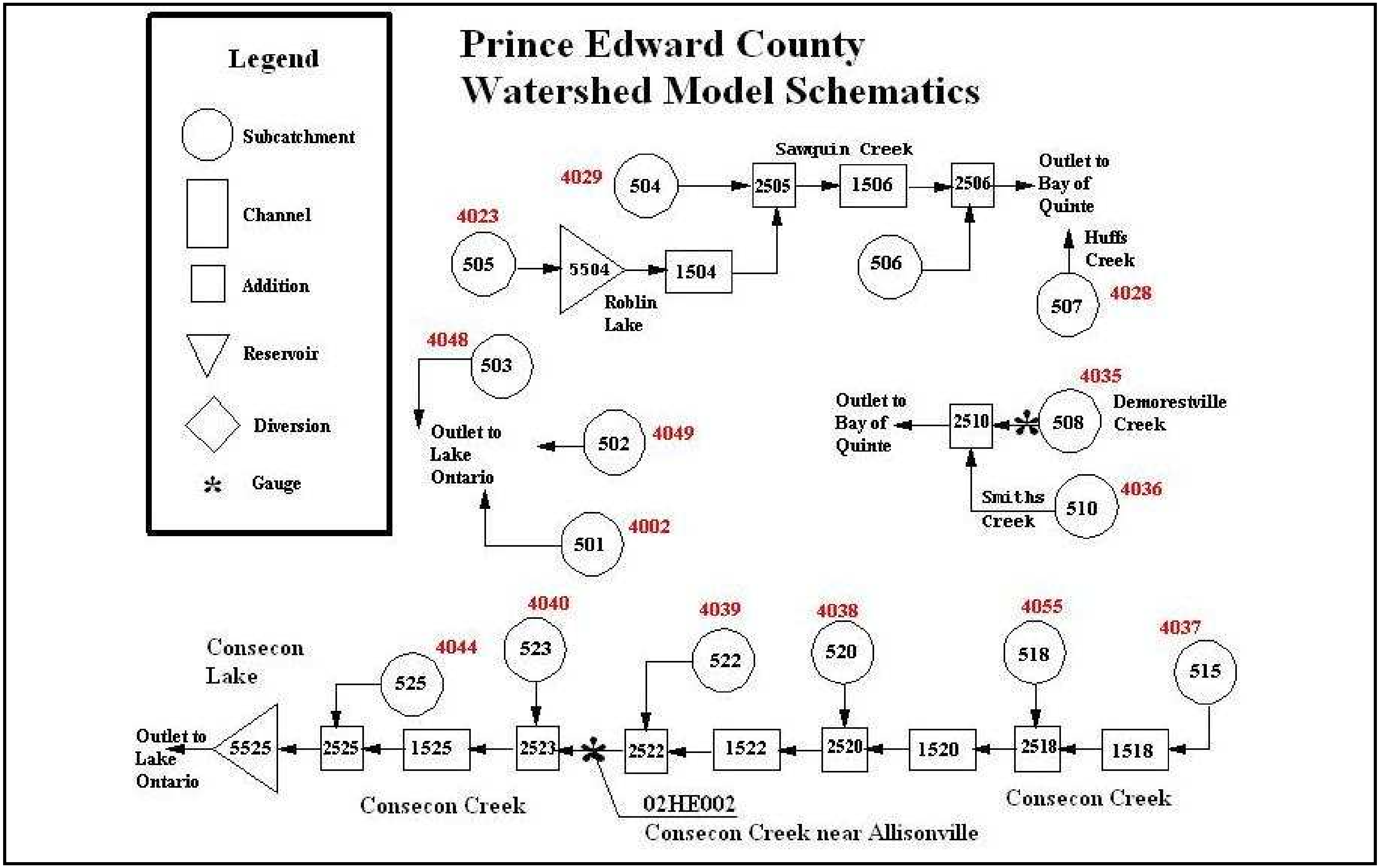


Figure 4 Schematic representation of the Prince Edward County hydrologic models

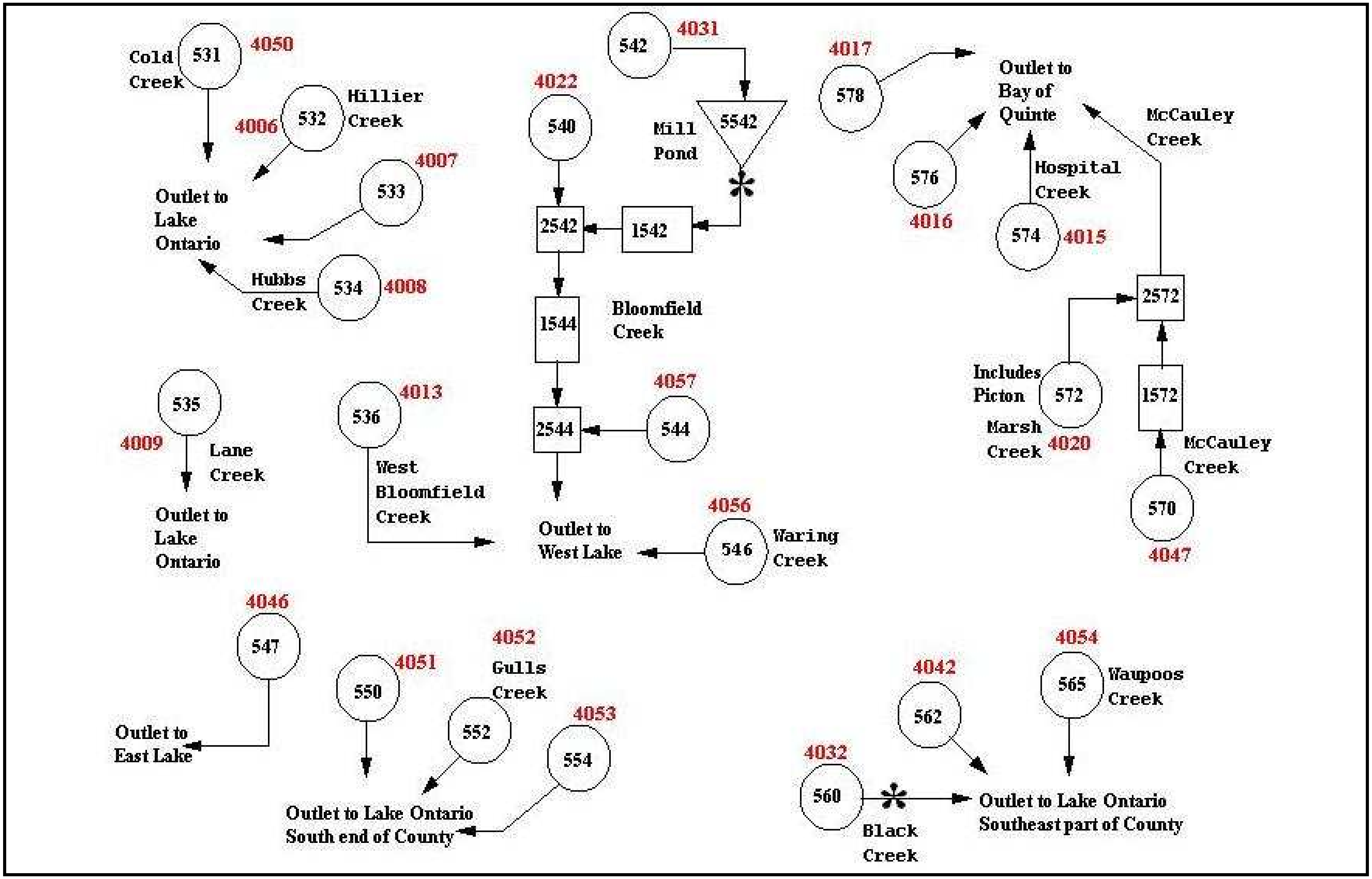


Figure 4 Continued

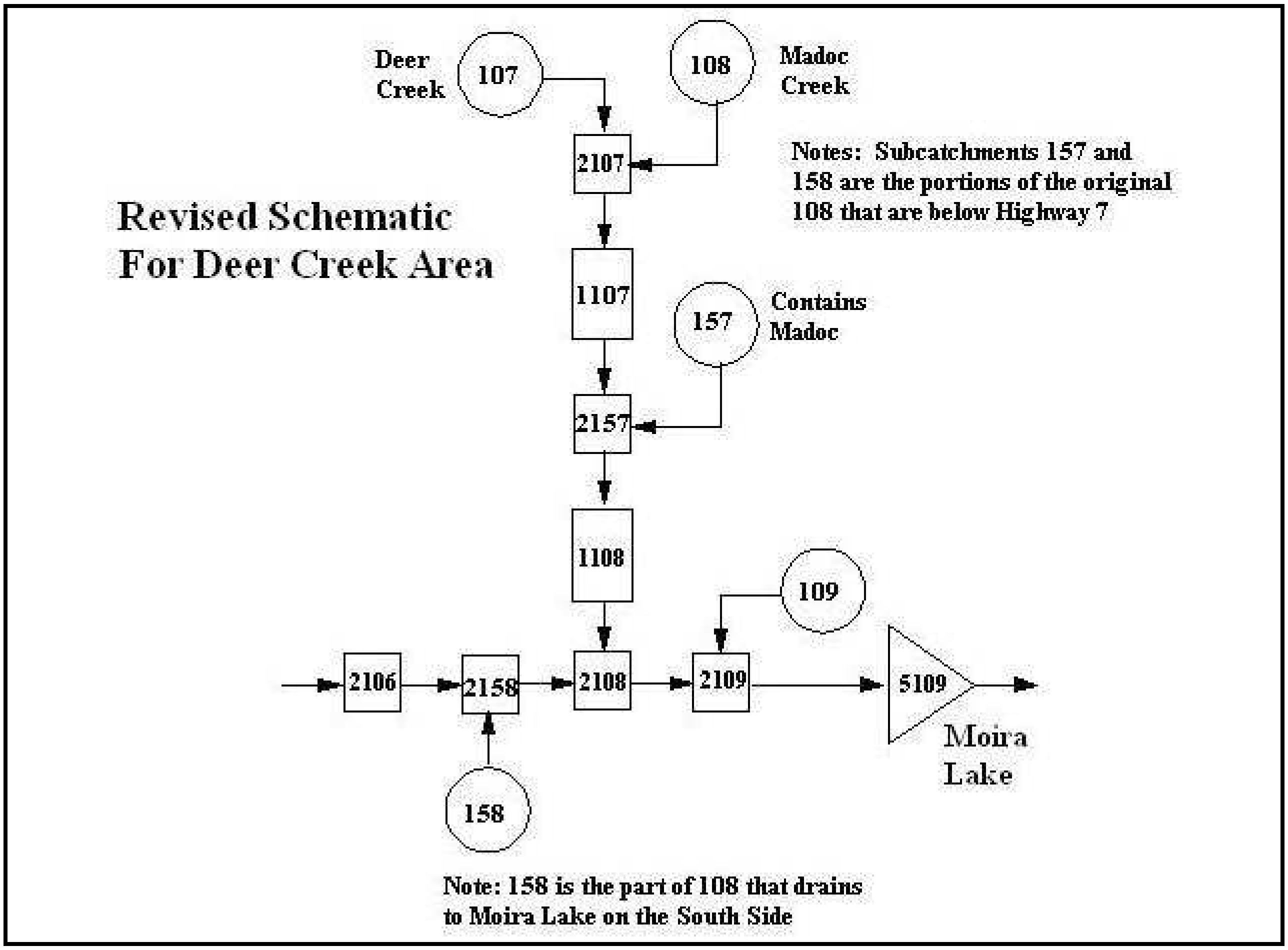


Figure 5 Revisions to the Deer and Madoc Creek portions of the Moira River model

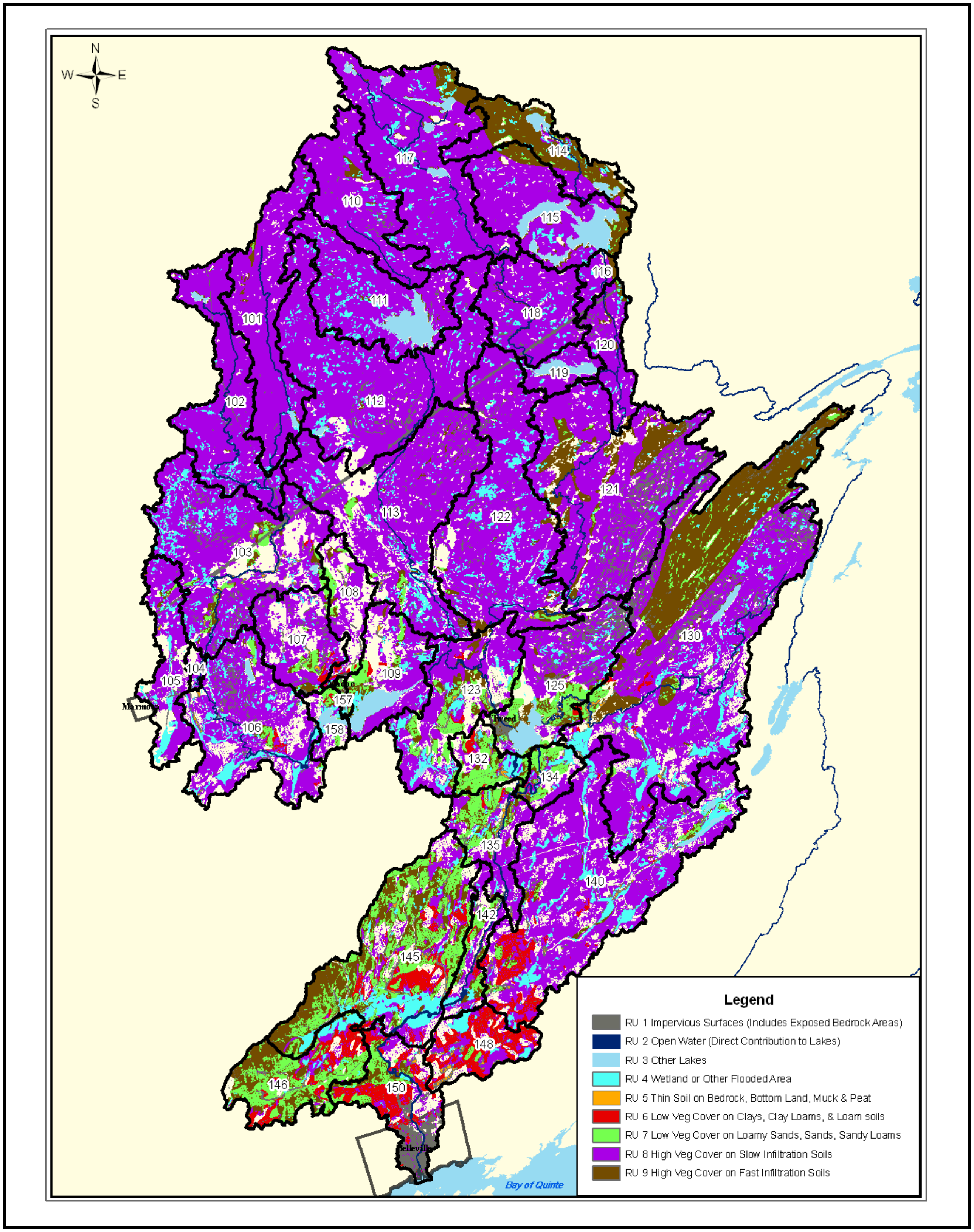


Figure 6   Hydrologic response units in the Moira River watershed model

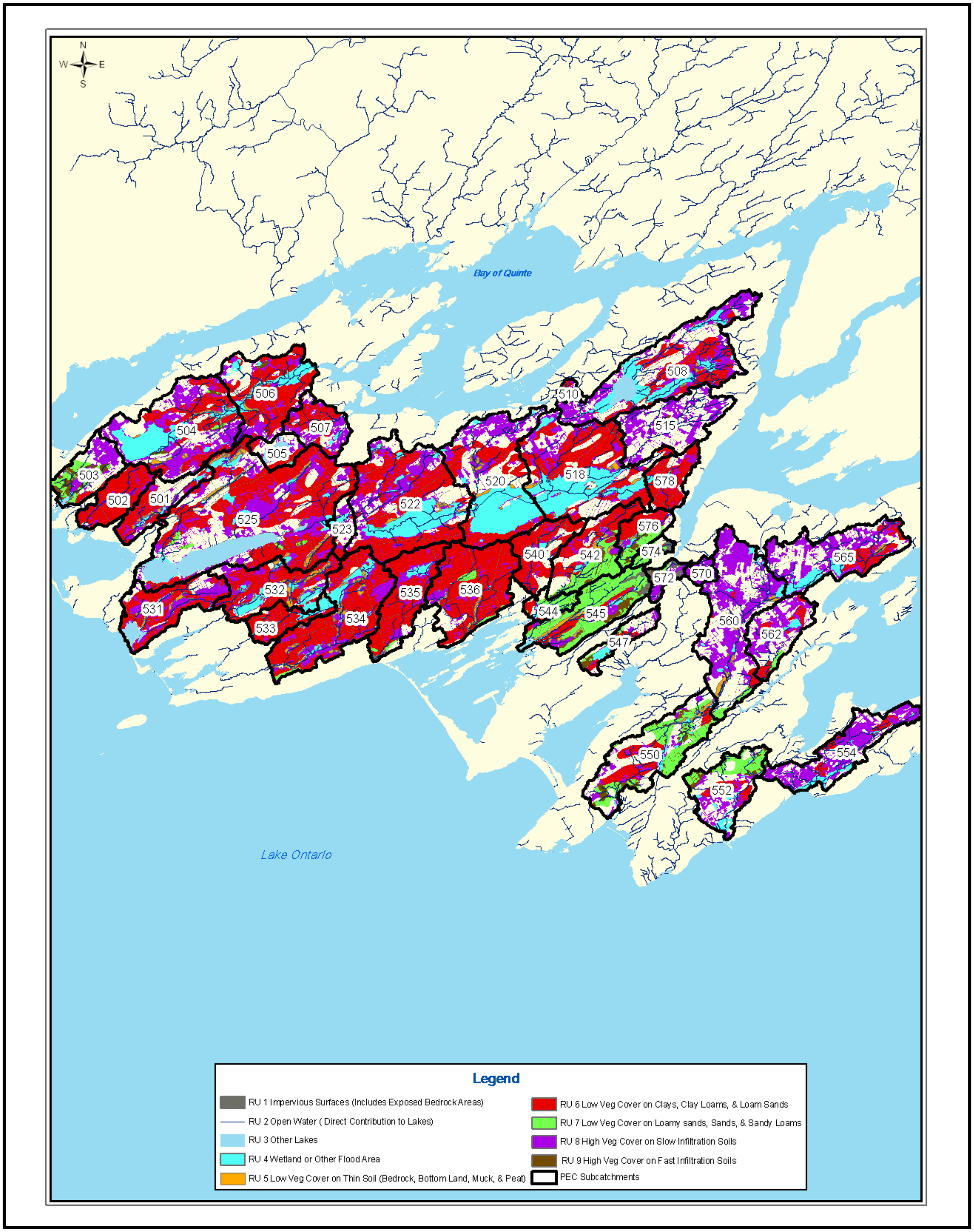


Figure 7 Hydrologic response units in the Prince Edward county watershed model

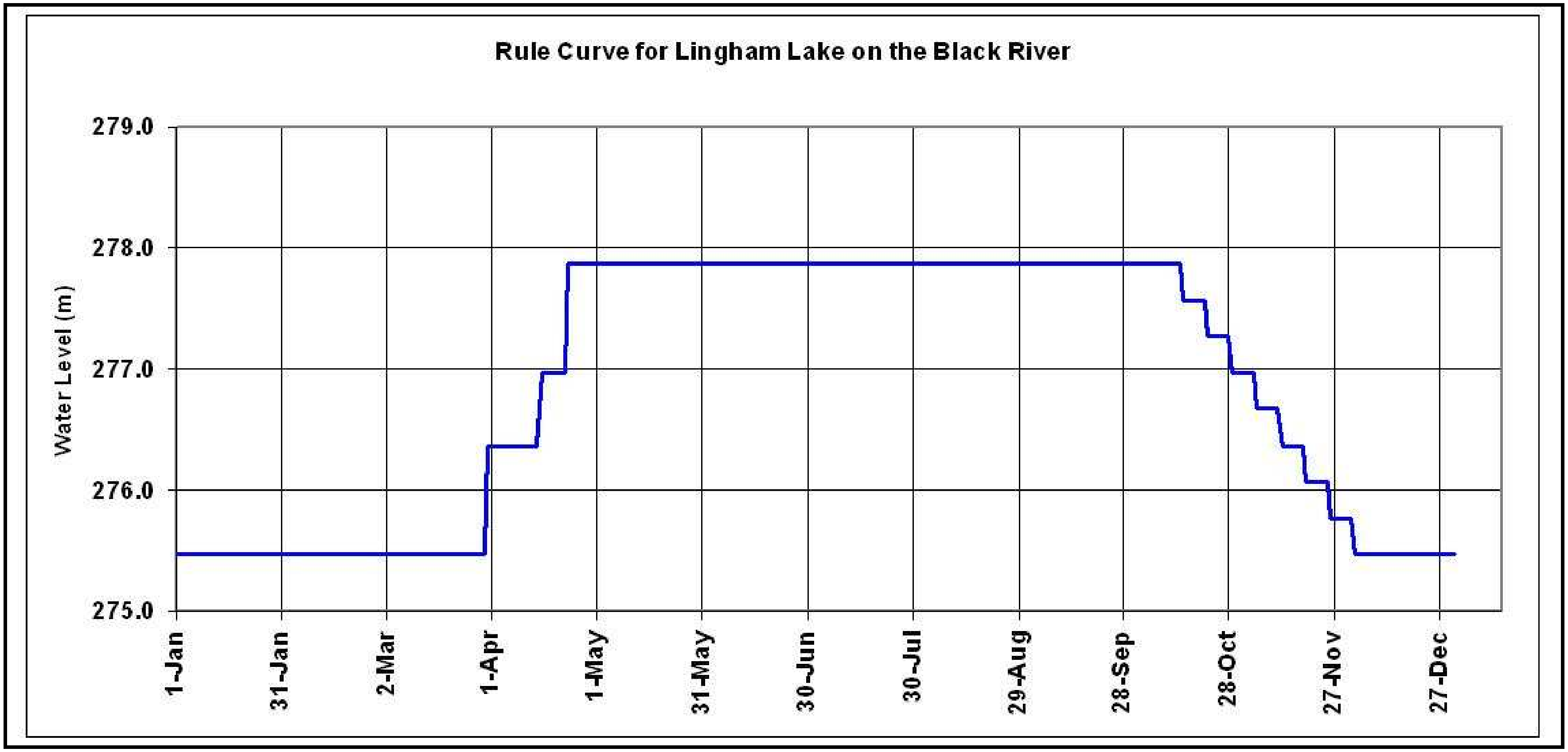


Figure 8 Typical rule curve for the controllable lakes in the Quinte Conservation watershed model

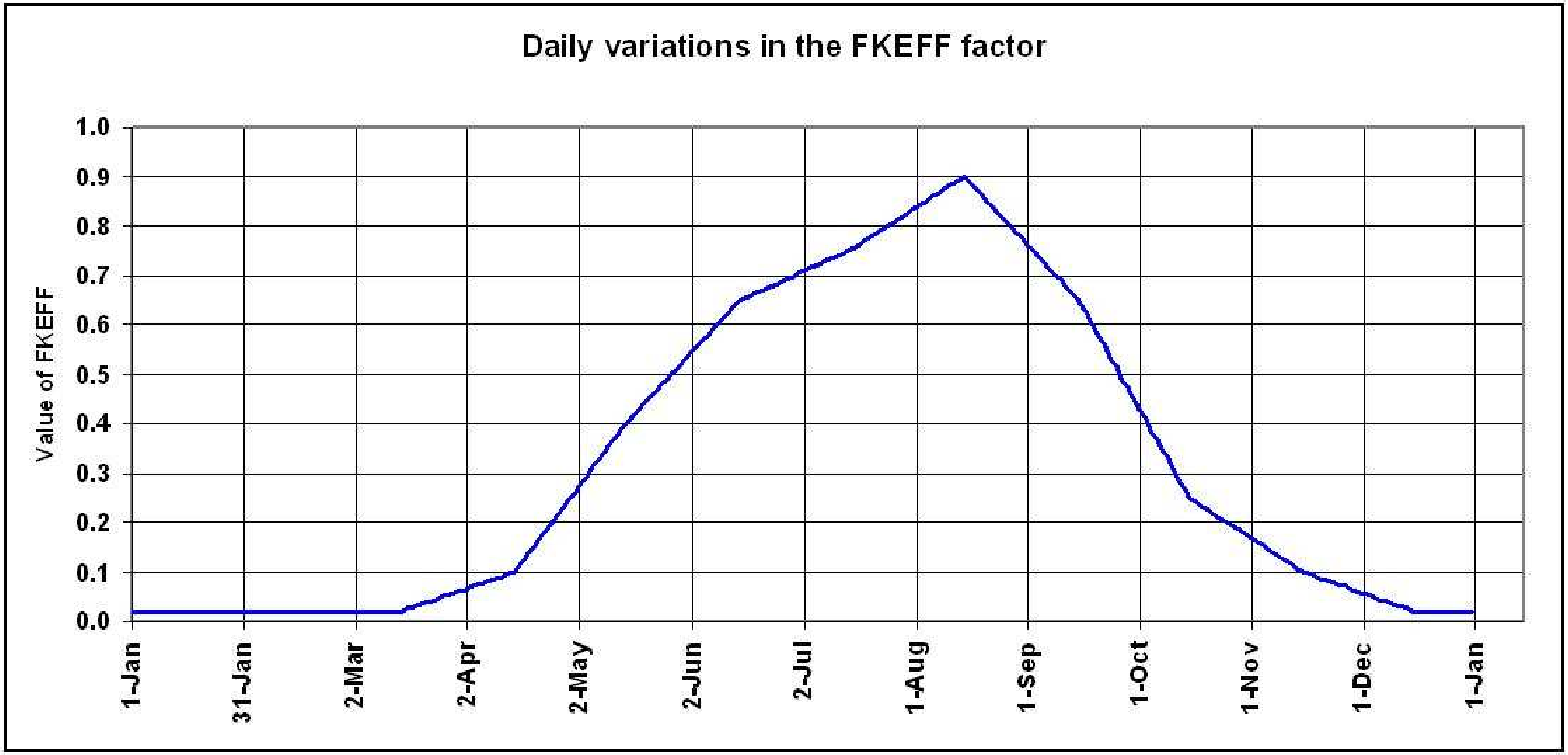


Figure 9 Daily variations in the effective hydraulic conductivity adjustment factor, FKEFF throughout a typical year.

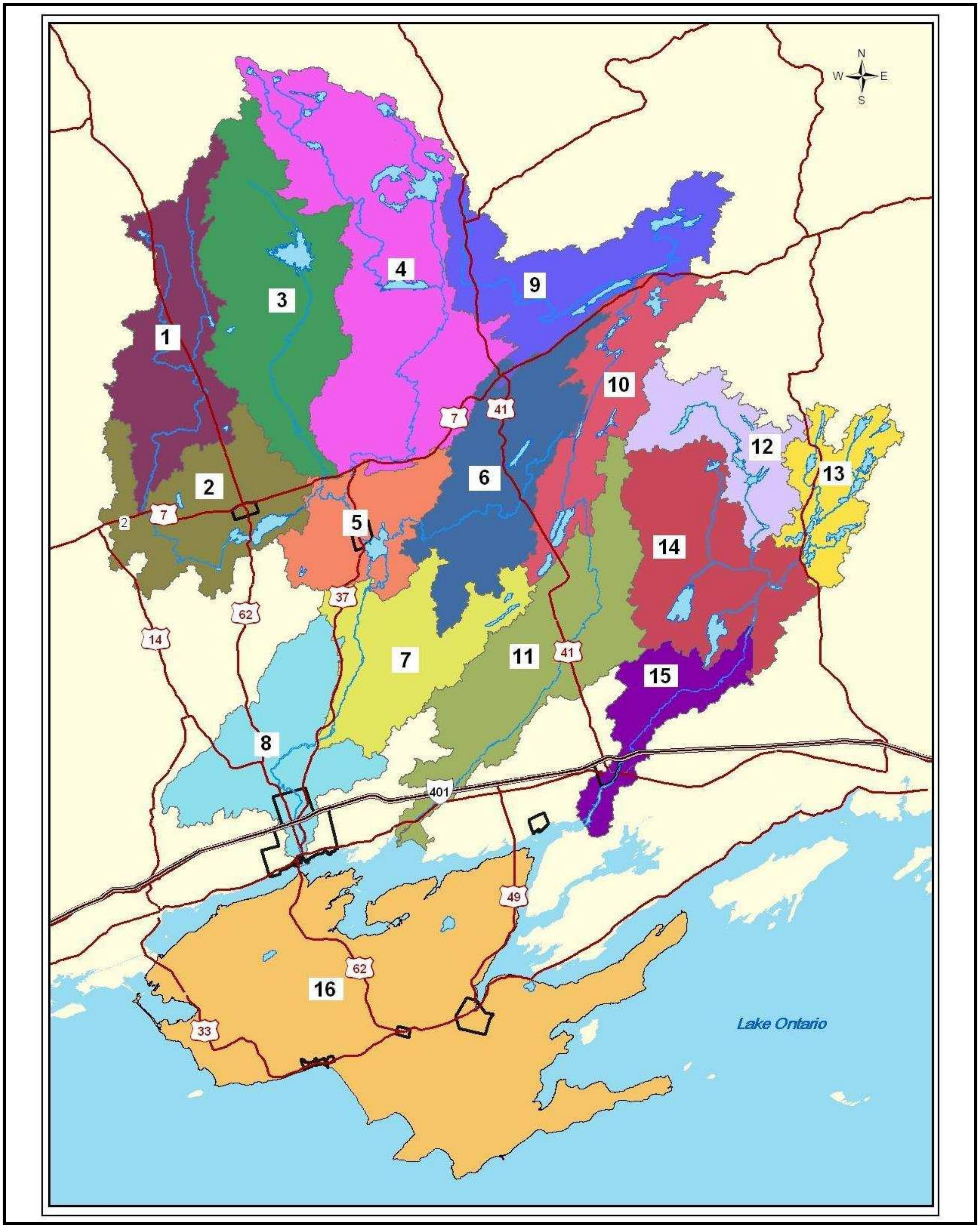
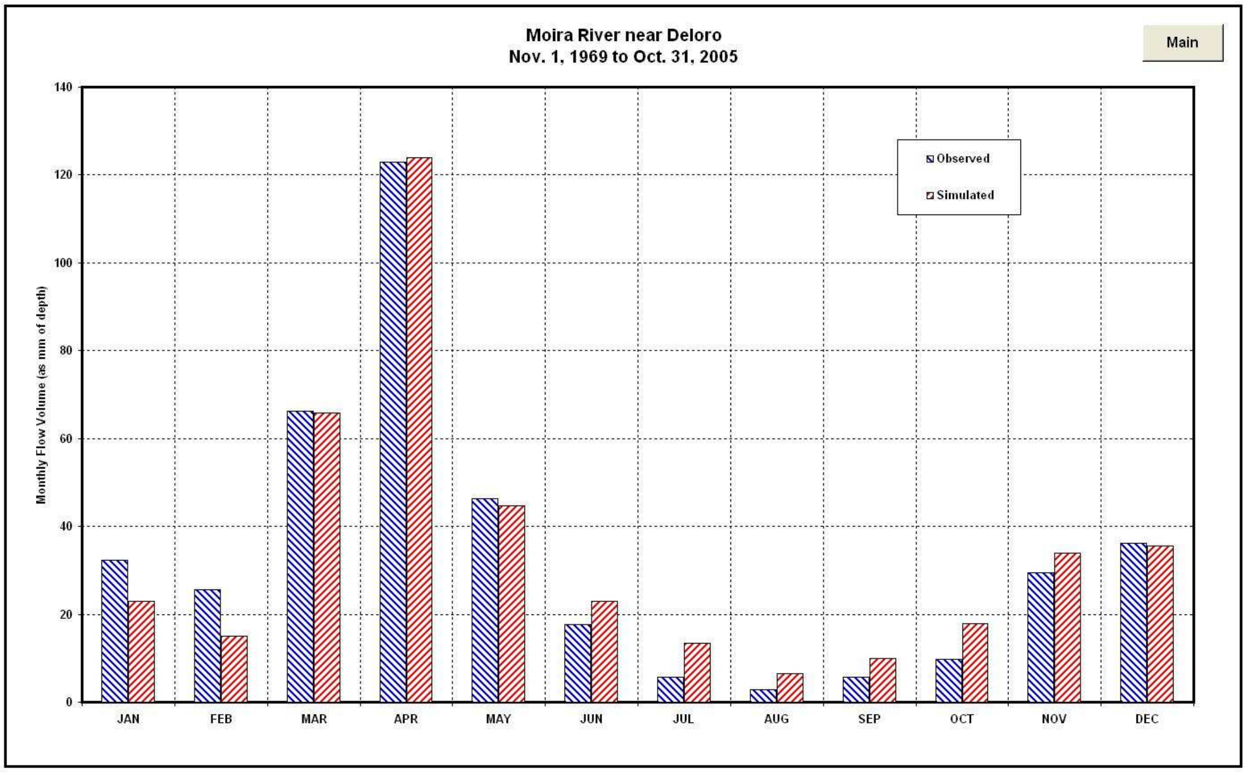


Figure 10 Zones of uniform meteorology for the Quinte Conservation watersheds



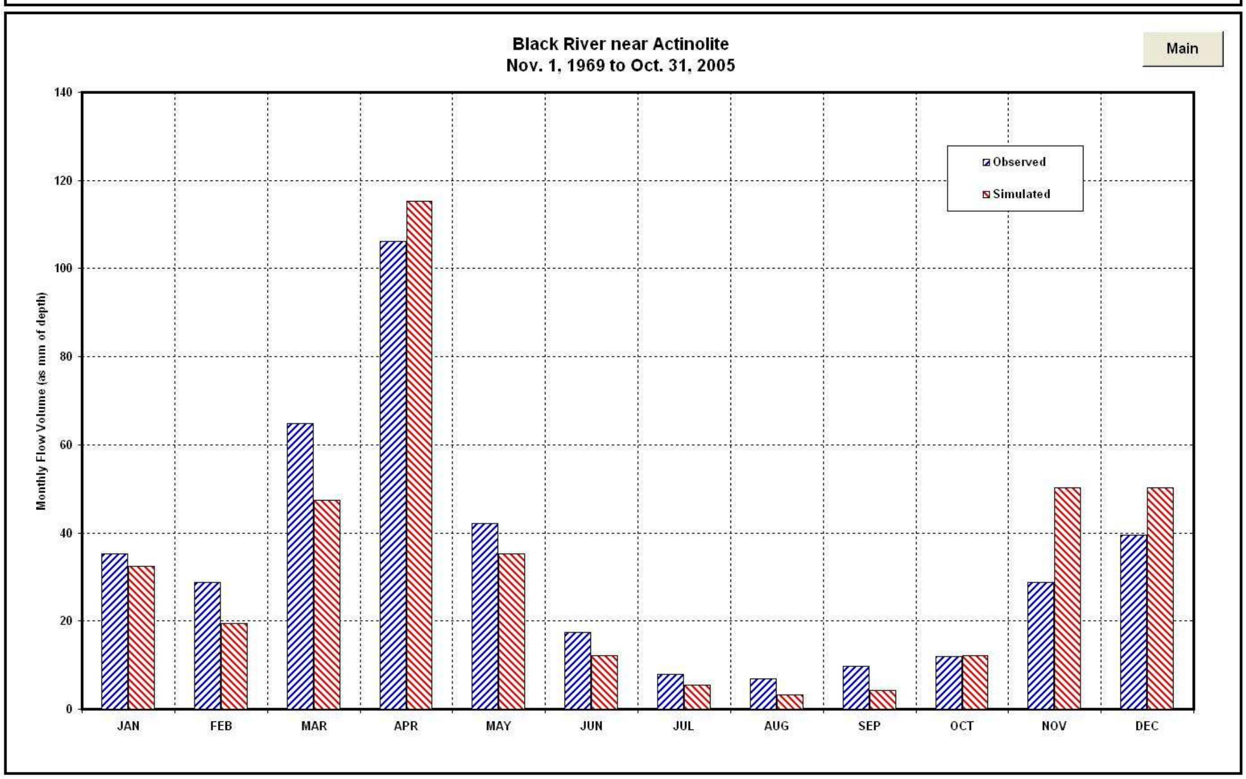
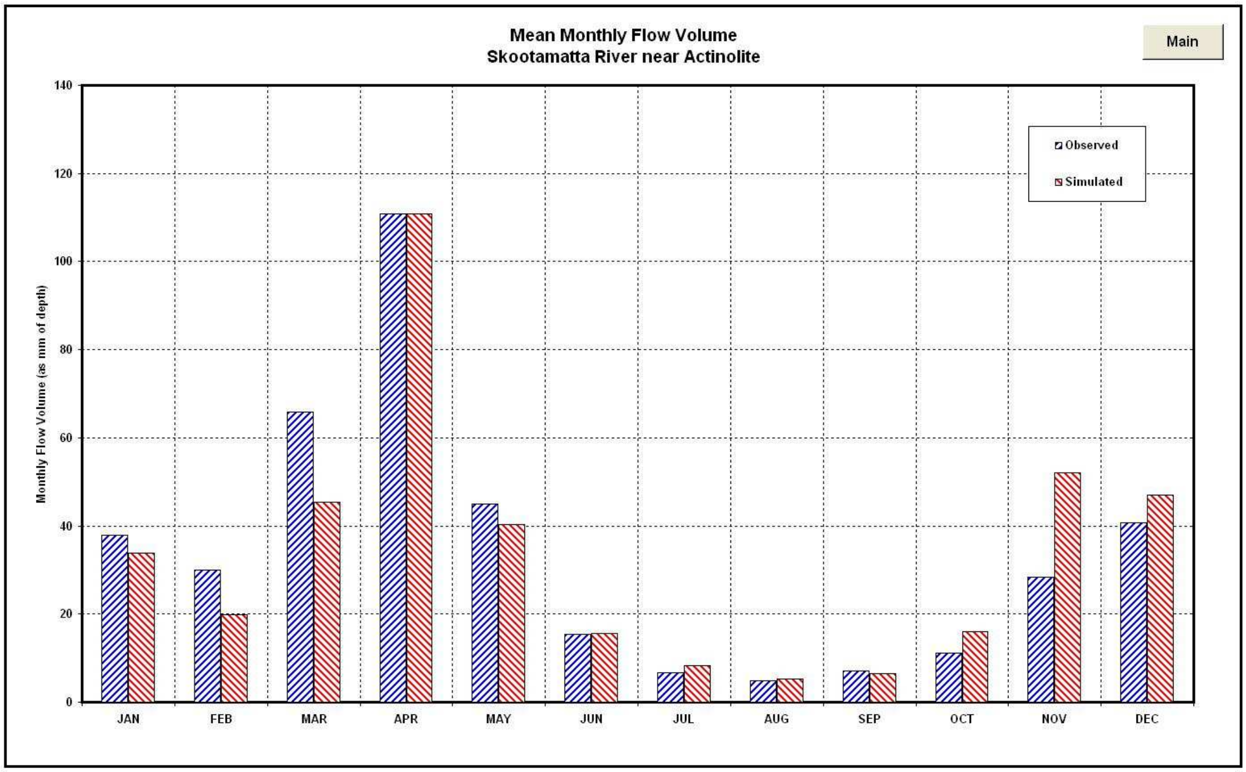


Figure 11 Observed and simulated mean monthly flow volumes for all five gauges



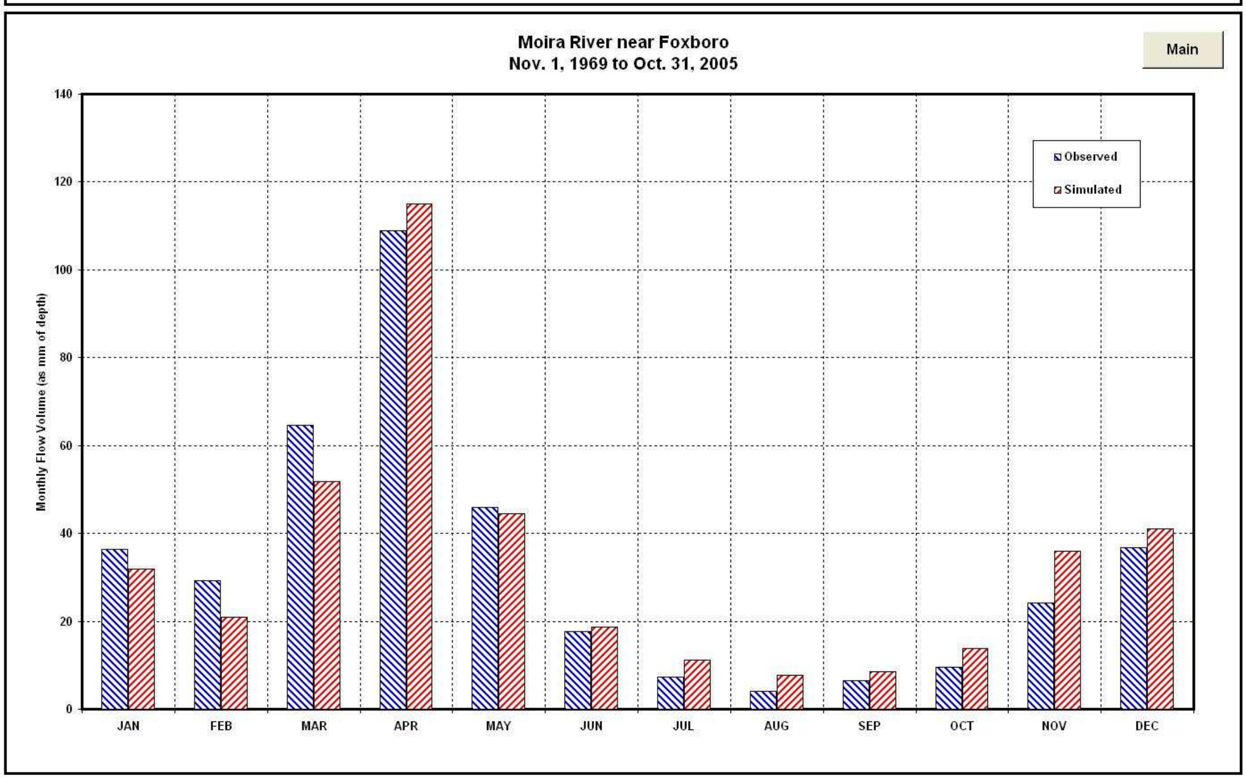


Figure 11 Continued

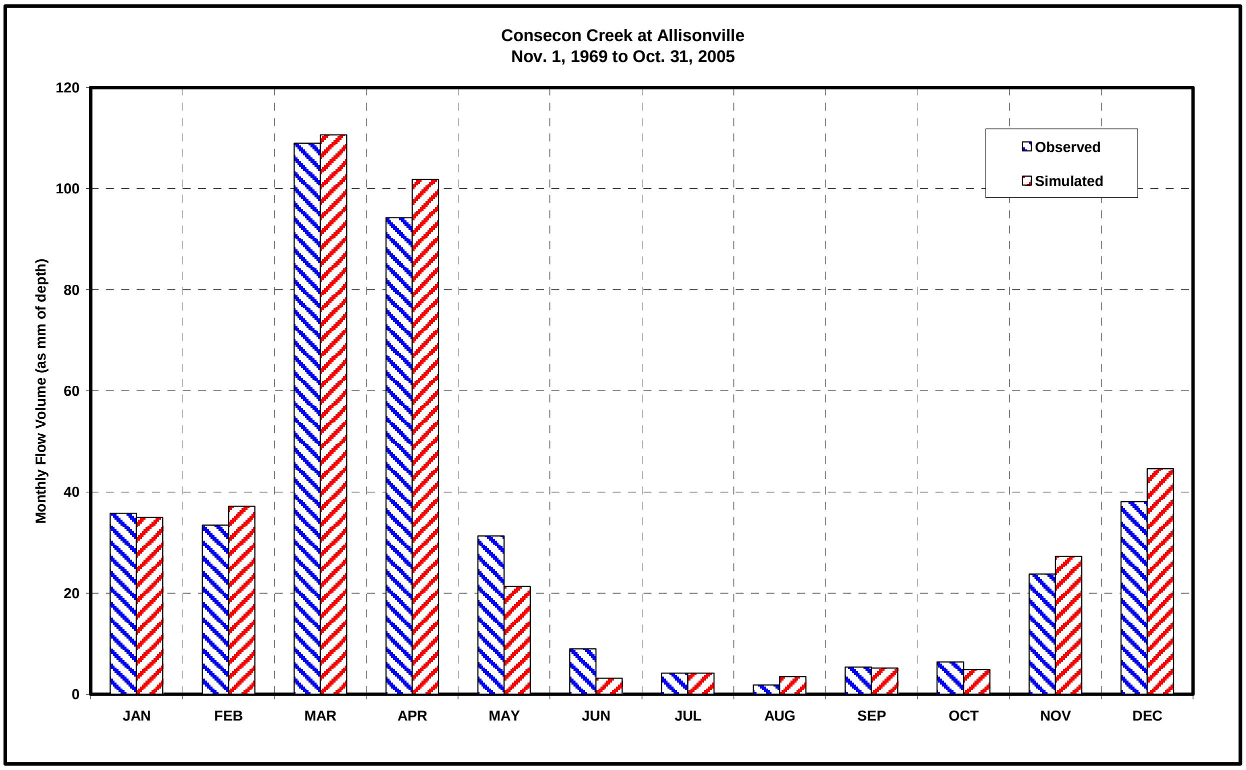


Figure 11 Continued

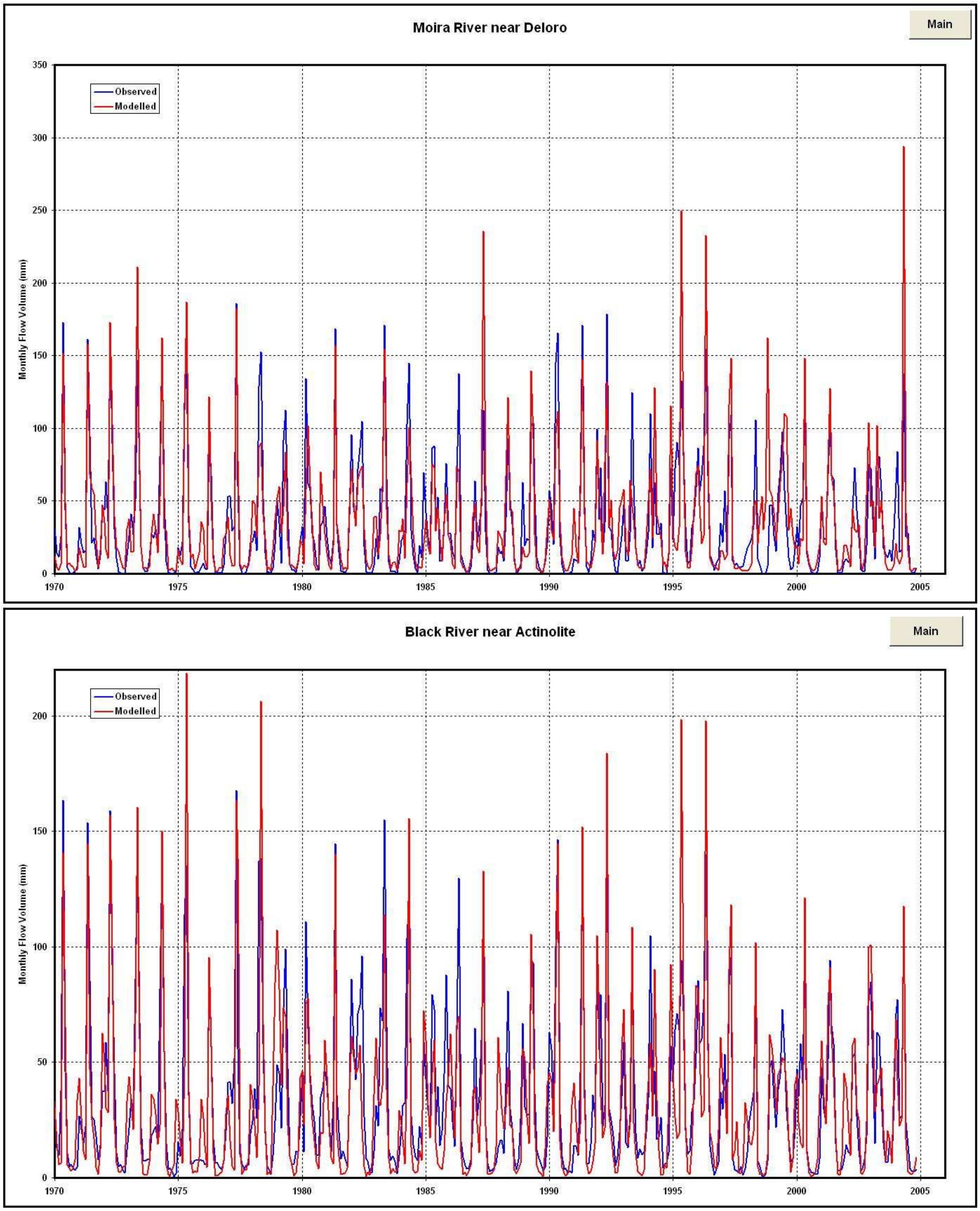
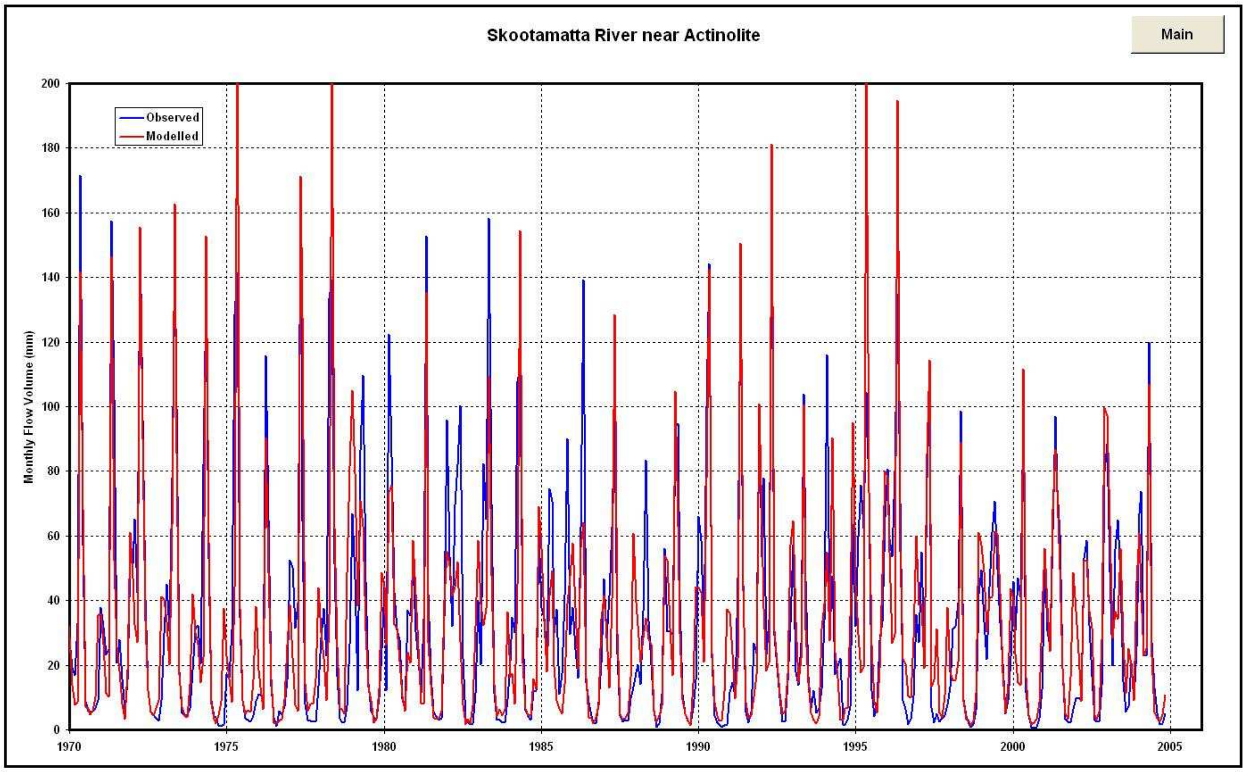


Figure 12 Observed and simulated monthly flow volumes



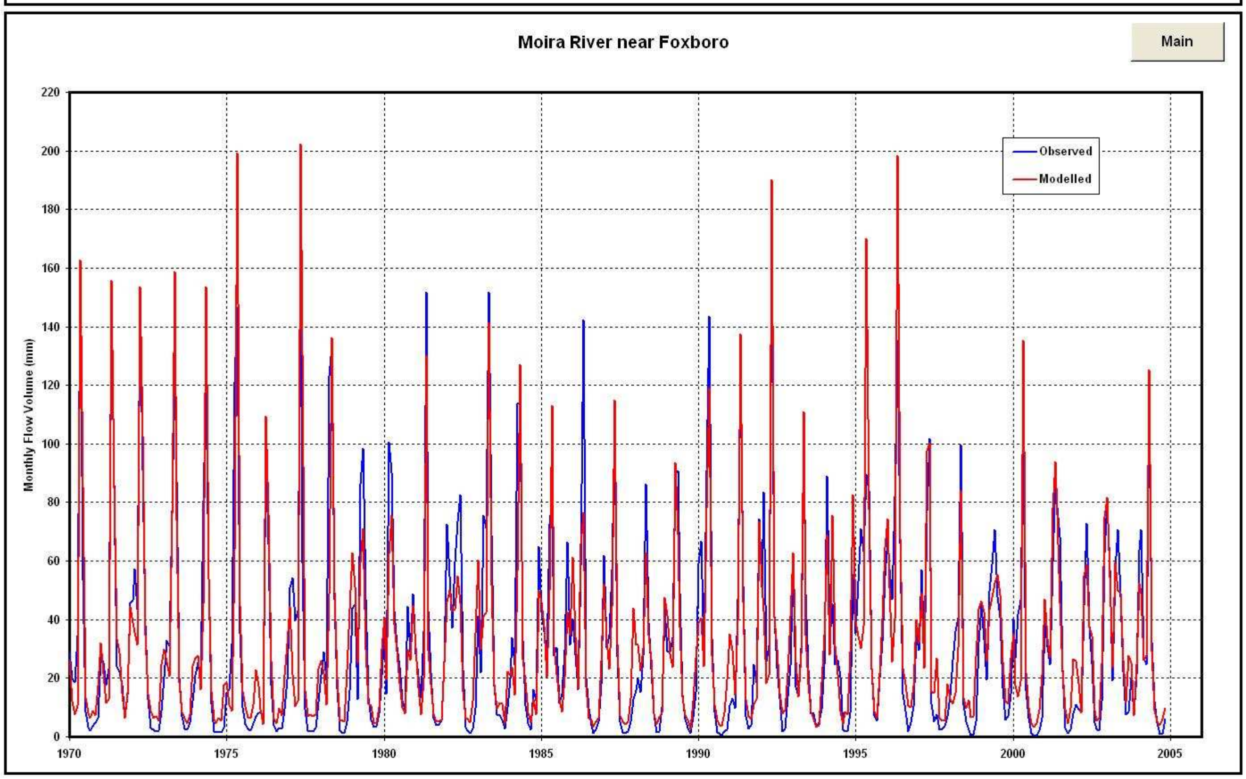


Figure 12 Continued

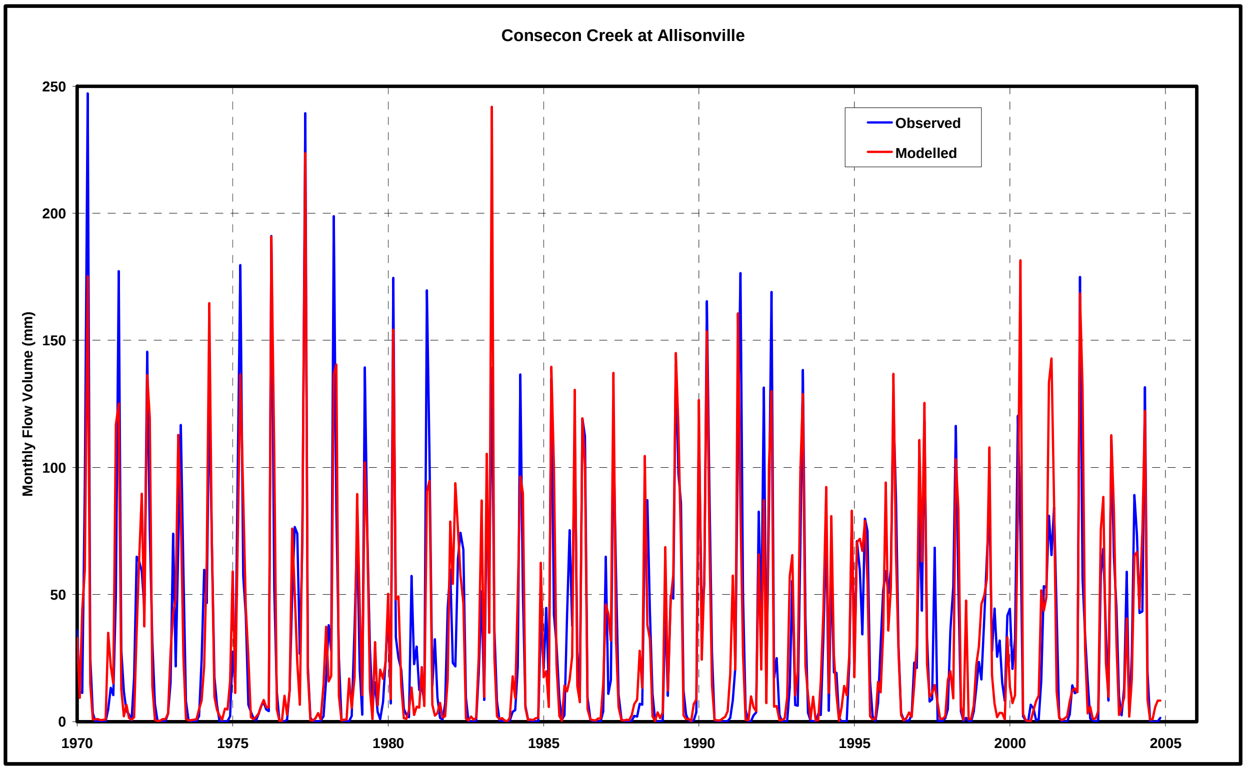
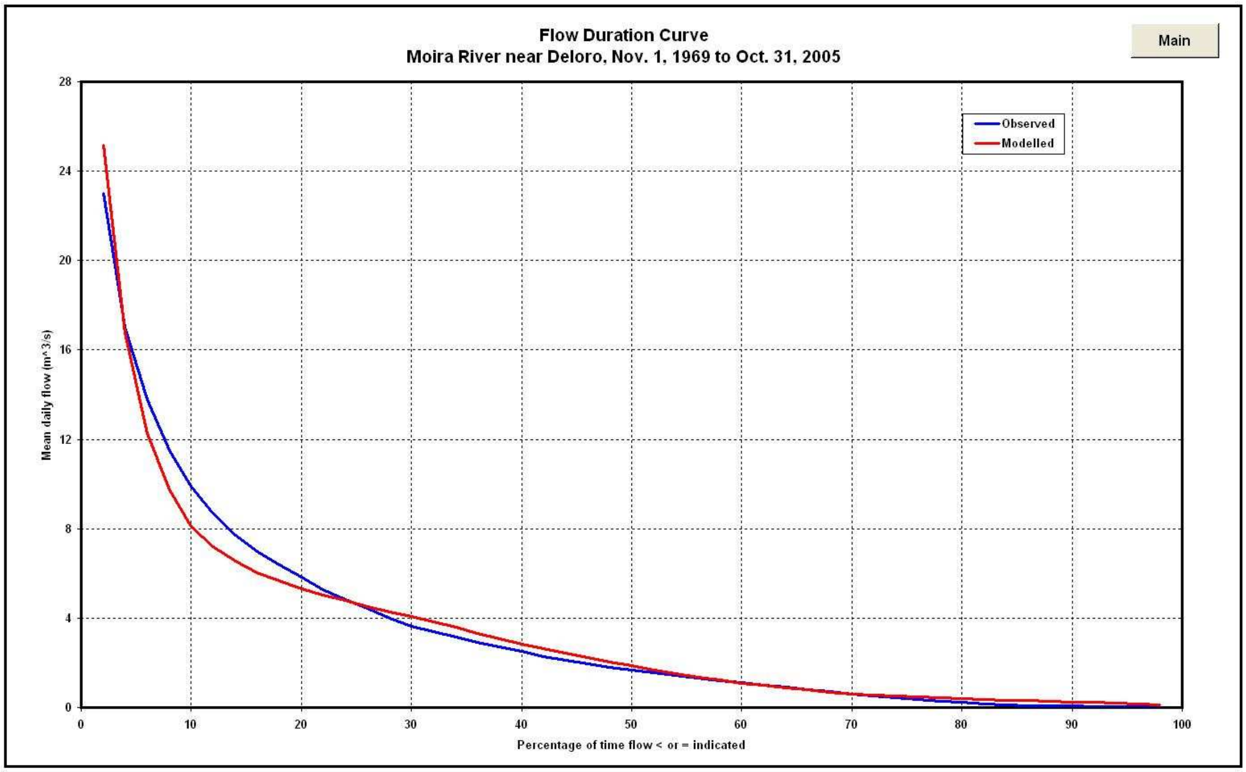


Figure 12 Continued



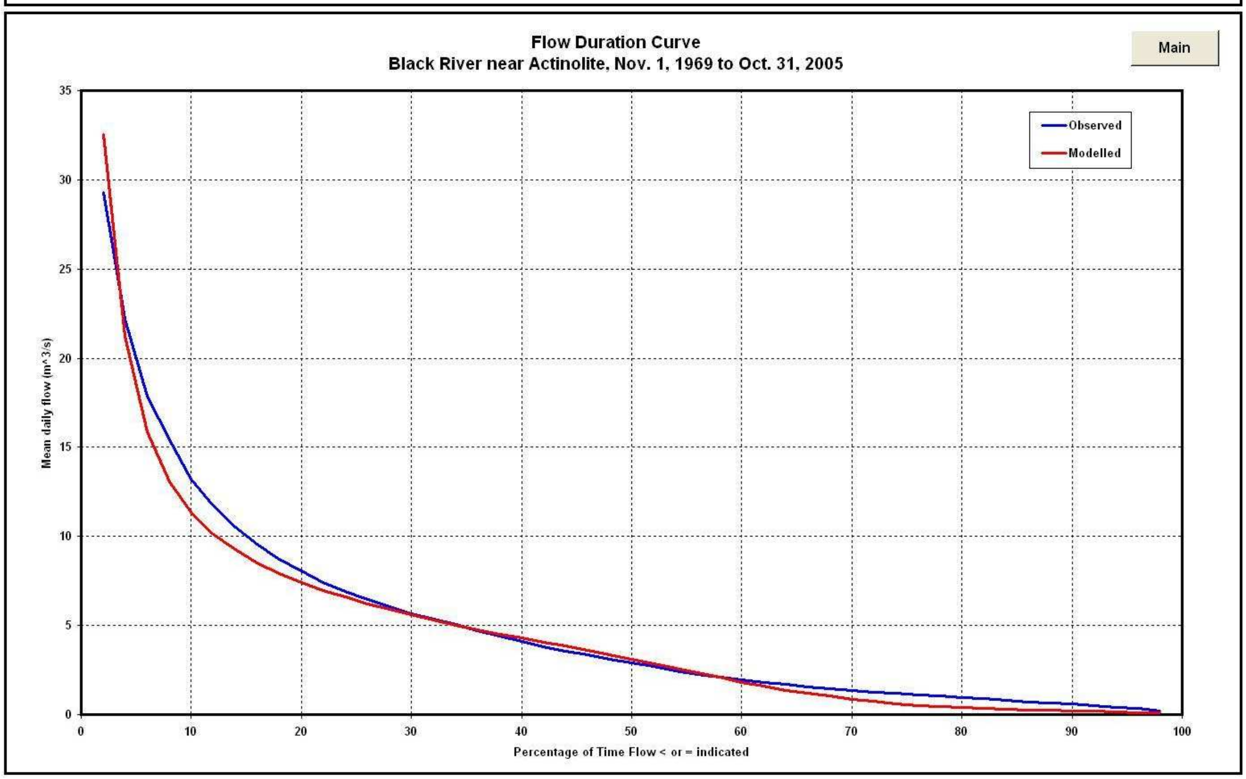
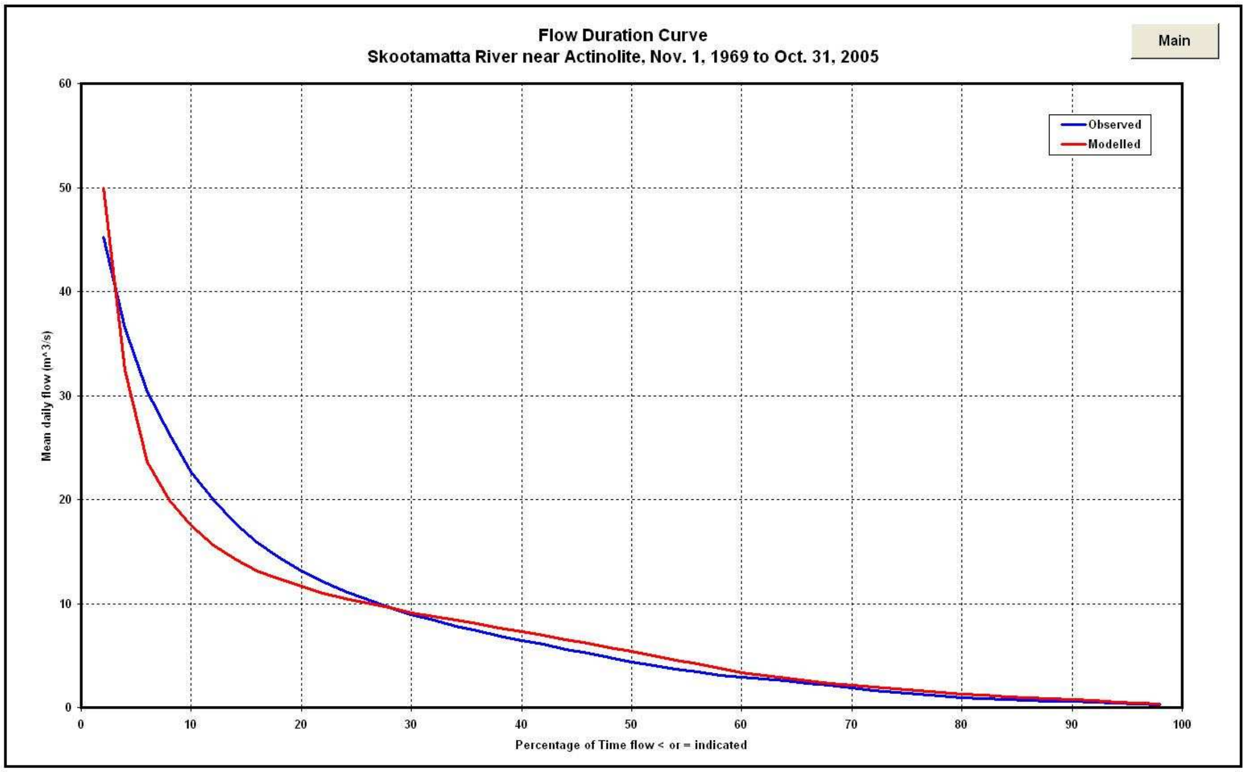


Figure 13 Measured and modelled flow duration curves



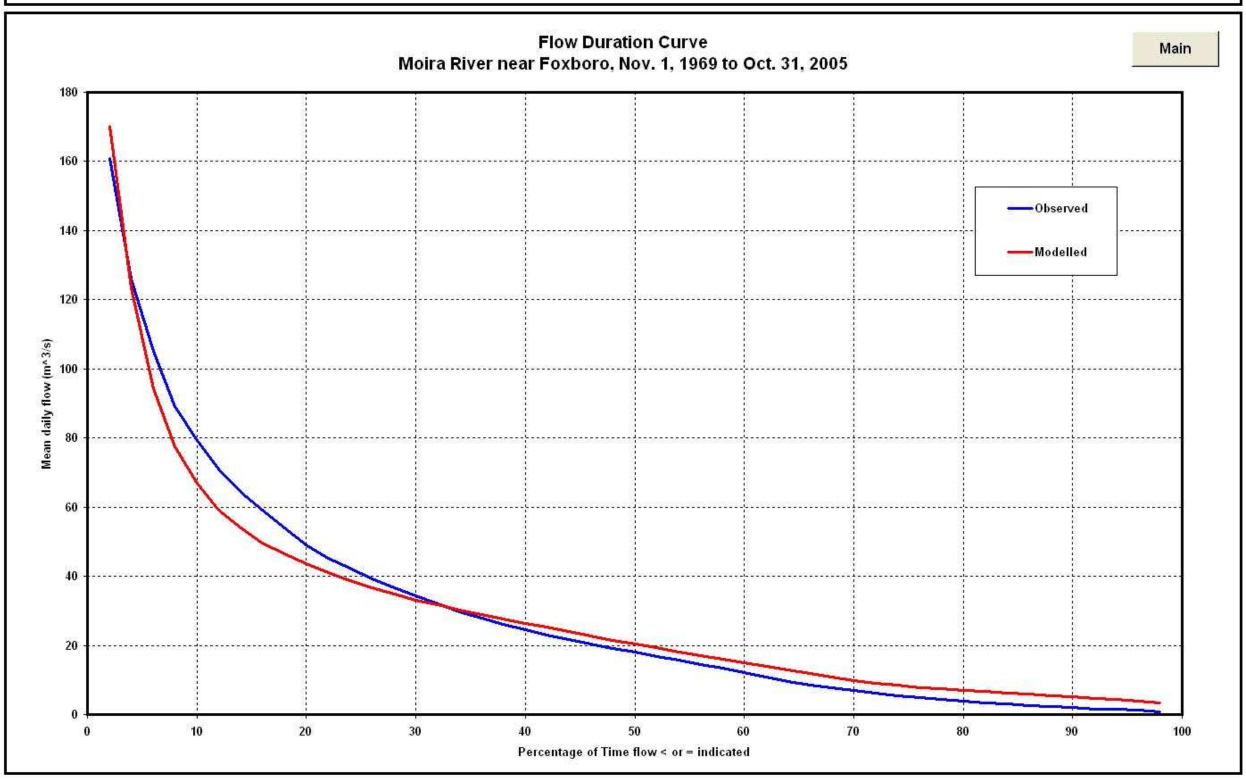


Figure 13 Continued

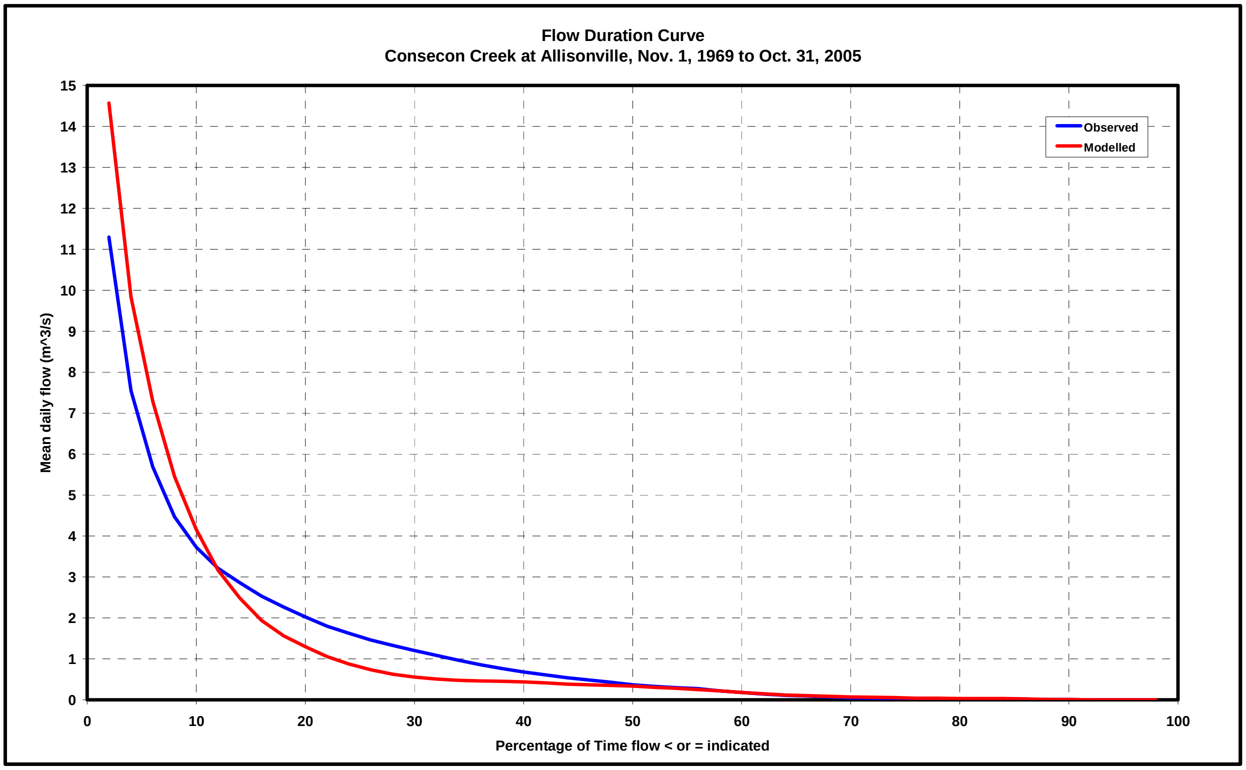
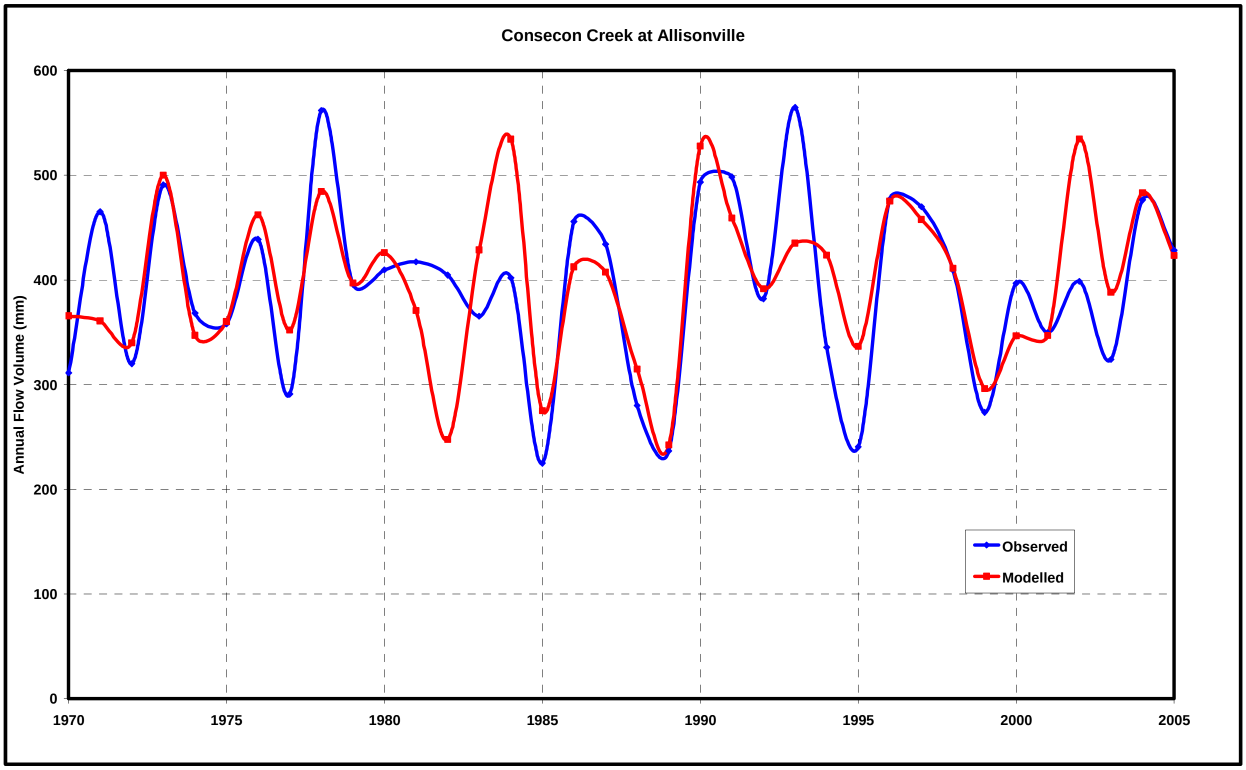


Figure 13 Continued



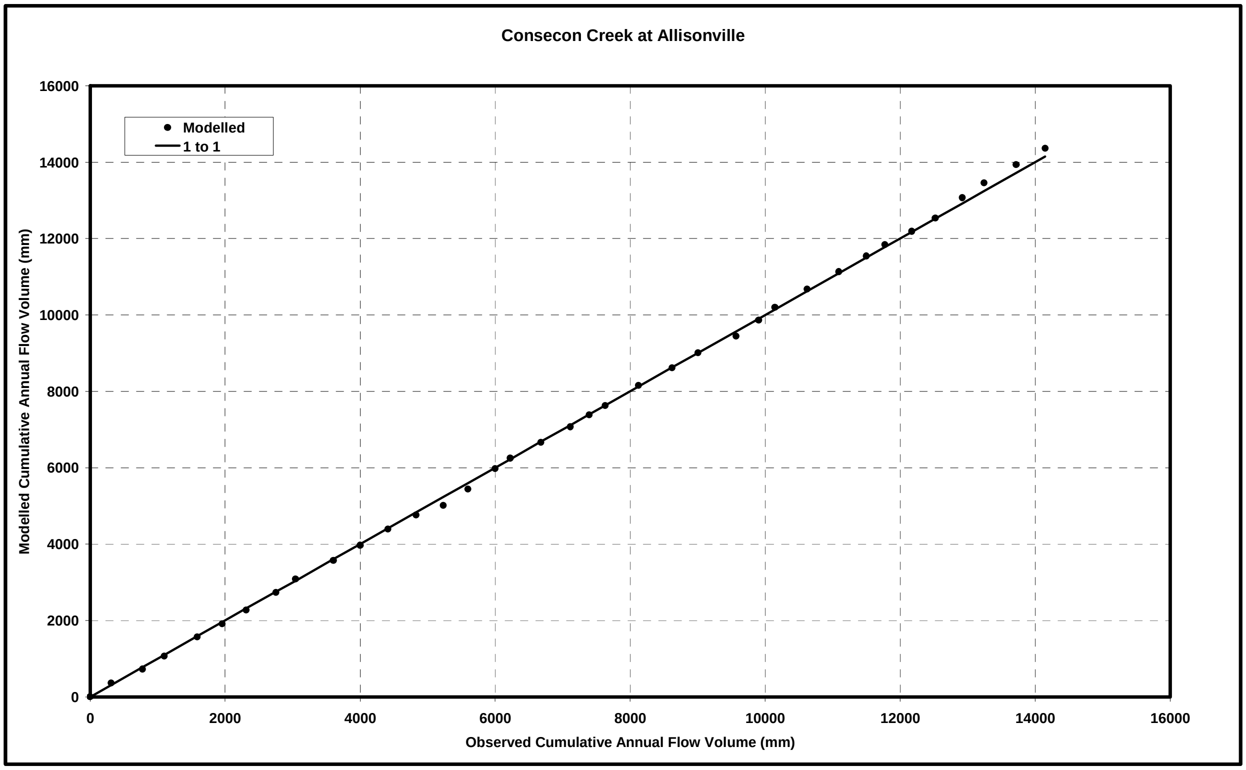
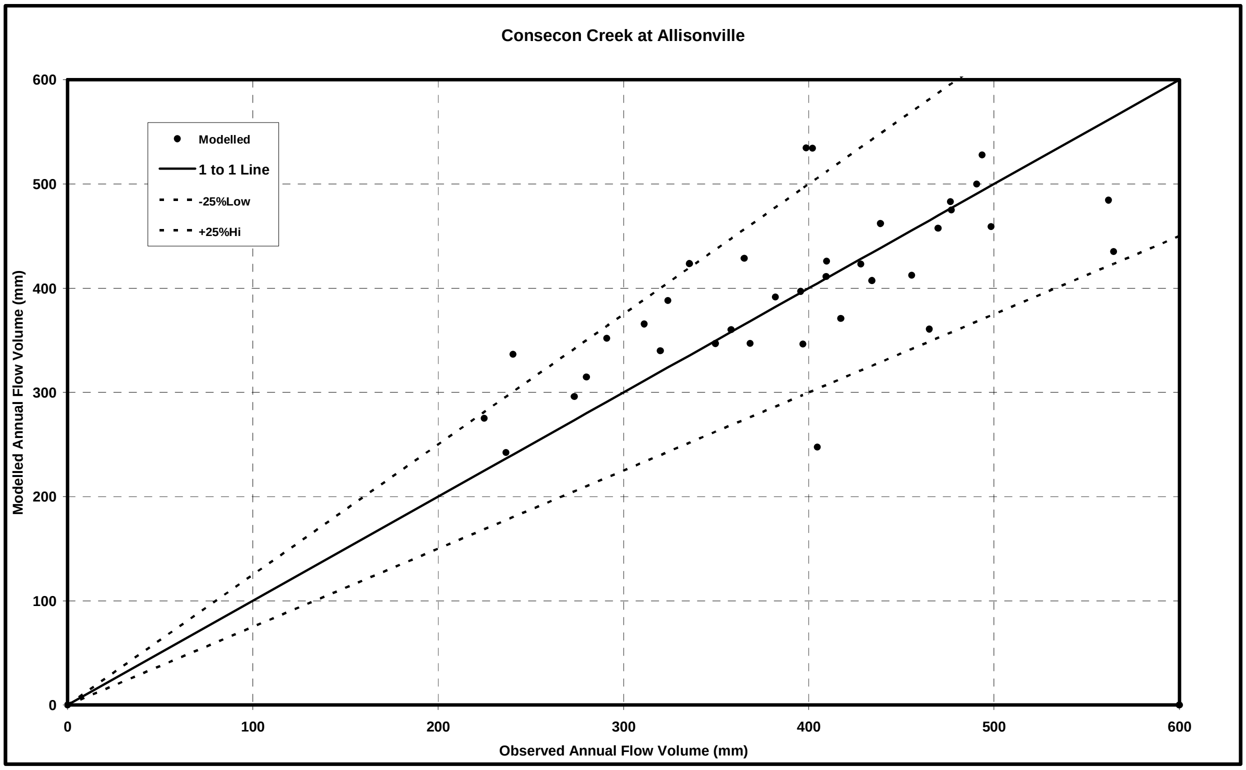


Figure 14A Other measured and modelled comparison plots available for model testing



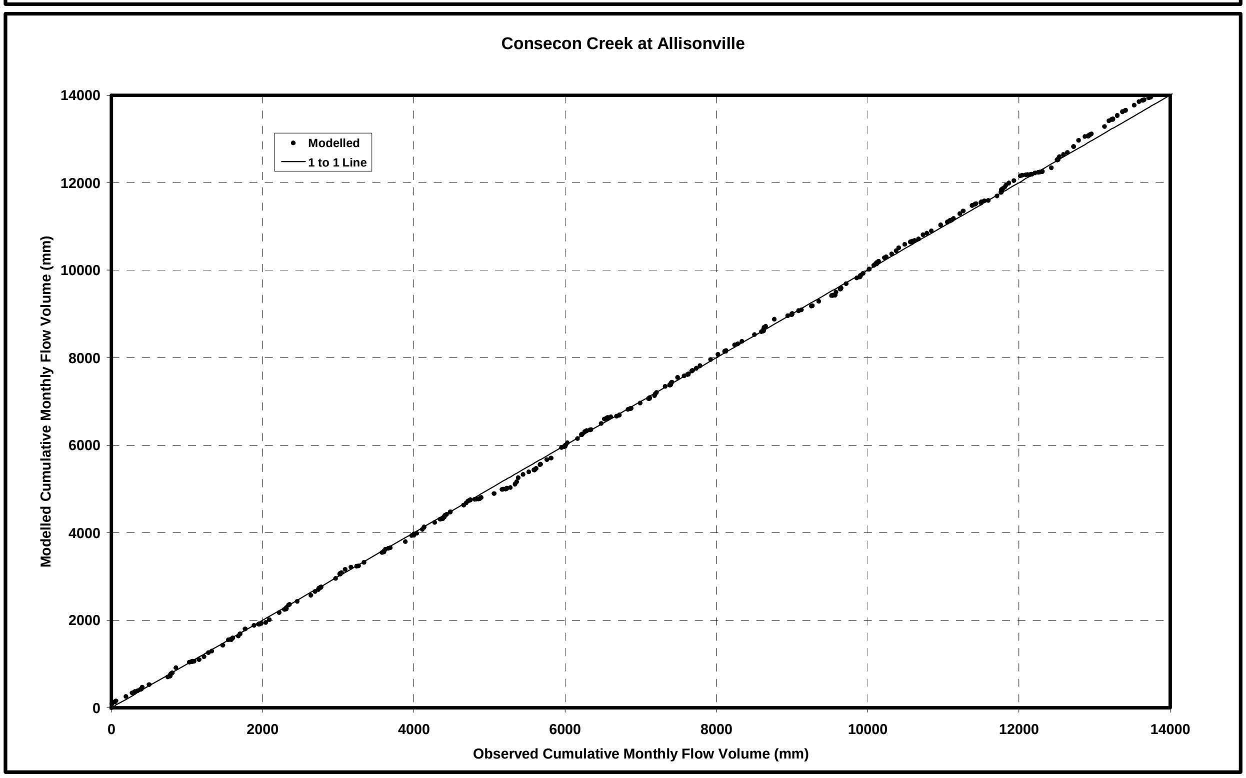


Figure 14B Continued

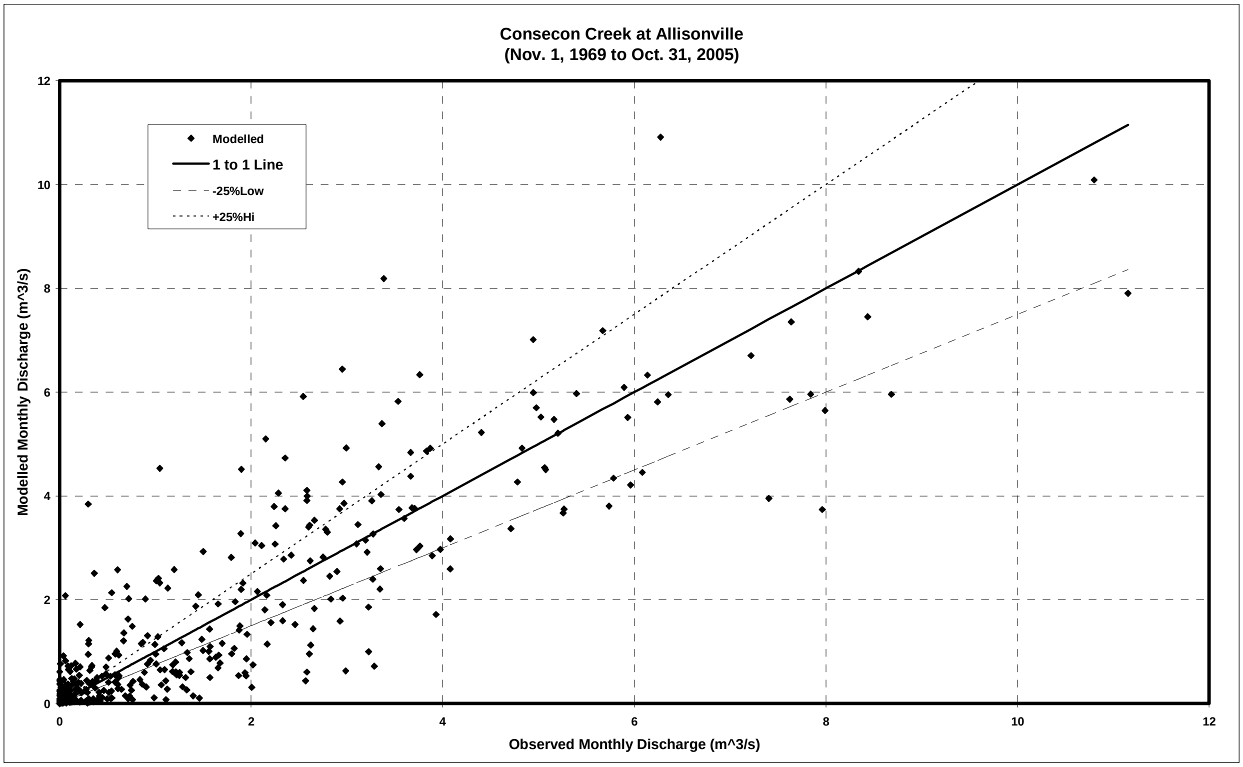
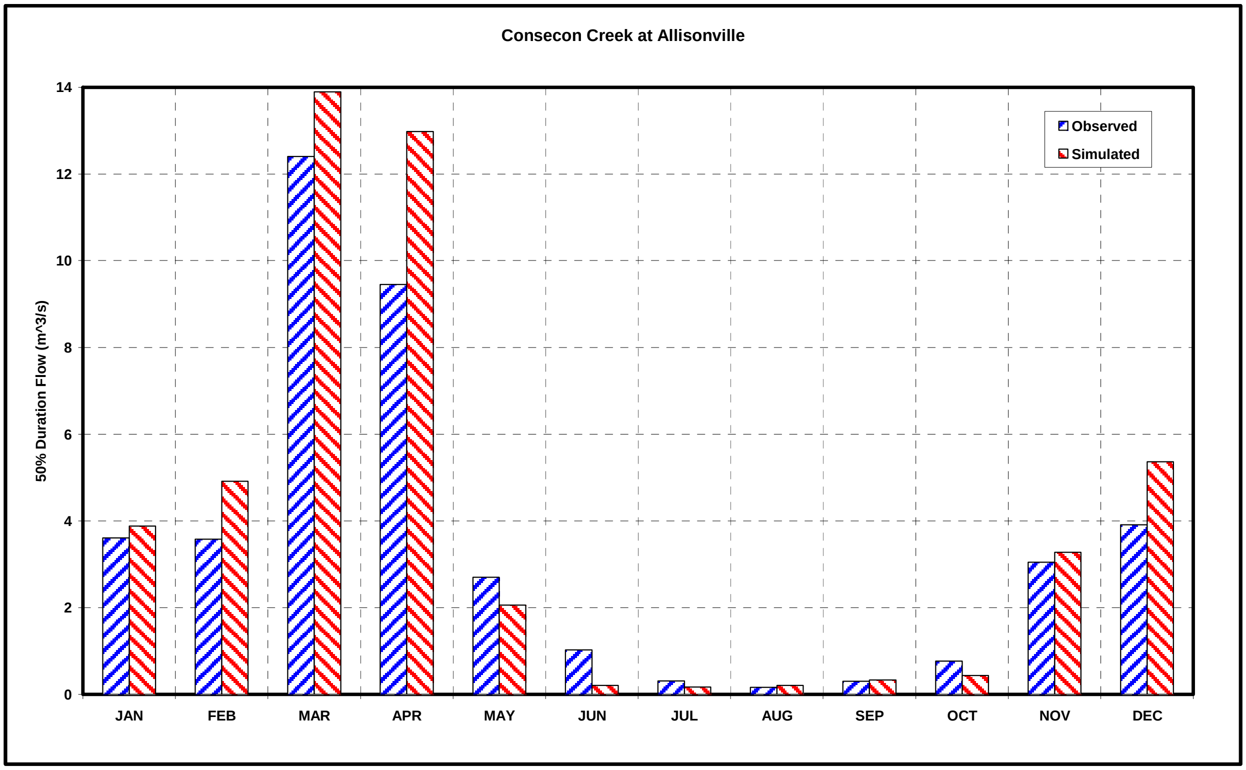


Figure 14C Continued



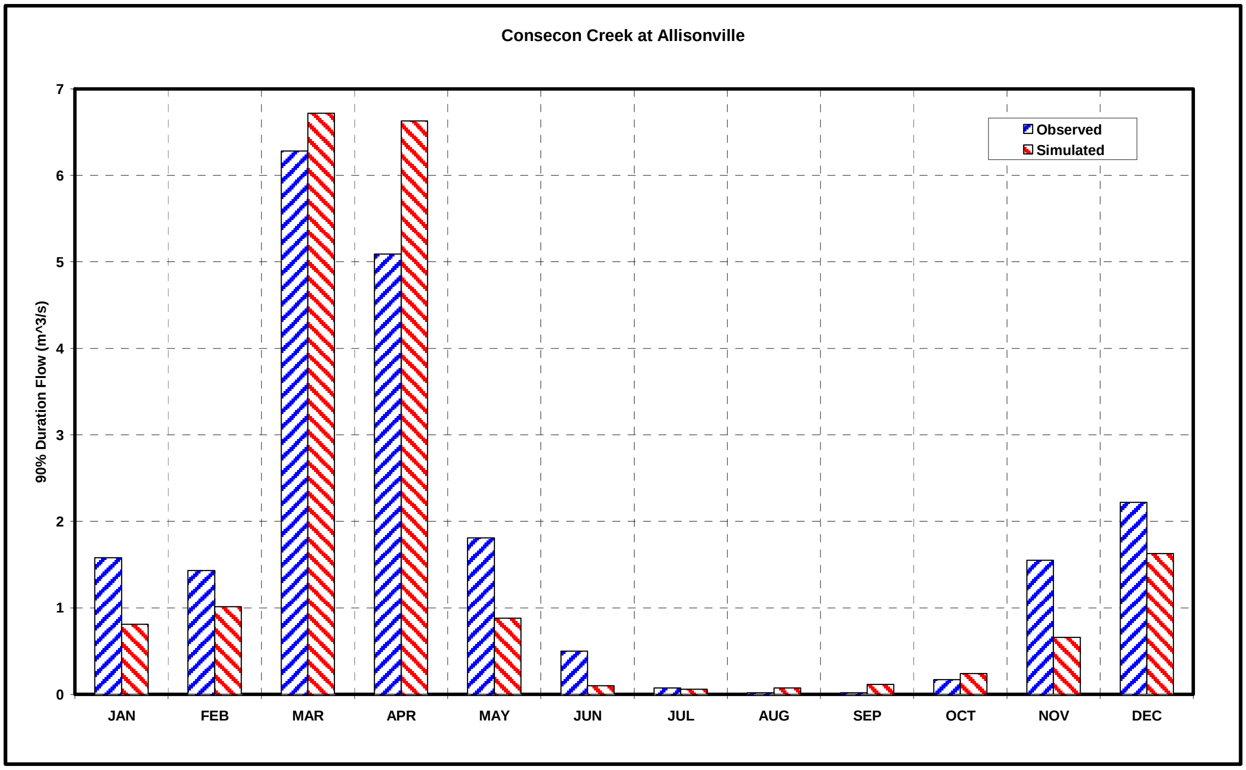


Figure 14D Continued

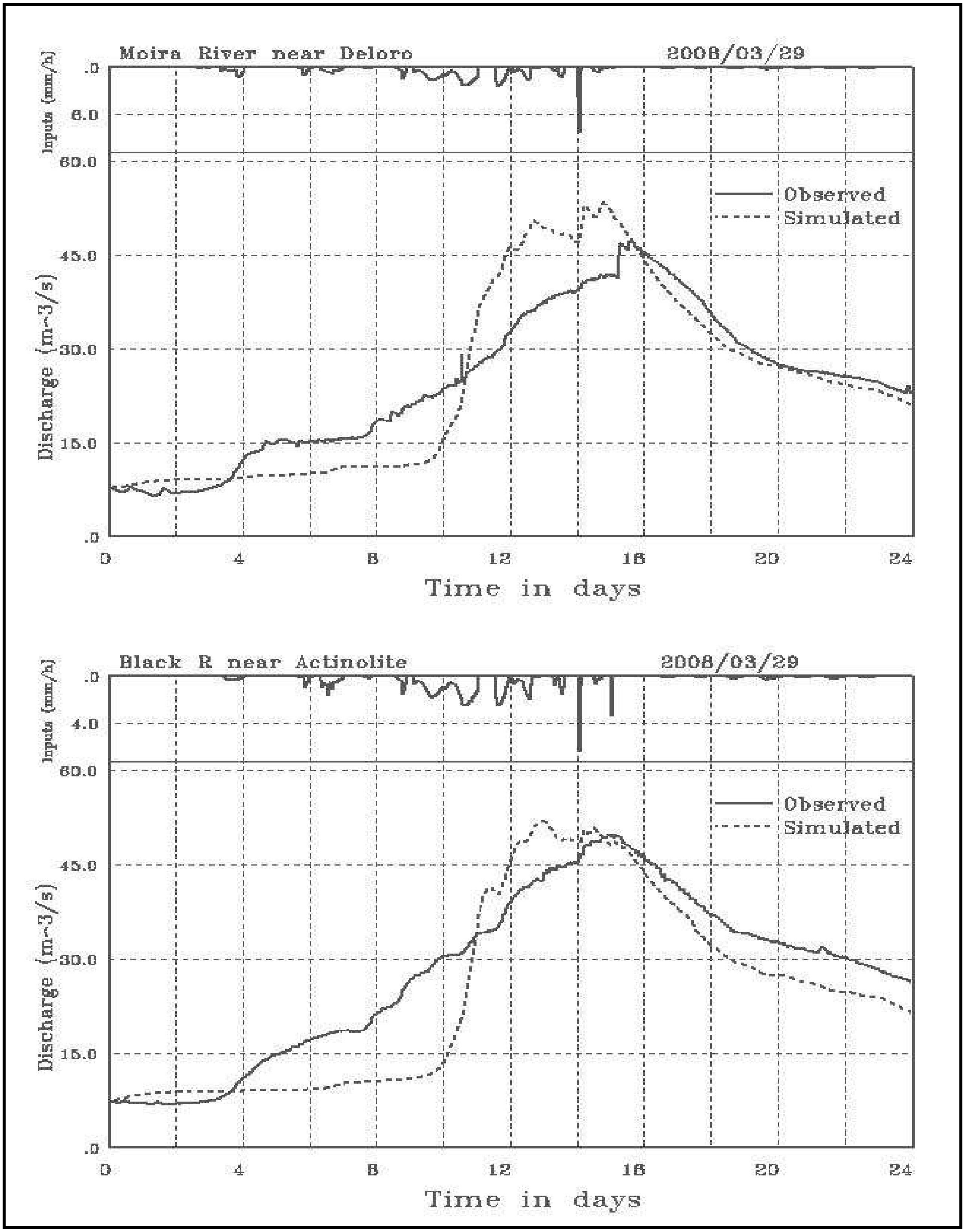


Figure 15A Observed and simulated hydrographs for March 29 to April 21, 2008 event period

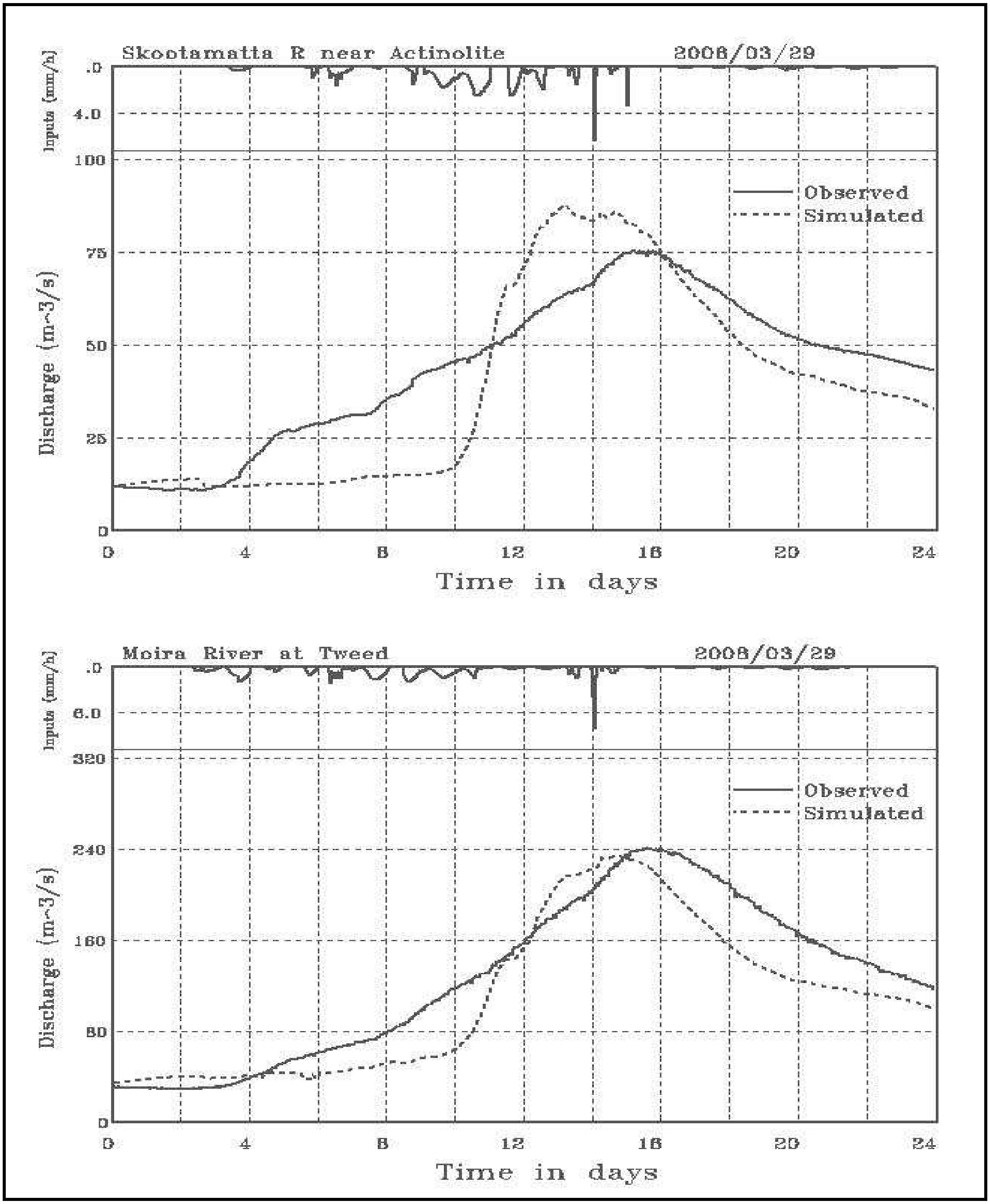


Figure 15B Continued

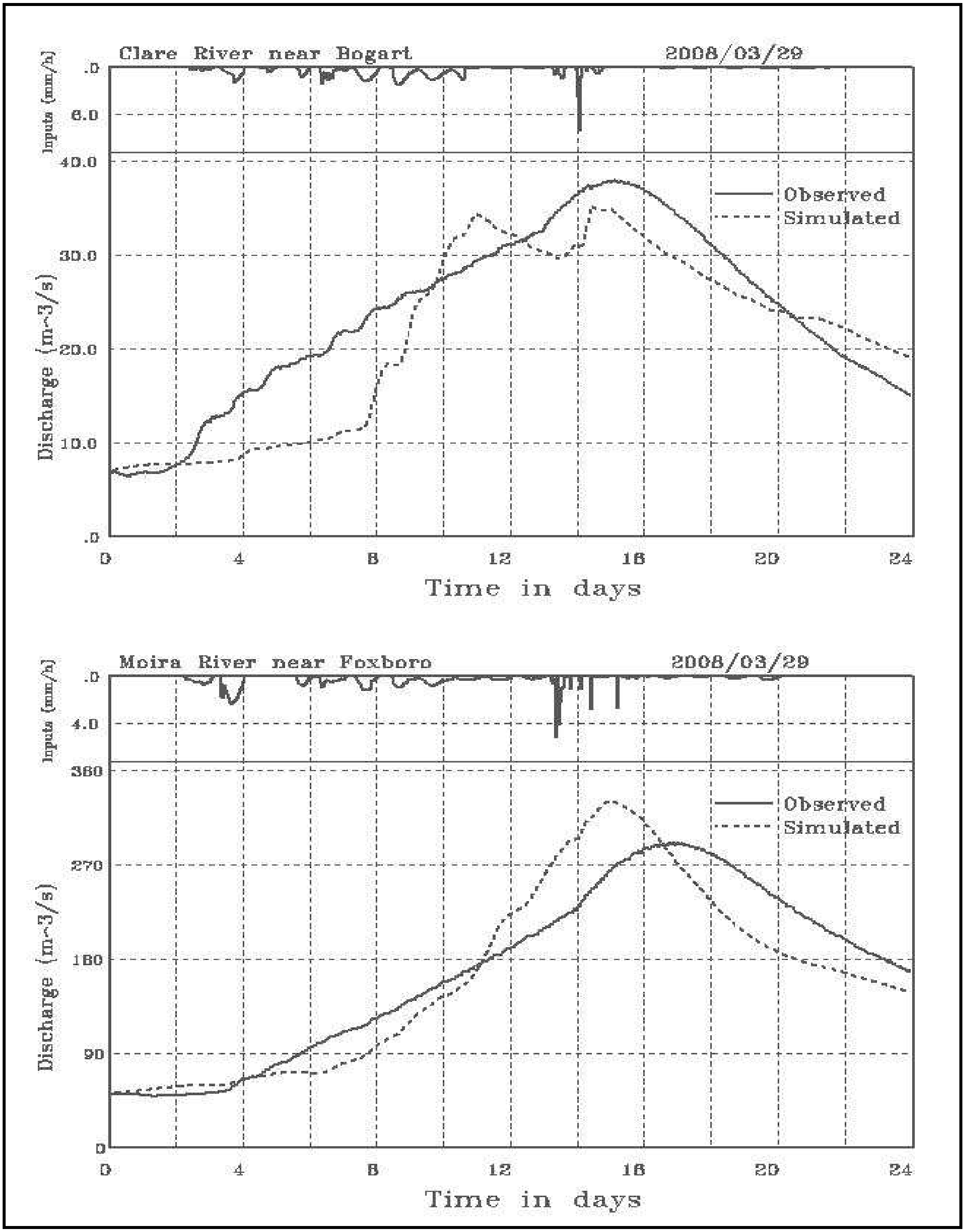


Figure 15C Continued

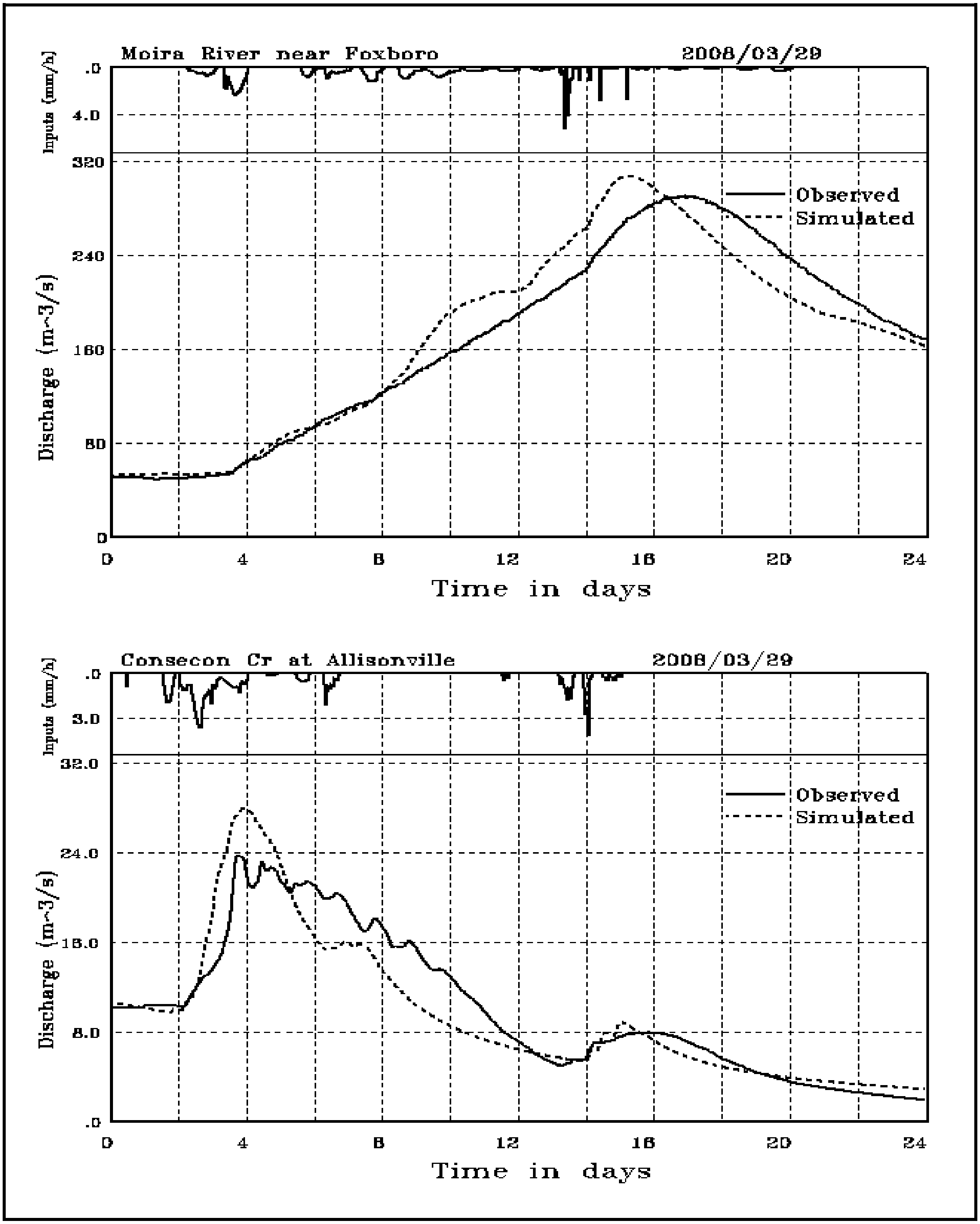


Figure 15D Continued

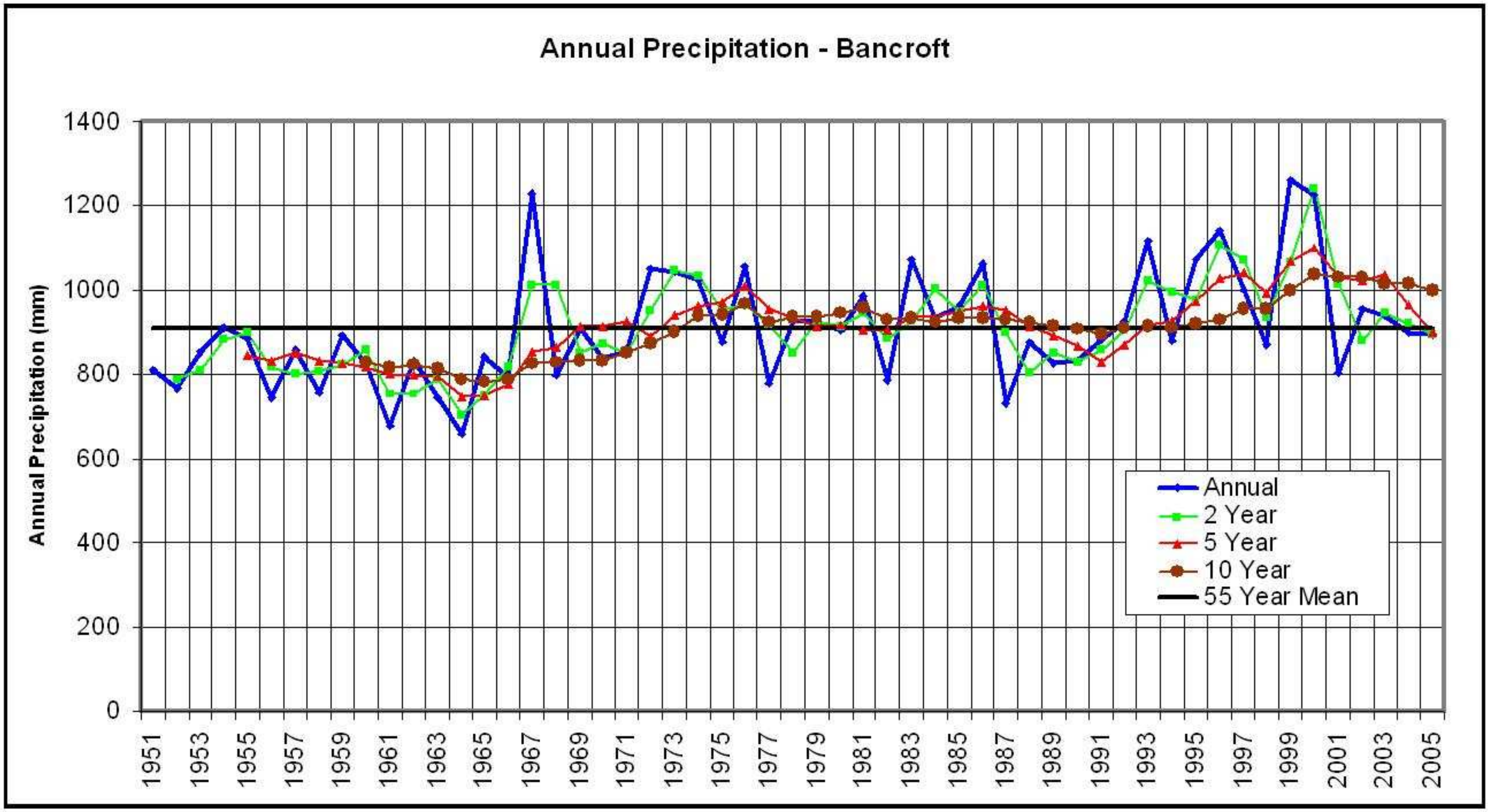


Figure 16 Time series of annual precipitation amounts for the Bancroft Auto (616I001) Climate Station

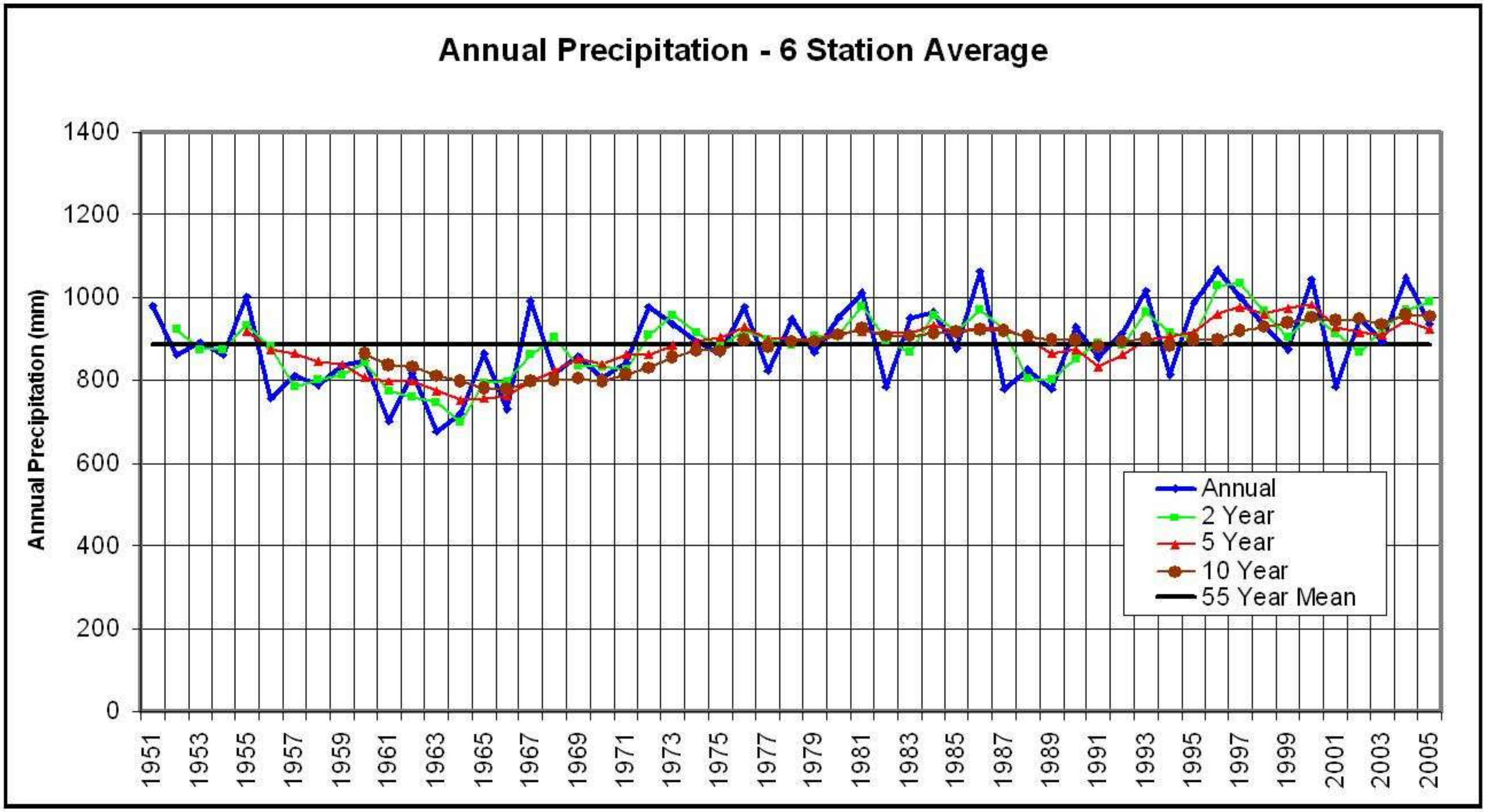


Figure 17 Time series of annual precipitation amounts (6 station average)

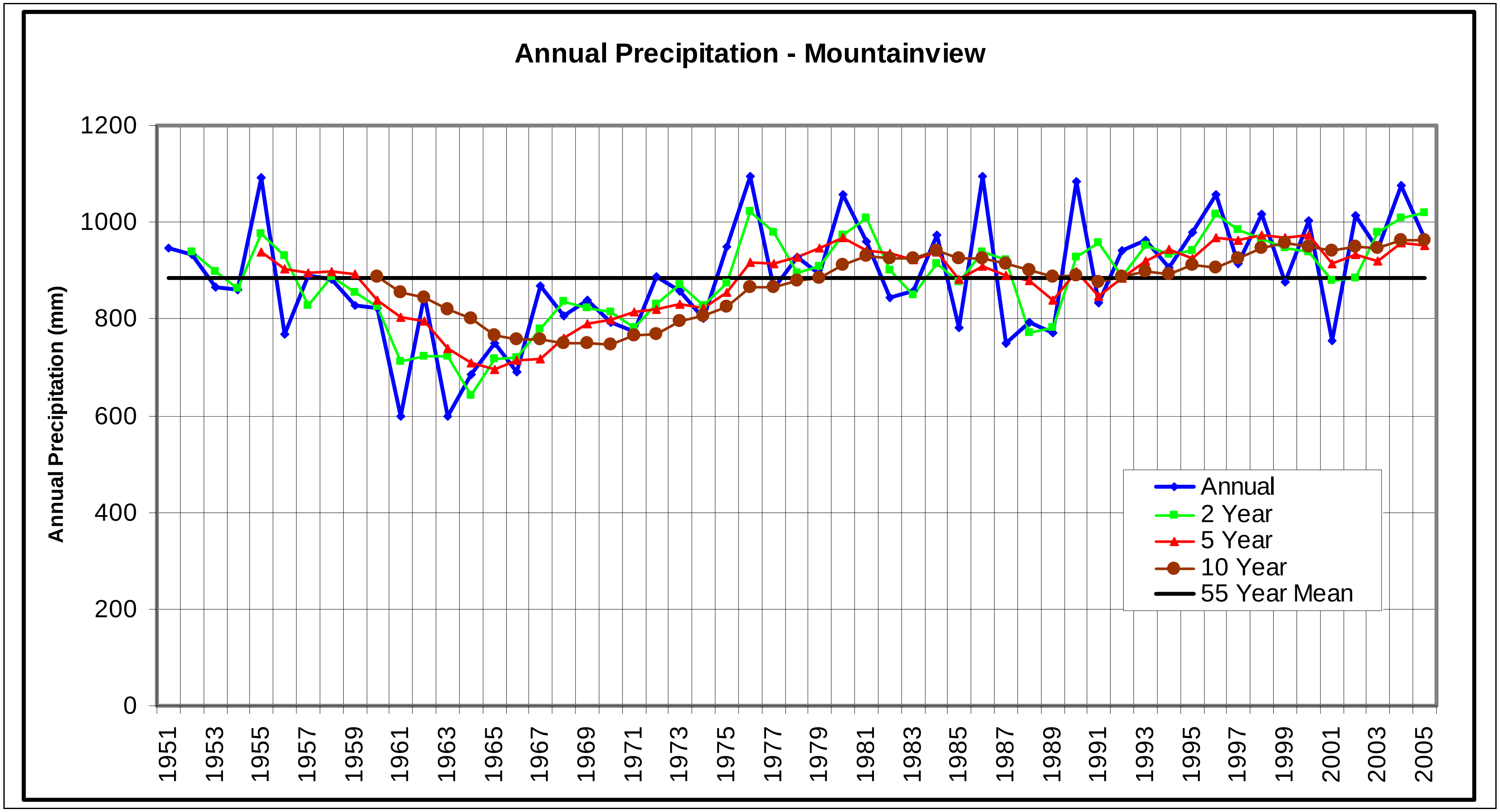


Figure 18 Time series of annual precipitation amounts for the Mountainview (615EMR7) Climate Station

Table 1A Hydrologic response unit drainage characteristics for the Moira River Watershed

Symbol	*Description*	*Units*	*Imp*	*Direct Open Lakes*	*Other Lakes*	*Wet Lands*	*Low Veg. Thin Soil BedRk*	*Low Veg. Clay, and Loams*	*Low Veg. Loamy Sands Sandy*	*High Veg. Slow Infilt. Soils*	*High Veg. Fast Infilt. Soils*
	Response Unit Number		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
DS	Maximum depth of depression Storage	(mm)	2	0	5	150	5	5	8	20	25
KEFF	Infiltration into 1st soil layer	(mm/h)	0	0	0.5	0.1	0.50	2	12	12	36
CS	Infiltration into 2nd soil layer	(mm/h)	0	0.1	0.1	0.1	0.10	1.5	9	9	27
D	Infiltration out of 2nd layer	(mm/h)	0	0.1	0.0r	0.1	0.05	0.2	1.2	1.0	3.6
SAV	Average suction at the wetting front	(mm)	0	200	200	200	200	200	200	200	200
	First Soil Layer										
HI	Soil layer thickness	(mm)	0	1	50	1	50	100	150	50	200
SMCI	Saturated soil-water content (porosity)	(vol/vol)	0	0.56	0.56	0.56	0.56	0.52	0.46	0.54	0.40
IMCI	Initial soil-water content	(vol/vol)	0	0.46	0.46	0.46	0.46	0.38	0.23	0.40	0.10
FCAPI	Field capacity soil-water content	(vol/vol)	0	0.46	0.46	0.46	0.46	0.38	0.23	0.40	0.10
WILTI	Wilting point soil-water content	(vol/vol)	0	0.27	0.27	0.27	0.27	0.17	0.07	0.19	0.04
	Second Soil Layer										
HII	Soil layer thickness	(mm)	0	1	150	1	150	450	450	350	450
SMCII	Saturated soil-water content (porosity)	(vol/vol)	0	0.56	0.56	0.56	0.56	0.52	0.46	0.54	0.40
IMCII	Initial soil-water content	(vol/vol)	0	0.46	0.46	0.46	0.46	0.38	0.23	0.40	0.10
FACPII	Field capacity soil-water content	(vol/vol)	0	0.46	0.46	0.46	0.46	0.38	0.23	0.40	0.10
WILTII	Wilting point soil-water content	(vol/vol)	0	0.27	0.27	0.27	0.27	0.17	0.07	0.19	0.04
X	Groundwater Contribution Indicator: 1=SS, 0=GW		0	1	1	1	1	1	0	0	0
FATR	Groundwater Fraction (not used in this model, set=1)		1	1	1	1	1	1	1	1	1
INC	Maximum depth of interception storage	(mm)	0	0	1.0	5.0	1	1	1	5	5

Background Source: *Hydrology of Floods in Canada* (Watt et al., 1989)

Table 1A Hydrologic response unit drainage characteristics for the Prince Edward County watersheds

Symbol	*Description*	*Units*	*Imp*	*Direct Open Lakes*	*Other Lakes*	*Wet Lands*	*Low Veg. Thin Soil BedRk*	*Low Veg. Clay, and Loams*	*Low Veg. Loamy Sands Sandy*	*High Veg. Slow Infilt. Soils*	*High Veg. Fast Infilt. Soils*
	Response Unit Number		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
DS	Maximum depth of depression Storage	(mm)	2	0	5	150	5	5	8	20	25
KEFF	Infiltration into 1st soil layer	(mm/h)	0	0	0.5	0.1	0.50	2	12	12	36
CS	Infiltration into 2nd soil layer	(mm/h)	0	0.1	0.1	0.1	0.10	1.5	9	9	27
D	Infiltration out of 2nd layer	(mm/h)	0	0.1	0.0r	0.1	0.05	0.2	1.2	1.0	3.6
SAV	Average suction at the wetting front	(mm)	0	200	200	200	200	200	250	200	250
	First Soil Layer										
HI	Soil layer thickness	(mm)	0	1	50	1	50	100	150	50	200
SMCI	Saturated soil-water content (porosity)	(vol/vol)	0	0.56	0.56	0.56	0.56	0.52	0.46	0.54	0.40
IMCI	Initial soil-water content	(vol/vol)	0	0.46	0.46	0.46	0.46	0.38	0.23	0.40	0.10
FCAPI	Field capacity soil-water content	(vol/vol)	0	0.46	0.46	0.46	0.46	0.38	0.23	0.40	0.10
WILTI	Wilting point soil-water content	(vol/vol)	0	0.27	0.27	0.27	0.27	0.17	0.07	0.19	0.04
	Second Soil Layer										
HII	Soil layer thickness	(mm)	0	1	150	1	150	300	300	200	300
SMCII	Saturated soil-water content (porosity)	(vol/vol)	0	0.56	0.56	0.56	0.56	0.52	0.46	0.54	0.40
IMCII	Initial soil-water content	(vol/vol)	0	0.46	0.46	0.46	0.46	0.38	0.23	0.40	0.10
FACPII	Field capacity soil-water content	(vol/vol)	0	0.46	0.46	0.46	0.46	0.38	0.23	0.40	0.10
WILTII	Wilting point soil-water content	(vol/vol)	0	0.27	0.27	0.27	0.27	0.17	0.07	0.19	0.04
X	Groundwater Contribution Indicator: 1=SS, 0=GW		0	1	1	1	1	1	0	1	0
FATR	Groundwater Fraction (not used in this model, set=1)		1	1	1	1	1	1	1	1	1
INC	Maximum depth of interception storage	(mm)	0	0	1.0	5.0	1	1	1	5	5

Background Source: *Hydrology of Floods in Canada* (Watt et al., 1989)

Table 2 Subcatchment characteristics for the Moira River watershed model

Moira River Watershed Model: Subwatershed Characteristics: UNITS=1 February 24, 2000; November 26, 2007; June 16, 2009

<=== Low Veg ====>|<=Hi Veg==>|<=Main Channel><=Off Channel><=Overland-><=Recession>

Number	Area (km^2)	Length (m)	Width (m)	Imp	RU 2	RU 3	RU 4	RU 5	RU 6	RU 7	RU 8	RU 9	MCVS	MCQR	OCVS	OCQR	FTB	FTLO	KSS	KGW
101	81.99	37036	2214	0.2	0.6	2.6	2.1	0.1	0.0	0.3	92.3	1.6	2.18	11.5	1.2	0.05	4	0	5	384
102	80.33	35221	2281	1.2	0.8	1.5	5.5	1.0	0.0	0.0	89.5	0.2	2.18	11.5	1.2	0.05	4	0	5	384
103	130.61	19151	2076	4.2	0.2	0.9	8.9	4.2	11.6	3.2	63.8	2.8	2.19	19.6	1.2	0.05	4	0	5	384
104	3.85	3424	371	0.5	0.0	0.8	2.3	2.6	48.1	0.0	45.8	0.0	2.12	2.8	1.2	0.05	4	0	5	384
105	43.25	15835	2731	1.1	0.0	1.0	16.8	3.0	10.1	0.6	64.8	1.4	2.14	6.7	1.2	0.05	4	0	5	384
106	99.60	16240	2023	4.5	1.5	1.1	12.3	2.5	14.2	1.7	60.5	1.2	2.18	11.5	1.2	0.05	4	0	5	384
107	45.20	10877	4156	4.2	0.0	0.8	3.4	4.6	21.9	5.7	55.3	4.1	2.14	6.7	1.2	0.05	4	0	5	384
108	29.56	16851	1750	0.5	0.0	1.5	0.6	4.3	38.2	8.8	38.4	5.4	2.14	6.7	1.2	0.05	4	0	5	384
157	2.53	4096	618	7.4	0.0	1.0	16.3	5.8	3.4	40.3	21.8	3.1	2.12	2.8	1.2	0.05	4	0	5	384
158	13.24	4709	2811	2.1	14.5	0.0	11.0	0.3	22.7	11.8	31.0	4.4	2.12	2.8	1.2	0.05	4	0	5	384
109	49.16	13727	5276	0.8	12.3	0.1	7.3	7.1	16.1	7.5	44.0	4.8	2.14	6.7	1.2	0.05	4	0	5	384
110	61.89	22445	2757	1.6	0.4	1.8	3.4	0.1	0.0	0.0	90.6	2.1	2.18	11.5	1.2	0.05	5	0	5	384
111	78.80	18167	4338	0.7	10.7	1.0	7.3	0.0	0.0	0.0	77.7	2.6	2.18	11.5	1.2	0.05	5	0	5	384
112	143.80	27540	4769	2.2	0.8	2.0	5.1	1.2	1.7	0.0	86.7	0.3	2.19	19.6	1.2	0.05	4	0	5	384
113	145.16	24164	2212	2.7	0.0	2.6	5.8	5.5	6.1	1.6	74.3	1.4	2.19	19.6	1.2	0.05	4	0	5	384
114	48.21	14322	3366	0.2	8.2	3.3	4.0	0.0	0.0	0.0	28.1	55.5	2.14	6.7	1.2	0.05	4	0	5	384
115	76.74	18930	4054	0.1	18.7	4.0	2.5	0.0	0.0	0.0	62.9	11.9	2.14	6.7	1.2	0.05	4	0	5	384
116	10.17	5630	927	0.9	0.0	10.4	5.3	0.0	0.0	0.0	73.1	10.2	2.12	2.8	1.2	0.05	5	0	5	384
117	129.52	28988	4468	0.5	4.0	2.1	4.9	0.0	0.0	0.0	82.9	5.4	2.18	11.5	1.2	0.05	5	0	5	384
118	54.70	16775	1091	2.3	0.0	3.9	4.5	0.0	0.0	0.0	88.5	0.8	2.18	11.5	1.2	0.05	4	0	5	384
119	16.61	6237	2851	1.3	24.0	2.8	1.7	0.0	0.0	0.0	69.7	0.4	2.12	2.8	1.2	0.05	4	0	5	384
120	28.87	17055	1198	3.4	0.3	3.5	3.6	2.2	0.0	1.5	79.6	6.0	2.12	2.8	1.2	0.05	2	0	5	384
121	164.74	23864	8372	8.2	0.0	3.4	2.7	1.8	0.0	3.6	67.0	13.2	2.18	11.5	1.2	0.05	2	0	5	384
122	147.53	36132	4083	2.5	0.1	2.4	9.1	2.0	2.3	1.3	77.8	2.5	2.19	19.6	1.2	0.05	2	0	5	384
123	77.36	21115	5959	1.1	0.5	0.8	9.3	3.6	13.9	12.6	49.8	8.4	2.18	11.5	1.2	0.05	2	0	5	384
125	75.05	20196	3716	12.7	7.1	3.2	5.3	5.4	3.4	13.2	41.2	8.4	2.18	11.5	1.2	0.05	2	0	5	384
130	314.69	32650	9638	6.4	1.5	2.6	7.6	1.0	6.6	1.5	48.4	24.3	2.19	19.6	1.2	0.05	4	0	5	384
132	22.04	8200	2688	2.2	0.0	0.7	11.5	2.5	22.4	38.2	11.8	10.7	2.12	2.8	1.2	0.05	4	0	5	384
134	17.47	7677	2276	3.4	0.0	3.7	10.4	2.3	19.3	25.8	26.8	8.3	2.12	2.8	1.2	0.05	4	0	5	384
135	40.66	10417	1201	2.5	0.0	2.2	3.9	3.0	13.9	21.8	42.2	10.4	2.12	2.8	1.2	0.05	2	0	5	384
140	198.66	31700	6267	1.1	0.8	0.1	9.6	0.9	19.4	1.4	65.1	1.5	2.19	19.6	1.2	0.05	5	0	5	384
142	24.35	10869	3496	3.2	0.0	3.5	8.1	0.9	20.1	19.0	34.0	11.2	2.14	6.7	1.2	0.05	2	0	5	384
145	138.16	22963	6017	2.2	0.0	0.5	10.4	1.9	17.3	26.5	14.0	27.3	2.19	19.6	1.2	0.05	3	0	5	384
146	58.41	15302	3817	2.2	0.0	0.2	6.1	1.0	19.2	35.4	8.0	27.8	2.18	11.5	1.2	0.05	3	0	5	384
148	37.22	30431	1223	2.2	0.0	0.0	7.8	3.4	62.0	2.5	21.9	0.2	2.14	6.7	1.2	0.05	3	0	5	384
150	52.90	14624	2421	11.0	1.4	1.1	1.8	2.6	23.9	35.5	14.5	6.8	2.18	11.5	1.2	0.05	2	0	5	384

Note: Response units defined in Table 1 and on page 5

Table 3 Subcatchment characteristics for the Prince Edward County watershed model

Prince Edward County Model: Subwatershed Characteristics: UNITS=1 February 24, 2000; November 26, 2007; December 10, 2009

<=== Low Veg ====>|<=Hi Veg==>|<=Main Channel><=Off Channel><=Overland-><=Recession>

	Area	Length	Width																	
Number	(km^2)	(m)	(m)	Imp	RU 2	RU 3	RU 4	RU 5	RU 6	RU 7	RU 8	RU 9	MCVS	MCQR	OCVS	OCQR	FTB	FTLO	KSS	KGW
501	8.72	5168	1687	1.7	0.0	0.0	5.6	2.7	69.6	0.0	20.4	0.0	2.54	1.39	1.2	0.05	2	0	5	384
502	8.24	5041	1635	1.0	0.0	0.2	1.6	0.0	82.3	0.0	14.9	0.0	2.54	1.39	1.2	0.05	2	0	5	384
503	9.62	4042	2380	2.0	0.0	0.1	2.7	1.3	31.7	18.5	28.5	15.2	2.56	2.38	1.2	0.05	2	0	5	384
504	29.74	8899	3342	1.4	0.0	0.0	18.9	2.0	44.7	0.6	31.3	1.0	2.59	5.05	1.2	0.05	2	0	5	384
505	3.62	2360	1533	2.4	24.5	0.03	2.3	0.9	58.1	0.0	12.4	0.4	2.52	0.57	1.2	0.05	2	0	5	384
506	20.00	9881	1012	1.2	0.11	0.07	13.2	2.2	64.5	0.07	17.9	0.7	2.58	3.18	1.2	0.05	2	0	5	384
507	8.49	4712	1802	2.4	0.0	0.1	3.9	1.4	50.9	0.0	41.4	0.0	2.54	1.39	1.2	0.05	2	0	5	384
508	32.51	11408	2850	1.7	5.0	0.0	15.9	0.7	45.3	0.0	31.1	0.2	2.59	5.05	1.2	0.05	2	0	5	384
510	1.35	1527	314	10.0	0.0	0.1	0.0	3.9	57.9	0.0	28.3	0.0	2.52	0.57	1.2	0.05	2	0	5	384
515	16.83	7109	2368	1.7	0.0	0.0	3.1	0.0	54.1	0.5	40.0	0.6	2.58	3.18	1.2	0.05	2	0	5	384
518	34.11	8968	1114	1.1	0.0	0.0	26.7	1.5	55.8	0.0	14.8	0.0	2.59	5.05	1.2	0.05	5*	0	5	384
520	29.96	10067	2214	1.0	0.0	0.1	28.8	1.7	48.2	0.0	20.2	0.0	2.59	5.05	1.2	0.05	5*	0	5	384
522	35.99	10520	1326	1.5	0.0	0.1	18.1	1.3	57.8	0.0	21.2	0.0	2.59	5.05	1.2	0.05	5*	0	5	384
523	3.51	2244	567	1.9	0.0	0.1	14.8	0.4	58.9	0.0	23.9	0.0	2.52	0.57	1.2	0.05	5*	0	5	384
525	63.70	16218	1667	1.9	11.4	0.2	4.9	2.6	57.7	0.8	20.3	0.3	2.59	5.05	1.2	0.05	5*	0	5	384
531	14.11	6532	2160	1.7	0.0	4.8	6.0	3.3	55.0	0.5	28.6	0.2	2.56	2.38	1.2	0.05	2	0	5	384
532	16.30	7805	2088	1.4	0.0	0.1	16.4	5.7	57.4	0.0	18.9	0.0	2.58	3.18	1.2	0.05	2	0	5	384
533	6.29	5594	1124	2.4	0.0	0.1	15.3	3.9	72.2	0.0	6.2	0.0	2.54	1.39	1.2	0.05	2	0	5	384
534	24.06	3843	6261	2.1	0.0	0.1	8.3	4.4	62.1	1.6	21.4	0.1	2.58	3.18	1.2	0.05	2	0	5	384
535	14.18	10985	1291	2.1	0.0	0.1	4.2	0.0	77.6	1.6	14.1	0.3	2.56	2.38	1.2	0.05	2	0	5	384
536	21.14	8107	2608	2.2	0.0	0.1	0.2	1.6	81.9	2.9	11.0	0.1	2.58	3.18	1.2	0.05	2	0	5	384
540	9.96	8097	1230	2.0	0.0	0.3	2.1	0.5	85.3	0.0	9.9	0.0	2.56	2.38	1.2	0.05	2	0	5	384
542	14.12	5559	2540	2.3	0.2	0.1	3.5	2.9	52.2	24.9	9.1	5.0	2.56	2.38	1.2	0.05	2	0	5	384
544	3.50	6774	690	7.1	0.0	0.2	8.2	4.0	24.9	50.0	1.6	3.9	2.52	0.57	1.2	0.05	2	0	5	384
545	16.04	3017	5317	3.1	0.0	0.3	4.6	5.9	11.1	56.2	8.2	10.7	2.58	3.18	1.2	0.05	2	0	5	384
547	5.07	8004	633	1.5	0.0	0.0	10.2	0.6	51.3	6.4	19.0	10.8	2.54	1.39	1.2	0.05	2	0	5	384
550	21.78	3509	6207	0.9	0.0	0.0	4.4	1.5	48.3	26.7	11.4	6.6	2.58	3.18	1.2	0.05	2	0	5	384
552	13.33	9519	1400	0.2	0.0	0.7	7.6	2.2	41.7	21.3	20.3	6.0	2.56	2.38	1.2	0.05	2	0	5	384
554	15.20	6243	2435	1.0	0.0	0.0	10.0	0.0	32.8	0.6	55.3	0.3	2.56	2.38	1.2	0.05	2	0	5	384
560	28.96	6957	4163	2.3	0.4	0.0	3.4	2.6	41.7	2.4	47.1	0.1	2.59	5.05	1.2	0.05	2	0	5	384
562	10.96	13177	832	1.3	0.0	0.0	3.9	2.1	49.4	3.6	39.6	0.2	2.56	2.38	1.2	0.05	2	0	5	384
565	19.61	7672	2556	0.7	0.0	0.0	9.6	2.9	44.9	1.1	40.4	0.3	2.58	3.18	1.2	0.05	2	0	5	384
570	2.04	1931	1056	2.7	0.0	0.2	0.0	0.4	11.3	0.0	85.0	0.0	2.52	0.57	1.2	0.05	2	0	5	384
572	2.88	2979	997	14.6	0.0	0.3	0.0	13.6	10.5	14.9	38.5	7.3	2.52	0.57	1.2	0.05	2	0	5	384
574	2.06	2352	876	9.1	0.0	0.0	0.0	0.0	14.2	72.2	0.2	4.2	2.52	0.57	1.2	0.05	2	0	5	384
576	6.08	5324	1142	4.5	0.0	0.0	3.2	2.2	40.0	30.7	9.2	10.2	2.54	1.39	1.2	0.05	2	0	5	384
578	7.21	4396	1640	3.2	0.0	0.0	24.7	0.1	55.2	0.0	16.7	0.0	2.54	1.39	1.2	0.05	2	0	5	384

Note: Response units defined in Table 1 and on page 5

Table 4 Channel characteristics for the Moira River and Prince Edward County watershed models

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Channel Data for Moira/PEC Watersheds       UNITS=2   Feb. 24, 2000; May 25, 2009
C---+---1----+---2----+---3----+---4----+---5----+---6----+---7----+---8----+---9----+--10
  NO| LENGTH| SLOPE  |   RCVS | NS|%CAN|   Remarks
1102   5598   0.00130    11.02  2   0      Moira River above Bannockburn
1103  20972   0.00116    11.03  2   0      Moira River: Bannockburn to Deloro
1104   3457   0.00111    11.04  2   0      Moira River: Deloro to Hwy #7
1106  16412   0.00089    11.06  2   0      Hwy #7 to Moira Lake (old 5)
1107   2982   0.00221    11.08  2   0      Deer Creek
1108   2888   0.00221    11.08  2   0      Deer Creek
1109   3105   0.00076    58085  2   0      Moira Lake to Black R (old 10)
1112  10050   0.00237    11.12  2   0      Lingham Lake to Sub 112 outlet  (old 12)
1113  21870   0.00237    11.13  2   0      Sub 112 outlet to Black River outlet (old 12)
1114   4919   0.00076    54180  2   0      Moira River: Black to Skootamatta (old 20)
1116   3655   0.00130    11.16  2   0      Skootamatta Lake to Sub 116 (old 15)
1120   8030   0.00130    11.20  2   0      Sub 116 to Partridge C (old 15)
1118  16714   0.00108    11.18  2   0      Partridge Creek to Deerock Lake
1119   1942   0.00108    11.19  2   0      Deerock Lake to Skootamatta River (old 16)
1121   6559   0.00135    11.21  2   0      Skootamatta: Partridge Ck to Sub 121 (old 18)
1122  23788   0.00135    11.22  2   0      Skootamatta: Sub 121 to Sub 122 (old 18)
1123   4327   0.00138    11.23  2   0      Skootamatta: Hwy #7 to Moira Confluence
1124   4284   0.00150    11.24  2   0      Moira: Skootamatta to Drag Lake Cr (old 25)
1125   2907   0.00133    50145  2   0      Moira: Drag Lake Cr to Tweed (old 25)
1126   5604   0.00114    11.26  2   0      Clair Creek
1135  11282   0.00128    36175  2   0      Moira: Stoco Lake to Chisholm Mills  (old 35)
1137   9705   0.00146    28865  2   0      Moira: Chisholm Mills to Plainfield (old 37)
1140   2090   0.00124    11.40  2   0      Parks Creek
1142   2322   0.00171    11.42  2   0      Moira: Parks Cr to Crystal Cr (old 45)
1145   1678   0.00042    14415  2   0      Moira: Crystal Cr to Foxboro (old 45)
1146    801   0.00126    11.46  2   0      Palliser Creek
1148   6523   0.00131    11.48  2   0      Corbyville Creek
1150   7284   0.00177     2600  2   0      Moira: Foxboro to Canifton
1152   7284   0.00178     2600  2   0      Moira: Canifton to Bay of Quinte
1504   3740   0.00078    15.04  1   0      Roblin's Lake Creek
1506   6546   0.00062    15.06  1   0      Sawquin Creek
1518  10216   0.00078    15.18  1   0      Consecon Creek
1520   4510   0.00077    15.20  1   0      Consecon Creek
1522   9048   0.00076    15.22  1   0      Consecon Creek
1523   2065   0.00060    15.23  1   0      Consecon Creek
1525  12741   0.00063    15.25  1   0      Consecon Creek
1540    597   0.00078    15.40  1   0      Bloomfield Creek, West Branch
1542    937   0.00085    15.42  1   0      Bloomfield Creek, East Branch
1544    754   0.00065    15.44  1   0      Bloomfield Creek, Main Stem
1572    963   0.00093    15.72  1   0      McCauley Creek
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Table 5 Quinte Conservation Watersheds – Modelled Lake (Reservoir) Summary

Lake/Reservoir Name	HYD NO	Drainage Area (km^2)	Surface Area (ha)	Range of Operating Head (m)	Maximum Operating Storage (ha-m)	Maximum Discharge Capacity (m3/s)	Characteristics Of Outlet Structure (No. Sluices, spillway width, stoplogs, or turbines)
Deloro Head Pond	5103	293	4.94	4.80	11.3	129	2 x 2.44 m – 8 stoplogs
Moira Lake Downey's Weir	5109	580	870	0.5	870	317	5 x 12.2 m – 2 stoplogs
Lingham Lake Black River	5111	141	944	5.43	3110	1152	1 x 18.8 m – 11 stoplogs Valve
Skootamatta Lake	5115	125	1348	3.3	11197.4	110	2 x 3.66 m – 11 stoplogs
Deerock Lake Skootamatta River	5119	201	377	5.1	2765.3	169	Crest length = 30 m and valve
Stoco Lake Moira River Cations Dam Chapman's Weir	5134	2195	562	0.56	370.9	1257	Mostly a large uncontrolled Spillway 5 Spillways, 2 stop logs 1 Spillway, 1 stop log
Roblin Lake	5505	3.62	88.6	0.75	69.0	2.9	1 Spillway, 5 stop logs
Consecon Lake	5525	184	700	0.12			2 uncontrolled Spillways
Bloomfield Mill Pond	5542	14.1	2.68	0.3	2.908	1.9	1 spillway, and one valve.

Table 6A

Monthly distribution of lake evaporation at selected locations in southern Ontario

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Windsor	18	18	18	84	117	133	145	122	81	52	35	20	843
Harrow	18	18	18	101	129	148	154	128	93	66	35	20	928
Ridgetown	18	18	18	85	118	131	150	122	89	58	35	20	862
Langton	18	18	18	90	124	138	155	138	88	36	35	20	878
Delhi	18	18	18	85	116	133	142	118	80	49	35	20	832
Simcoe	18	18	18	90	120	139	152	127	89	53	35	20	879
Hamilton	18	18	18	98	111	125	144	123	81	46	35	20	837
Guelph	15	15	15	80	122	138	147	118	78	48	30	18	824
Elora	12	12	12	78	117	133	143	117	75	43	30	18	790
Blue Springs	12	12	12	70	100	115	140	112	72	42	30	18	735
Hornby	12	12	12	70	111	125	151	129	80	49	30	18	799
Burketon	12	12	12	75	94	120	128	109	67	43	30	15	717
Bowmanville	12	12	12	75	115	124	142	119	77	48	30	15	781
Lindsay	10	10	10	70	118	131	150	146	80	45	30	15	815
Morven	10	10	10	50	115	114	145	135	80	49	25	15	758
Hartington	10	10	10	50	102	116	138	120	73	43	25	12	709
Kemptville	10	10	10	35	123	125	130	113	71	49	20	12	708
Ottawa	10	10	10	35	113	131	141	112	73	41	20	12	708

Notes: 1. values taken from pan evaporation measurements summarized in AES documents. 2. Amounts given in mm

Note: Assembled by Whiteley (2008)

Table 6B

Daily Potential Evaporation & Evapotranspiration Rates													
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Windsor	0.58	0.64	0.58	2.80	3.77	4.43	4.68	3.94	2.70	1.68	1.17	0.65	2.31
Harrow	0.58	0.64	0.58	3.37	4.16	4.93	4.97	4.13	3.10	2.13	1.17	0.65	2.54
Ridgetown	0.58	0.64	0.58	2.83	3.81	4.37	4.84	3.94	2.97	1.87	1.17	0.65	2.36
Langton	0.58	0.64	0.58	3.00	4.00	4.60	5.00	4.45	2.93	1.16	1.17	0.65	2.40
Delhi	0.58	0.64	0.58	2.83	3.74	4.43	4.58	3.81	2.67	1.58	1.17	0.65	2.28
Simcoe	0.58	0.64	0.58	3.00	3.87	4.63	4.90	4.10	2.97	1.71	1.17	0.65	2.41
Hamilton	0.58	0.64	0.58	3.27	3.58	4.17	4.65	3.97	2.70	1.48	1.17	0.65	2.29
Guelph	0.48	0.53	0.48	2.67	3.94	4.60	4.74	3.81	2.60	1.55	1.00	0.58	2.26
Elora	0.39	0.42	0.39	2.60	3.77	4.43	4.61	3.77	2.50	1.39	1.00	0.58	2.16
Blue Springs	0.39	0.42	0.39	2.33	3.23	3.83	4.52	3.61	2.40	1.35	1.00	0.58	2.01
Hornby	0.39	0.42	0.39	2.33	3.58	4.17	4.87	4.16	2.67	1.58	1.00	0.58	2.19
Burketon	0.39	0.42	0.39	2.50	3.03	4.00	4.13	3.52	2.23	1.39	1.00	0.48	1.96
Bowmanville	0.39	0.42	0.39	2.50	3.71	4.13	4.58	3.84	2.57	1.55	1.00	0.48	2.14
Lindsay	0.32	0.35	0.32	2.33	3.81	4.37	4.84	4.71	2.67	1.45	1.00	0.48	2.23
Morven	0.32	0.35	0.32	1.67	3.71	3.80	4.68	4.35	2.67	1.58	0.83	0.48	2.08
Hartington	0.32	0.35	0.32	1.67	3.29	3.87	4.45	3.87	2.43	1.39	0.83	0.39	1.94
Kemptville	0.32	0.35	0.32	1.17	3.97	4.17	4.19	3.65	2.37	1.58	0.67	0.39	1.94
Ottawa	0.32	0.35	0.32	1.17	3.65	4.37	4.55	3.61	2.43	1.32	0.67	0.39	1.94
NOTE: Rates given in mm/day													

Note: Assembled by Whiteley (2008)

Table 7 Model parameters for each block of equivalent snow accumulation

PARAMETER	SYMBOL	UNITS	FIELDS PLOUGHED	FIELDS GRASS	FOREST	ROADWAY EASEMENTS	FENCE LINES	FOREST EDGES
Constant melt factor	KMI	(mm/d-C^o)	0.3	2.0	0.2	4	4	0.2
Variable melt factor	KMII	(mm/d-C^o)	32	29	22	24	24	23
Refreeze factor	KF	(mm/d-C^o)	16	16	11	16	12	11
Base Temperature	TBAS	(C^o)	0	0	0	0	0	0
Sublimation rate	SUBLIM	(mm/d)	0.33	0.33	0.33	0.33	0.33	0.33
Threshold density	MRHO	(vol/vol)	0.40	0.37	0.35	0.40	0.40	0.37
Compaction Constant:	A	(hours)	0.10	0.10	0.10	0.10	0.10	0.10
Compaction Constant:	B	(1/C^o)	7.0	7.0	7.0	7.0	7.0	7.0
Holding Capacity	HCAP	(cm)	9.5	17	44	35	55	2000
For Each ZUM		**% Area =====➔**						
1 Upper Moira River			6	4	82	2	2	4
2 Moira Lake Area			9	6	77	2	2	4
3 Black River			4	2	86	2	2	4
4 Skootamatta River			5	4	83	2	2	4
5 Tweed-Stoco Lake			16	10	64	2	2	4
6 Clare River			5	4	83	2	2	4
7 Parks Creek			11	8	73	2	2	4
8 Lower Moira			41	28	19	3	3	6
9 Upper Salmon River			4	2	90	1	1	2
10 Middle Salmon R			4	2	90	1	1	2
11 Lower Salmon River			49	24	15	3	3	6
12 Upper Napanee R			4	2	90	1	1	2
13 Central Napanee R			35	17	40	2	2	4
14 Eastern Napanee R			4	2	90	1	1	2
15 Lower Napanee R			60	30	2	3	3	2
16 Prince Edward County			38	26	20	3	3	10

Table 7 Continued

General Parameters Applied to All Blocks in Each ZUM

PARAMETER	SYMBOL	UNITS	VALUE
New snow density constant	NEWDEN	(vol/vol)	0.160
Constant for new snow relative density as a function of air	BETA		0.060
Eroded snow density	RHOE	(vol/vol)	0.120
Irreducible water saturation	SWI	(vol/vol)	0.07
Initial liquid water content	ILWC	(mm)	0.00

Table 8A Monthly parameter adjustment factors applied for the Moira River Watershed

GAWSER Parameter Adjustment Table Generated From: Moira River

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FDS	0.75	1.00	1.00	1.00	1.10	1.25	1.25	1.25	1.10	1.00	0.75	0.75
FKEFF	0.02	0.02	0.02	0.10	0.40	0.65	0.75	0.90	0.65	0.25	0.10	0.02
FCS	0.03	0.02	0.02	0.09	0.40	0.50	0.60	0.75	0.35	0.30	0.13	0.06
FD	0.07	0.07	0.06	0.05	0.06	0.06	0.10	0.11	0.09	0.08	0.08	0.08
FKO	5.00	6.00	5.50	4.50	4.00	4.50	5.50	6.00	5.00	4.00	3.50	4.00
FKSS	4.00	4.00	4.25	4.50	4.75	5.00	5.50	5.50	5.25	5.00	4.75	4.50
FHI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FKMF	0.25	0.33	0.48	0.52	0.70	1.40	2.00	2.00	1.50	1.00	0.35	0.30
FNEW	1.00	1.00	1.10	1.10	1.00	1.00	1.00	1.00	1.00	1.00	1.10	1.10
FEVAP	0.00	0.00	0.00	1.67	3.29	3.87	4.45	3.87	2.43	1.39	0.83	0.00
FMCR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FOCF	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FOCR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FKE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FKD	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FDD	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRCC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FSSC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FTE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FTEM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FDINS	0.20	0.20	0.20	0.50	0.70	1.20	1.50	1.50	1.20	0.70	0.20	0.20

Table 8B Monthly parameter adjustment factors applied for the PEC watersheds

GAWSER Parameter Adjustment Table Generated From: Moira River

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FDS	1.00	1.00	1.00	1.00	0.50	0.60	1.00	1.00	1.00	1.00	1.00	1.00
FKEFF	0.02	0.02	0.02	0.08	0.25	0.50	0.80	1.00	0.75	0.35	0.20	0.06
FCS	0.03	0.02	0.02	0.09	0.35	0.45	0.75	0.90	0.65	0.25	0.13	0.06
FD	0.04	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
FKO	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
FKSS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FHI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FKMF	0.25	0.33	0.93	1.23	1.46	1.57	1.52	1.33	1.05	0.76	0.25	0.15
FNEW	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FEVAP	0.00	0.00	0.00	1.67	3.29	3.87	4.45	3.87	2.43	1.39	0.83	0.00
FMCR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FOCF	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FOCR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FKE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FKD	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FDD	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FRCC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FSSC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FTE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FTEM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FDINS	0.20	0.20	0.20	0.40	0.50	0.85	1.50	1.50	1.00	0.60	0.40	0.20

Table 9

WATER BALANCE SUMMARY FOR HYDROGRAPH 1145
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Location: Moira River near Foxboro
Scenario File: wbsum2.dat (Existing Conditions)
Period: 1969/11/01 to 2005/10/31 Area: 2547.4800 km^2

Water Balance Quantities (in mm)

Month	Precip	ET	Runoff	Infiltration (Baseflow)	Infiltration (Losses)	Total Flow
JAN	67.7	8.4	7.8	22.8	28.7	30.6
FEB	61.5	7.7	5.8	15.3	32.7	21.1
MAR	78.0	9.2	32.2	19.6	16.9	51.8
APR	77.6	30.8	84.8	29.8	-67.8	114.6
MAY	78.6	76.5	19.4	25.1	-42.4	44.5
JUN	79.5	100.4	4.9	13.8	-39.6	18.7
JUL	64.7	97.5	3.2	7.9	-43.9	11.1
AUG	77.6	75.4	3.2	4.6	-5.6	7.8
SEP	91.8	62.9	4.4	4.3	20.2	8.6
OCT	79.6	45.2	6.0	7.7	20.6	13.8
NOV	93.4	20.1	14.6	21.3	37.4	36.0
DEC	91.9	9.2	12.3	28.8	41.7	41.0
Total	941.8	543.3	198.6	201.0	-1.1	399.6

Extreme Flows Summary
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Return Period (Years)	High Flows (m^3/s)	Low Flows (m^3/s)
1.25	178.000	4.6400
2.00	259.000	3.6400
5.00	352.000	2.8600
10.00	406.000	2.5200
20.00	453.000	2.2700
25.00	467.000	2.2000
50.00	510.000	2.0100
100.00	549.000	1.8600
200.00	587.000	1.7300
500.00	635.000	1.5900

Flow-Duration Summary
=====================

PCT% Time	Flow (m^3/s)	PCT% Time	Flow (m^3/s)
98.0	2.690	50.0	20.353
90.0	5.146	40.0	26.414
80.0	6.984	30.0	33.122
70.0	9.918	20.0	43.467
60.0	14.871	10.0	66.543

Table 10 Assignment of climate station data to each Zone of Uniform Meteorology in the long-term simulations

Zum Number	Primary Climate Station	Climate Stations used for Missing Value Fill-in Work
1	616I001 Bancroft Auto	6160473 Bancroft OMNR 6160468 Bancroft L'Amable 6160465 Bancroft 6163156 Haliburton A (Corrected)
2	6154479 Madoc	6154780 Madoc (Old) 6159010 Tweed 6159019 Tweed Ontario Hydro 6154995 Marmora 6153843 Ivanhoe 6153935 Kaladar (Corrected)
3 & 4	6161662 Cloyne Ontario Hydro	6100521 Barrett Chute 6161739 Coe Hill 6162787 Gilmour 6105010 Matawatchan 6105760 Ompah 6105762 Ompah-Seitz 6101077 Calabogie 616I001 Bancroft Auto (Corrected)
5, 6, 7	6152555 Frankford MOE	6158733 Trenton A (Corrected)
8	6150689 Belleville	6150700 Belleville 6150717 Belleville Par Lab 6158733 Trenton A (Corrected)
16	615EMR7 Mountview	6155498 Mountain View (Old) 6156535 Picton A (Corrected) 6150689 Belleville (Corrected)

Table 11a Comparison of key hydrograph statistics for mean annual flows (for Nov. 1, 1969 to Oct. 31, 2005)

Gauge Station		***Mean Annual Flow (m^3/s)***	***Std. Dev.***	***Min Flow***	***Max Flow***	***E^2***	***Std Error Est.***
Deloro (02HL005)	Observed	3.79	0.96	1.89	6.26		
	Modelled	3.89 (+2.6%)	0.95	2.19	6.39	0.359	0.763
Black River (02HL003)	Observed	5.46	1.25	2.90	7.74		
	Modelled	5.29 (-3.1%)	1.14	3.13	8.05	0.434	0.871
Skootamatta (02HL004)	Observed	8.71	1.97	4.68	12.4		
	Modelled	8.63 (-1 %)	1.92	4.88	13.1	0.526	1.32
Foxboro (02HL001)	Observed	31.6	6.89	18.9	44.5		
	Modelled	32.4 (+2.5%)	6.28	20.1	48.6	0.645	3.77
Consecon (02HE002)	Observed	1.46	0.321	0.83	2.09		
	Modelled	1.48 (+1.5%)	0.282	0.90	1.98	0.299	0.236

Note: E^2 (Model efficiency) values given for the entire 36-year long-term period.
Differences (%) between observed and modelled mean annual flows are noted in brackets

Table 11b Comparison of key hydrograph statistics for monthly flows (for Nov. 1, 1969 to Oct. 31, 2005)

Gauge Station		*Mean Monthly Flow (m^3/s)*	*Std. Dev.*	*Min Flow*	*Max Flow*	*E^2*	*Std Error Est.*
Deloro (02HL005)	Observed	3.79	2.60	0.006	21.3		
	Modelled	3.89 (+2.6%)	3.24	0.096	33.7	0.661	2.81
Black River (02HL003)	Observed	5.46	3.47	0.070	27.8		
	Modelled	5.29 (-3.1%)	3.67	0.077	36.2	0.717	3.31
Skootamatta (02HL004)	Observed	8.71	5.63	0.17	44.9		
	Modelled	8.63 (-1 %)	5.91	0.34	58.8	0.693	5.33
Foxboro (02HL001)	Observed	31.6	19.0	0.40	163		
	Modelled	32.4 (+2.5%)	19.7	2.64	199	0.811	14.8
Consecon (02HE002)	Observed	1.46	1.26	0	11.2		
	Modelled	1.48 (+1.5 %)	1.15	0.003	10.9	0.758	0.96

Note: E^2 (Model efficiency) given for the 36-year (432 months) long-term monthly flows.
Differences (%) between observed and modelled monthly flows are noted in brackets

Table 12 Comparison of key hydrograph statistics for the April 2008 Event (for March 29 to April 21, 2008)

Gauge Station	*Hyd Number*	*Drainage Area (km^2)*		*Hyd Volume (mm)*	*Peak Flow (m^3/s)*	*E^2*	*GFI*
Deloro (02HL005)	2104	297.2	Observed	172.2	47.1	0.731	85.1
			Modelled	171.6	53.2		
Black River (02HL003)	2113	429.7	Observed	134.1	49.8	0.735	83.7
			Modelled	117.7	51.9		
Skootamatta (02HL004)	2122	678.3	Observed	133.3	75.2	0.512	71.3
			Modelled	117.7	87.7		
Tweed (02HL007)	1125	1715.9	Observed	152.5	241	0.825	87.8
			Modelled	131.1	234		
Clare River (02HL008)	1126	315	Observed	155.5	37.9	0.709	82.6
			Modelled	139.1	35.2		
Foxboro (02HL001)	1145	2547.5	Observed	140.3	290	0.818	87.2
			Modelled	132.1	330		
Consecon (02HE002)	2522	116.9	Observed	178.3	23.6	0.829	87.5
			Modelled	170.5	27.9		

Note: E^2 = Model efficiency

Table 13 Summary of Precipitation Amount for Selecting Drought Years

Climate Station	*1950-2005 Mean Annual*	*1950-2005 Minimum*	*1950-2005 Maximum*	*Minimum 2 Years*	*Minimum 10 years*
Bancroft	909.3	660.3 (1964)	1259.9 (1999)	702.0 (1963-1964)	783.3 (1956-1965)
Cloyne Ontario Hydro	861.9	616.2 (1961)	1169.8 (1996)	619.2 (1963-1964)	688.2 (1955-1964)
Madoc	921.0	738.6 (1982)	1142.3 (1955)	768.9 (1982-1983)	872.3 (1957-1966)
Frankford MOE	869.8	577.9 (1963)	1181.3 (1986)	673.4 (1962-1963)	759.5 (1957-1966)
Belleville	876.9	676.4 (1989)	1116.2 (1955)	697.8 (1988-1989)	776.2 (1961-1970)
Mountainview	883.8	598.8 (1963)	1096.1 (1976)	641.5 (1963-1964)	747.3 (1961-1970)
6 Station Average	887.1	676.8 (1963)	1068.4 (1996)	699.2 (1963-1964)	779.7 (1957-1966)

Table 14 Water Balance Summaries for different scenarios for each gauge location and key point of interest under existing conditions

Gauge Or POI	*Scenario*	*Total Prec (mm)*	*Actual ET (mm)*	*Runoff (mm)*	*Baseflow (mm)*	*Net Storage (mm)*	*Total Flow (mm)*
Deloro (2104)	Mean (1950-2005)	929.3	556.6	190.9	179.5	2.3	370.4
	2 Year (1963-64)	713.8	556.9	88.4	129.4	-60.9	217.8
	10 Year (1957-66)	803.0	541.8	120.0	137.3	3.9	257.3
Black (2113)	Mean (1950-2005)	947.7	555.5	200.0	187.6	4.7	387.6
	2 Year (1963-64)	869.4	546.4	184.2	176.2	-37.8	360.4
	10 Year (1957-66)	891.6	542.7	201.5	146.2	1.1	347.7
Skootamatta (2122)	Mean (1950-2005)	984.7	555.1	213.6	215.0	1.0	428.6
	2 Year (1963-64)	899.1	550.5	197.6	195.0	-44.0	392.6
	10 Year (1957-66)	923.7	545.0	212.3	168.7	-2.3	381.0
Foxboro (1145)	Mean (1950-2005)	941.8	542.8	198.2	200.6	0.2	398.8
	2 Year (1963-64)	805.6	522.9	161.0	165.9	-44.0	327.0
	10 Year (1957-66)	855.9	525.9	176.6	153.8	-0.4	330.4
Roblin Lake Inflow (505)	Mean (1950-2005)	892.1	398.7	454.4	39.0	-0.1	493.1
	2 Year (1963-64)	658.6	344.3	310.5	25.3	-21.6	335.8
	10 Year (1957-66)	765.0	374.4	359.1	30.2	1.3	374.4
Roblin Lake Outflow (5505)	Mean (1950-2005)	892.	548.0	305.3	38.8	-0.1	344.1
	2 Year (1963-64)	658.6	499.1	183.8	17.9	-41.2	201.7
	10 Year (1957-66)	765.0	526.1	215.4	27.6	-4.1	243.1
Sawguin Creek Outlet (2506)	Mean (1950-2005)	892.1	516.6	307.0	68.2	0.4	375.1
	2 Year (1963-64)	658.6	443.2	200.9	44.6	-30.1	245.4
	10 Year (1957-66)	765.0	484.0	224.3	55.2	1.4	279.6
Consecon (2522)	Mean (1950-2005)	892.1	516.1	308.6	66.3	1.1	374.9
	2 Year (1963-64)	658.6	440.4	205.5	41.6	-28.9	247.1
	10 Year (1957-66)	765.0	482.8	230.4	49.8	2.0	280.2