CONCEPTUAL WATER BUDGET

Quinte Region

Final Report

Prepared December 8, 2006

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1. Introduction, Purpose and Objectives

The development of a water budget is a requirement of Quinte Conservation (QC) as part of the drinking water source protection program. The water budget is being completed to assist in the understanding of the climate, the quantities of ground and surface water available, how this water moves through the QC watershed and how it is being used along its path of flow.

In the guidance document Interim Water Budget Technical Direction Version 3.0 (Draft April 10, 2006); different levels of water budget assessment are described as ranging from conceptual understanding to simple and complex modelling. To comply with the guidelines, the Conceptual understanding and a Tier 1 simple or complex model are the minimum requirements. Subject to the level of stress identified in this initial work, completion of a Tier 2 or 3 water budget may be required.

This work builds on the watershed characterization that has been developed in previous work and presumes a basic familiarity of the reader to the conditions of the Quinte region watersheds. Some very brief review of the physical, meteorological and hydrological setting is provided however for assistance in understanding the context of some of the discussion and how certain decisions were made in the modelling components for the water budget. As the purpose of the conceptual stage of water budgeting is to scope the major influences on movement of water though the study area on a course time scale by employing the available data, some later refinement may be warranted on both scale and aerial extent. The decision to advance further water budgeting work would be made on a subwatershed basis and will consider other factors such as seasonal water supply variations and may suggest additional data accumulation.

This report outlines QC's progress in water budget development, the current understanding of water flows within our watersheds, and the next steps related to water budget assessment. The assessment has entailed evaluation of the following components:

- Climate
- Geology/Physiography
- Land Cover
- Groundwater
- Surface water &
- Water Use

Each of these elements is described below and the methodology through which they were combined into a simple GIS model to represent hydrologic conditions within the watershed region is also discussed. The following figure is supplied to orient the reader on the location of the Quinte Conservation region.

Figure 1: Study Area Extents and Watershed Divisions

2. Overview of Quinte Conservation & Physical Setting

Quinte Conservation is a grouping of three separate conservation authorities referred to as the Moira River, Napanee and Prince Edward Region Conservation Authorities. Collectively these 3 regions cover 6200 square kilometres with QC owned properties including over 30000 acres of land in small parcels at some of the 39 water control structures, to large tracts of over 1,000 acres, many with significant natural features.

More than 117,000 people live within the study area, of which approximately half reside in small to medium sized urban centres such as the City of Belleville, and Towns of Napanee, Picton, and Deseronto. The water supply for these larger urban centres is predominantly from the Great Lakes. The balance of the population lives in rural areas where groundwater is the primary source of water supply for domestic, commercial and agricultural needs. This includes several small urban areas serviced by Municipal groundwater supply.

An overview of the physical setting within the QC Watershed has been prepared below.

2.1 Climate

Climate conditions in the QC watershed were evaluated through review of Environment Canada data as modelled by Natural Resources Canada – Canadian Forestry Service (McKenney, D, et al, 2006). This information included spatial models of Canada and North American wide climate normals for the period 1971 to 2000 including mean monthly temperature and precipitation levels. Both Canadian and United States meteorological stations were used in the assessment with the location of Canadian Stations as well as local climate stations as illustrated by Figure 3. Some of the climate stations, located in and around the Quinte Region, are discussed under section 4.1 with a summary of average annual precipitation recorded at each station in Table 9.

A second climate data set was also prepared by the same contributors for a longer period of record including 1931 to 2000. The longer term data, as summarised in Appendix A, is considered in the current study in section 4.2 in order to compare the longer period of flow records available for both the Moira and Napanee River systems. Since stream flow information is not available for most gauging stations in the QC watershed that is consistent with this longer period of climatological information, the authors have elected to rely on data from the 1971 to 2000 period for the preparation of the conceptual water budget. Hence all figures and tables contained herein were prepared using the more current, but shorter dataset. Exceptions are noted.

In the GIS environment values of mean monthly temperature, precipitation, potential evapotranspiration (PET), and actual evapotranspiration (AET) have been determined. These are summarised in Table 1. Mean monthly temperature for the region averages at

6.5 °C and ranges from -8.2 to 20.2 °C. The mean annual precipitation over the watershed area is 919 mm with a high of 1020 mm in the southern portion of Prince Edward County to a low of 860 mm in the northern reaches of the Moira Watershed. The annual PET was calculated by the Thornthwaite Method (1955) to be in the order of 585 mm with AET determined to be slightly lower at 550 mm. An illustration of the relationship between monthly precipitation and evapotranspiration is provided in Figure 2 indicating high evapotranspiration and decreased precipitation in the summer months resulting in a water deficit during this period. This can be seen where the AET curve is below the PET curve. The spatial distribution of the mean annual temperature and precipitation within the region is also illustrated by Figures 4 and 5 respectively.

General agreement of the calculated evapotranspiration rates is apparent by comparing the values in Table 1 with those published in mapping of the region by the MNR shown in Figure 6 taken from the Hydrogeology of Southern Ontario by Singer et al 1997. Other references supporting this calculation include the Water Resources of the Moira River Drainage Basin (MOE, 1974) and The Atlas of Canada (Natural Resources Canada, 2006).

Table 1: 1971 – 2000 Average Temperature, Precip, ET - Quinte Region

Month	Average Temperature (°C)	Average Precipitation (mm)	Avg PE (mm)	Avg AE (mm)
January	-8.2	77	0	0
February	-7.2	60	0	0
March	-1.6	73	0	0
April	5.6	74	29	29
May	12.6	76	78	78
June	17.6	77	113	110
July	20.2	65	132	114
August	19.2	79	115	100
September	14.5	89	74	74
October	8.2	77	37	37
November	2.0	87	7	7
December	-4.9	83	0	0
	6.5	**919**	**585**	**550**

PE = Potential Evapotranspiration, AE= Actual Evapotranspiration
Calculated by Thornthwaite Method 1955

Figure 2: Quinte Region Water Deficit Time Sequence

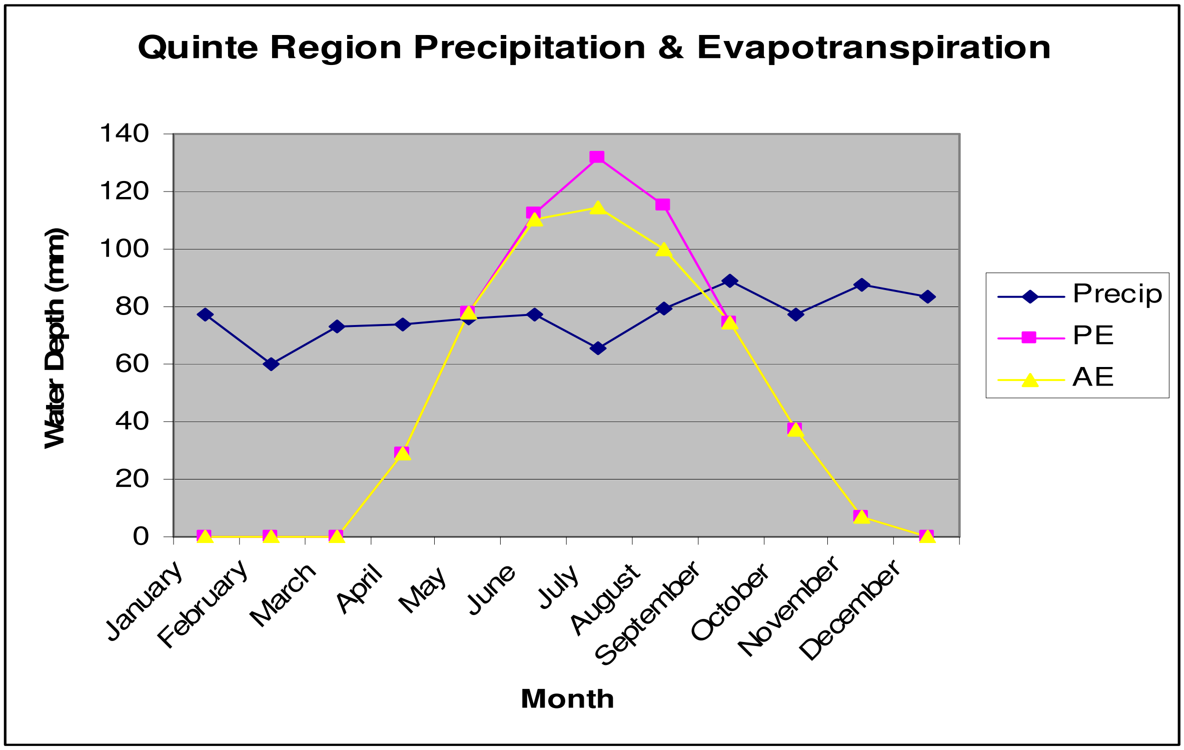
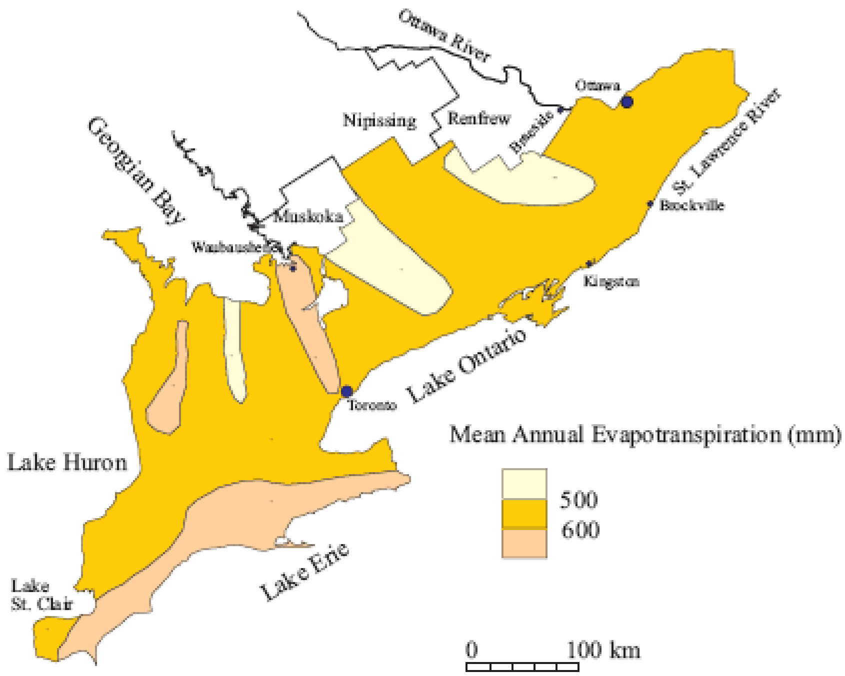


Figure 3: Climate Stations

Figure 4: Mean Annual Temperature

Figure 5: Mean Annual Precipitation

Figure 6: Estimated Southern Ontario Evapotranspiration, from Singer et al. (1997)



2.2 Geology/Physiography

Knowledge of the physical and geologic characteristics of the watershed is required to understand the movement of both ground and surface water in the QC watersheds. A description of the topography, physical bedrock, and overburden geology are briefly summarised below.

Much of the information about the physical watershed characteristics has been derived from the Quinte Regional Groundwater Study (Dillon, 2004) as well as other regional reports such as the Prince Edward County Hydrogeologic Study (Water & Earth, Science and Associates, 1985) and the Water Resources of the Moira River Drainage Basin (MOE, Water Resource Report 6, 1974).

2.2.1 Topography

The watershed topography is variable ranging from the rocky highlands of the Precambrian Shield at the north to the more subdued relief of the limestone plains at the south along the shores of the Bay of Quinte and Lake Ontario. Predominant topographic gradient is to the south – southwest with elevations at a high of 400 metres above sea level (masl) in the north and ranging down to approximately 80 masl at the south along the shore of the Bay of Quinte. The relief rarely exceeds 50 metres with elevations in the middle of the watershed region typically in the order of 150 to 300 masl. At the south, in Prince Edward County the topography is even more subdued with maximum elevations of 150 masl at inland plateaus with slope outwards towards the Bay of Quinte and Lake Ontario. In some areas topography is controlled by bedrock faults with surface expression as escarpments resulting in steep relief. Such features are also evident in the other watersheds with the valleys of the Salmon and Napanee Rivers extending along fault zones.

A review of the Digital Elevation Model (MNR) and grouping of topography into different classes provided the following results with the majority of the watershed in the low to moderate slope categories.

Slope Class	% Coverage of Watershed
• Flat land – 0 -1.5 %	- 39.1 %
• Rolling land – 1.5 – 3%	- 24.4 %
• Hilly land > 3%	- 36.6 %

2.2.2 Bedrock Geology

The QC watershed is predominated by shallow soil over fractured bedrock and as such the bedrock geology is one of the most prevalent factors controlling the hydrogeology. Two distinct geologic regions exist with the northern area directly underlain by Precambrian igneous and metamorphic rocks and in the southern region the Precambrian rocks are covered by up to 300 metres of Paleozoic limestone. The boundary between the Palaeozoic and Precambrian rocks can be approximated by a line drawn in a west to east direction from Marmora, through Madoc, Tweed, Tamworth and Enterprise. A plan view of the bedrock geology is provided by Figure 7 with a generalised north-south cross section shown as A-A’ in Figure 8.

The Precambrian bedrock is often exposed or near surface on the Canadian Shield, comprising metasedimentary, metavolcanic, and plutonic rocks. Due to complex geology, this region has been divided into belts and terranes. The main belt within the QC region is the Central Metasedimentary belt with the terranes named as Elzevir, Sharbot Lake, and Frontenac. More specifically the different types of rocks found in the shield area can be described as including plutonic rocks consisting of granite, syenite, diorite, gabbro, anorthosite, and amphibolite; metasedimentary rocks consisting of paragneiss, pellitic schists, gneisses, marble and para-amphibolite; metavolcanic rocks consisting of basic volcanics, greenstone, and pillow lava.

Figure 7: Bedrock Geology

Figure 8: Bedrock Geology Cross Section

The Palaeozoic rocks of the region are primarily Ordovician aged limestones of the Simcoe group underlain by the Shadow Lake Formation of the Basal Group (collectively called the Ottawa group). The Simcoe group is comprised of four distinct limestone formations as listed below in Table 2. The thickness of the limestone units increases in a southerly direction reaching depths of up to 300 metres in southern Prince Edward County (as identified through oil and gas exploration wells) where the younger Lindsay and Verulam formations can be found.

Table 2: Bedrock Formations

Formation	Member**	Map Unit*	Age	Thickness	Lithology
SIMCOE GROUP					
Lindsay	Upper	6b	Upper Ordovician	0 to 90 m (usually <30m)	limestone and shale
	Lower	6a	Upper Ordovician		nodular limestone with shale interbeds
Verulam Formation		5	Middle Ordovician	0 to 70 m	interbedded limestone and shale
Bobcaygeon	Upper	1c, 4b	Middle Ordovician	0 to 60 m	limestone with shaly partings
	Lower	1c, 4a	Middle Ordovician		limestone and calcarenite
Gull River Formation	Upper	1b, 3, 3c	Middle Ordovician	0 to 30 m	dolomitic limestone and weathered limestone
	Middle	1b, 3, 3b	Middle Ordovician		shaly laminated limestone and massive bedded
	Lower	1b, 3, 3a	Middle Ordovician		crystalline limestone
BASAL GROUP					
Shadow Lake Formation		1a,2	Middle Ordovician	0 to 20 m	dolostone with interbeds of sandstone and shaly partings
PRECAMBRIAN					
		37 to 48	Precambrian	Basement rock	igneous and metamorphic rocks

* Formation shown as map units displayed on original source mapping

** Member is a subgroup of a Formation

This Table was taken from Quinte Regional Groundwater Study Final Report – Dillon Consulting October, 2004.

2.2.3 Structural Geology

The geological processes shaping the landscape of the QC region have included faulting, erosion and uplift. The Paleozoic rocks were deposited as sediments that are essentially flat lying layers (gentle dip of 3 metres per km). However faulting has occurred throughout with some of the major faults as depicted by Figure 7 and listed as follows:

- The Salmon River fault follows the course of the river with the west side being down thrust by approximately 30 metres. This fault extends from Kaladar at the north and can be traced into Prince Edward County at the south.
- The Picton fault follows the shoreline of Prince Edward County from Deseronto to Picton where it splits into two separate branches extending to Sandbanks and Point Petre. This fault may also be traced as extending to the north and following the course of the Napanee River towards Sharbot Lake.
- Other faulting is evident in the Precambrian Region including the Moira Lake Fault in the vicinity of Madoc.

2.2.4 Overburden Geology

The overburden geology of the QC region as previously indicated may be described as comprising a thin layer of drift less than one metre depth over fractured bedrock. In some areas of the Precambrian shield, the overburden is thin or absent and the terrain is characterized by rock and knob topography. However, sporadic soil deposits may be found on the shield in bedrock depressions and valleys some of which include organic swamp and bog deposits.

In spite of the predominance of shallow soil cover, some significant soil deposits are found in various landform features throughout the region. These deposits, as listed in Table 3, are comprised of glacial Till (stony and sandy matrix), glaciofluvial sand and gravel, and lacustrine sand, silt, and clay. Generalised mapping of overburden geology is illustrated by Figure 9 with soil thickness represented by Figure 10.

The various landforms where significant soil deposits are found include eskers, a kame moraine, and drumlins. The kame moraine, the most significant landform, is located along the southwest boundary of the Moira watershed extending for an approximate distance of 24 kilometres and reaching heights of 60 to 90 metres above the surrounding land surface. This feature is primarily comprised of sand and gravel and has been interpreted as an extension of the Oak Ridges Moraine onto to the east side of the Trent River. Significant eskers in the region include the Tweed, Marlbank, Picton and Cherry Valley Eskers. The Tweed esker is a narrow ridge of sand and gravel trending in a southerly direction between Tweed and Zion Hill for an approximate distance of 29 kilometres. The Marlbank esker is a ridge of sand and gravel extending from Marlbank into the northern portion of Tyendinaga Township. The Picton and Cherry Valley Eskers are also ridges of sand and gravel extending above limestone bedrock to heights of 20-25 metres.

Table 3: Areas of Significant Overburden Deposits

Municipality	Description	Typical Thickness
Quinte West	Kame Morraine – extension of oak Ridges	70 metres
Madoc	Till plain and eskers,	<20 m
Centre Hastings	Dummer moraines, drumlins, & eskers,	<20 to 80 m
Tweed	Till plain, Dummer moraines, eskers,	<10 – 40 m
Belleville	Dummer moraines and drumlin field north of Moira River, eskers, -Thurlow	<20 to 80 m
Tyendinaga	Till plain, clay deposits near Shannonville	Mainly shallow
Stone Mills	Till plain in Erinsville-Tamworth,	Mainly shallow
Prince Edward County	Esker, Cherry Valley & Picton-West Lake	20 - 25m

This Table has been taken and modified from the Quinte Regional Groundwater Study Final Report – Dillon Consulting October, 2004.

Figure 9: Overburden Geology

Figure 10: Overburden Thickness

2.3 Land Cover

The land cover of the region can influence the distribution of surface runoff, evapotranspiration and groundwater recharge. Mapping of the QC region has been completed by the Ministry of Natural Resources for the period 1996-99. This mapping indicates a significant portion of the shield area is forested, while much of the lowlands to the south and the Prince Edward County Region are agricultural and low cover.

Large pockets of high cover forested areas can be found in the mid and southern regions and tend to be associated with areas of wetlands and parcels with reduced access. These are areas that are more difficult to put into agricultural production and have either not been cleared or have been removed from production due to low productivity. Lesser expanses of forest in the same region survive as parks, conservation areas and woodlots.

Large portions of the Palaeozoic regions with shallow soil conditions were intensively farmed at one time. However, the agricultural productivity of such areas has been reduced and removed from production. Such areas are now regenerating forest cover resulting in higher land cover.

Settlement areas within the region tend to be concentrated in the southern half of the watershed with the largest population centres in Belleville, Napanee, and Picton. These urban areas are characterized as having a low land cover.

Rain falling on forested areas will experience more interception and transpiration and result in reduced surface runoff in contrast to cultivated fields and cropland. Thus, areas with high forest cover will tend to have less runoff than areas with less vegetative growth.

The MOE Hydrogeological Technical Information Requirements for Land Development Applications April, 1995, provides a methodology and coefficients that can be applied to a drainage area for separating the runoff (or surplus water) into direct overland runoff from that which may be considered groundwater recharge. This methodology considers land cover as a component of the separation or partitioning exercise by assigning a factor whereby more dense land cover would have a higher factor for retaining water resulting in more potential groundwater recharge. Further discussion of this methodology is provided in Section 3.4 followed by the results of the exercise.

2.4 Surface Water

The three largest watersheds in the Quinte Region are found north of the Bay of Quinte. These are the Moira, Salmon and Napanee Rivers draining from the north to the south into the Bay of Quinte. River gradients are typically higher in the north and are reduced through the south. In Prince Edward County the watersheds are smaller and shorter by comparison to those found at the north. The gradients range from a high of 19 m per 1000 m to below 0.4 m per 1000 m. The location of the main basins was presented earlier in Figure 1 and in more detail in Figure 12.

A table of river gradients is produced below to show the distribution of river reach gradients across the region. For comparison to the larger rivers, the Consecon Creek (largest watershed in Prince Edward County) is also considered.

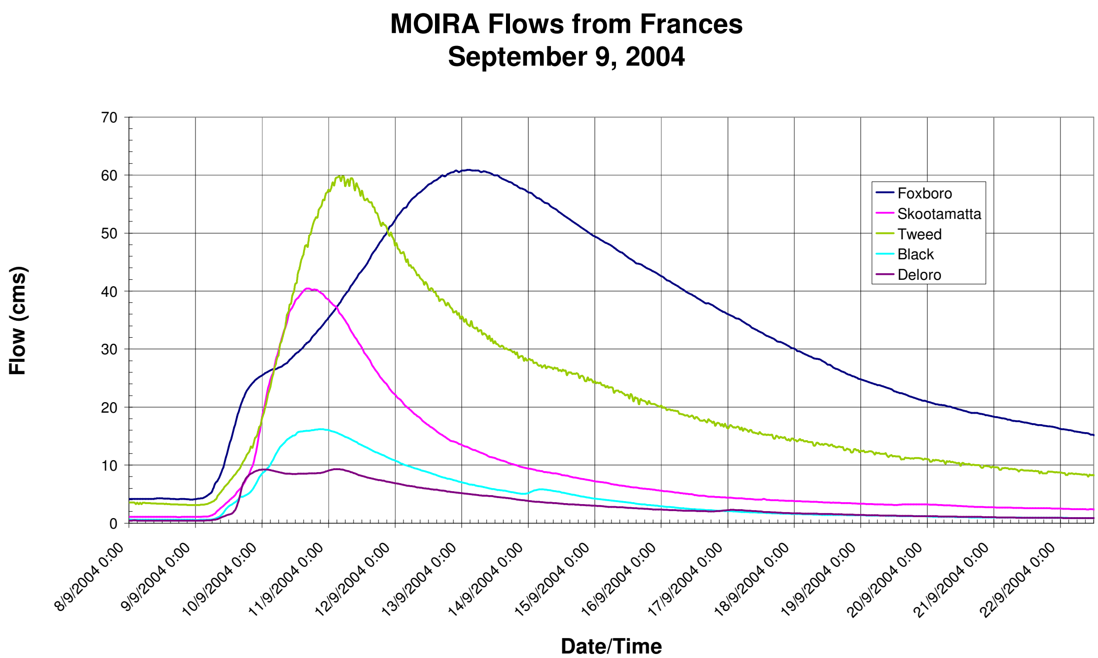
Table 4: Major River Gradients

River	Location	Distance (km)	Gradient (m/1000m)
Moira	Headwaters to Moira Lake	76.6	2.4
	Moira L. to Stoco L.	21.6	0.7
	Stoco L. to Plainfield	26.4	1.3
	Plainfield to Corbyville	15.3	0.05
	Corbyville to mouth	7.6	3
Salmon	Headwaters to Kennebec Lake	34.4	2.2
	Kennebec L. to Beaver L.	40.3	0.8
	Beaver L. to Upstream of Forest Mills	24.5	1.5
	Forest Mills to Lonsdale	13.8	3.3
	Lonsdale to mouth	14.2	0.6
Napanee	Depot Creek	22.3	1.9
	Depot Cr. to Downstream of Newburgh	25.6	1.7
	Newburgh to Springside Dam	9.76	0.8
	Springside Dam to mouth	9.6	0.1
Consecon	Headwaters to Big Swamp	6.4	3.3
	Through Big Swamp at Allisonville	15.2	0.5
	Allisonville to Melville	4.8	1.27

The shield region is dominated by poorly drained areas including discontinuous wetlands and lakes. Northern sections of the lowlands are characterized by broader wetlands, fens, bogs, and swamps and fewer lakes. By contrast the southern half of the lowlands is devoid of lakes, but wetlands are still present. Here, rivers are more incised into the bedrock and are less connected to their floodplains. This is evident of the Salmon and Napanee rivers which follow bedrock faults and preglacial valleys running parallel to each other. The valley depths may reach up to 30 metres in the Salmon River and 50 metres in the Napanee River.

The response of the Moira, Salmon, and Napanee drainage basins to storm events gives some understanding to the impact of their large natural reservoirs on runoff. Environment Canada stream flow monitoring stations provide a view of the effect of the reservoirs on the peak runoff. Below is a compilation of hydrographs for the Moira gauging stations showing the lags in the basin as runoff from the Frances storm event in late 2004. The rainfall began late in the evening on September 8th and ended early afternoon on September 9th dropping approximately 40 to 50 mm in the north part of the watershed to 130 mm in the south. The grid divisions on the abscissa on both figures are 24 hour periods.

Figure 11a: Hydrographs of Moira Stations

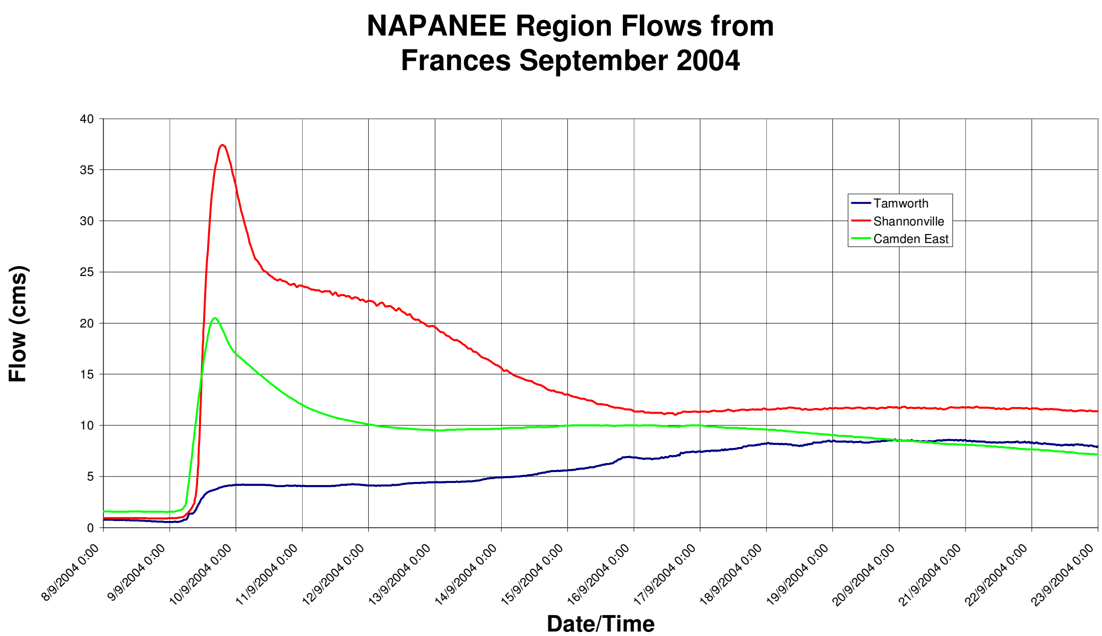


Through inspection of Figure 11a, the three upper stations, Deloro (Moira River), Black River, and Skootamatta River can be seen to peak early within 24 hours after the event. The Tweed station has about a 12 hour lag behind these upper gauges, specifically the Skootamatta gauge. The Foxboro gauge, located near the bottom end of the watershed, indicates that flows peak 48 hours later then observed at the Tweed gauge. The Tweed gauge is located on the northern fringe of the lowlands and flows must be routed through Stoco Lake and the more subdued reaches of the Moira River before being recorded at the Foxboro gauge. Similar lags are experienced in the Salmon and Napanee systems. The lag periods are shorter for storm events which occur under winter conditions.

Response of the Salmon and Napanee River systems to rain events differs from those of the Moira and can be seen by inspection of the hydrographs in Figure 11b where the hydrographs for the same event are reproduced. The Tamworth station is located on the

Salmon system just downstream from the outlet of Beaver Lake and the Shannonville gauge is near the river mouth. The Camden East gauge records the Napanee River flows upstream of the town of Napanee several kilometres north of the river mouth. By simple inspection one can note the almost simultaneous responses of all three stations to the rain input and the delayed but apparent second peak for all three stations. The second peak for the Camden East gauge occurred about six days later on the 16th while the Salmon River stations evidenced a second peak almost ten days after the initial peaks. This second peak is attributed to the lake storage upstream of all the gauges. Figure 12 shows the locations of all the stream gauging stations.

Figure 11b: Hydrographs of Salmon and Napanee Rivers



The drainage network in Prince Edward County is not well as well organized as those for the Moira, Salmon and Napanee Rivers. Water surrounds 'The County' and the short creeks drain outward from inland plateau areas to the nearest shoreline. Owing to its flatter topography, areas of The County are poorly drained, evidenced by several large marshes, both internally and near the outlets of the creeks to Lake Ontario or the Bay of Quinte. Flood events in the County are dominated by spring melt events and the flow in the Creeks respond quickly to storm events.

2.4.1 Summary of Stream Flow Monitoring Data

Flows across the region are monitored by Water Survey of Canada and a summary of the stations, mean annual flows and annual runoff is presented in the following table. Table 5 contains a complete listing of all systematically collected flow data for the watersheds of the Quinte region.

Table 5: All Stream Gauging Stations

Station Name	Catchment Area* (km^2)	WSC ID	Period of Record	Mean Annual Flow (cms)	Runoff Expressed as mm/yr
MOIRA RIVER NEAR DELORO	*296*	02HL005	1965 - 2004	3.77	402
BLACK RIVER NEAR ACTINOLITE	*430*	02HL003	1955 - 2004	5.15	378
SKOOTAMATTA RIVER NEAR ACTINOLITE	*678*	02HL004	1955 - 2004	8.42	392
MOIRA RIVER NEAR TWEED	*1762*	02HL007	2002 - 2004	21.4	383
MOIRA RIVER NEAR TWEED	*1762*	02HL101	1968 - 1977	26.9	481
MOIRA RIVER NEAR THOMASBURG	2210	02HL104	1969 - 1970	*25.2*	*360*
CLARE RIVER NEAR BOGART	*179*	02HL102	1968 - 1977	2.79	492
PARKS CREEK NEAR LATTA	*199*	02HL006	1984 - 1992	2.28	362
PARKS CREEK NEAR LATTA	*199*	02HL103	1968 - 1977	3.13	497
MOIRA RIVER NEAR FOXBORO	*2593*	02HL001	1915 - 2005	30.4	370
SALMON RIVER NEAR SHANNONVILLE	*909*	02HM003	1958 - 2004	10.7	371
NAPANEE RIVER AT CAMDEN EAST	*697*	02HM007	1974 - 2004	8.69	393
NAPANEE RIVER AT NAPANEE	777	02HM001	1915 - 1974	9.13	371
DEPOT CREEK AT BELLROCK	*181*	02HM002	1957 - 2004	1.98	345
BLOOMFIELD CREEK AT BLOOMFIELD	13.9	02HE001	1970 - 1992	0.168	381
CONSECON CREEK AT ALLISONVILLE	*117*	02HE002	1970 - 2004	1.48	399
DEMORESTVILLE CREEK AT DEMORESTVILLE	29	02HE003	1970 - 1977	0.404	435

* Catchment areas in italics determined by GIS using Digital Elevation Model. Otherwise catchment areas are those reported by Water Survey of Canada.

Figure 12: Flow Monitoring Stations and Catchments

2.5 Hydrogeology

Aquifers in the QC region are predominantly comprised of fractured bedrock with isolated overburden aquifers in areas of thick soil deposits. In the southern portions of the watersheds the main aquifer is found in limestone bedrock with Precambrian bedrock aquifers common in the north. The boundaries of these bedrock flow systems are represented by the limits of the geologic formations, as illustrated by the bedrock geology map presented earlier in the report as Figure 7. In the absence of significant aquitards, these aquifers are considered to be unconfined, however in some areas, where the density of fractures in the bedrock is low, confined conditions may exist. In general the decrease in fracture density occurs with depth in the bedrock as the upper horizons have been subject to weathering and dissolution from the movement of water.

Groundwater movement is generally in the top 10 to 30 metres of the fractured bedrock with recharge occurring through infiltrating precipitation in areas of shallow soil cover or permeable deposits of sand and gravel. In view of shallow soil conditions throughout the watershed recharge to the ground water occurs over the majority of the Region.

Overburden aquifers are not extensive throughout the study area but are present where there is sufficient depth of sand and gravel. Such conditions exist in the south western portion of the Moira watershed, in the vicinity of the Kame Moraine, and at the Picton Esker near West Lake in Prince Edward County. These aquifers are relatively isolated but are interpreted as being hydraulically connected with the underlying bedrock, and serve as storage reservoirs providing recharge to the fractured bedrock.

2.5.1 Water Wells

Much of the information about groundwater conditions in the QC Region has been derived from Ontario Water Well Records for which there are approximately records for 22,000 wells in the area of study. The distribution of these wells, as illustrated by Figure 14, is with higher density in the southern areas where much development has occurred versus the northern areas where there is sparse development.

The records indicate that 95% of the wells in the Region are drilled into the bedrock aquifers with the remaining 5% in the overburden. The general characteristics of the various aquifer units are summarised in Table 6 and generally as follows. Yield from the fractured limestone aquifer ranges from poor to adequate for supplying domestic needs. The quality of supply may also be variable with hard water often found in the limestone as well as mineralised, gas and sulphur encountered when wells are drilled too deep (i.e. depths of greater than 30 metres). Natural water quality problems may also be encountered when wells are drilled in the vicinity of groundwater discharge zones. The yield and quality of water from wells drilled in the Precambrian and Overburden aquifers are generally reported as good. However low yield wells may also be encountered on the Precambrian shield subject to the size and density of fractures in the bedrock.

Overburden materials that are generally not suitable for water supply may also provide poor quantity and quality.

Table 6: Summary of Aquifer Properties

Material/ Formation	Lithology	Water Quality	Yields*
Upper Lindsay	Limestone/shale	Hard, sometimes sulphury	Poor
Lindsay	Limestone	Hard, sometimes sulphury	Poor
Verulam	Limestone/shale	Hard, often sulphury	Poor to Moderate
Bobcaygeon	Limestone	Hard	Poor to Moderate
Gull River	Dolostone/shale/ sandstone	Hard	Poor to Moderate
Shadow Lake	Sandstone/siltstone	Fresh, sometimes mineral	Very Good
Precambrian	Igneous/meta-morphic	Fresh, sometimes mineral	Moderate
Nearshore &Beach	Sand and silt	Fresh, mineral	Very Good
Eskers/Kames	Sand and gravel	Fresh, mineral	Very Good
Clay	Silt and clay	Sulphury	Poor
Till	Sand, silt, gravel	Fresh, mineral	Moderate

* Note: This ranking is qualitative and is based on the amount of water that is normally needed to supply the domestic household needs (13L/min). A poor well seldom meets this requirement, while a good or very good well usually or always meets this requirement.

2.5.2 Groundwater Flow

The water table through out the Region is typically a reflection of surface topography with groundwater flowing from areas of high ground to low. Water table elevation throughout the region is illustrated by Figure 13 showing the gradient and direction of groundwater movement. The regional direction of groundwater flow is similar to surface drainage, in a south to southwest direction. However, variation to this generalisation is evident in areas of steep topography. Likewise in Prince Edward County the water table mimics topography with flow outwards from high inland plateaus towards the shorelines. Please note that water table elevations were determined using well record data and lower confidence exists where the density of wells is low. Faults throughout the region can affect groundwater flow by first serving as a channel through which groundwater can flow. However, faults can also serve as a boundary or divide between aquifers where flow does not cross this zone.

Figure 13: Water Table Elevation

2.5.3 Recharge and Discharge Areas

The location of groundwater recharge areas was evaluated based on mapping completed under the Quinte Regional Groundwater Study (Dillon, 2004). This mapping is included as Figure 14 which is the result of the determination of vertical hydraulic gradient, depth to water table and where topography falls below the water table surface (i.e. escarpments) to delineate areas of groundwater recharge and discharge. From review of the mapping it is evident that significant recharge areas are associated with elevated topography and groundwater discharge occurs in lowlands and at abrupt changes in elevation (escarpments). A note of caution for review of the recharge/discharge mapping (Figure 14) is that well records were used in the interpretation of hydrogeologic conditions. In the northern areas of the watershed the density of well records is low compared to the south, therefore the degree of confidence in the interpretation is lower at the north.

In addition to the mapping of recharge/discharge areas using vertical hydraulic gradients, information generated from this conceptual water budget exercise could be considered as useful for the identification of significant recharge areas. As previously mentioned, The MOE Hydrogeological Technical Information Requirements for Land Development Applications (April, 1995), provides a methodology for separating the runoff (or surplus water) into direct overland runoff and groundwater recharge. Through application of this methodology areas of higher recharge potential were identified. The results of this methodology are discussed later in the report and illustrated by Figures 26 and 27.

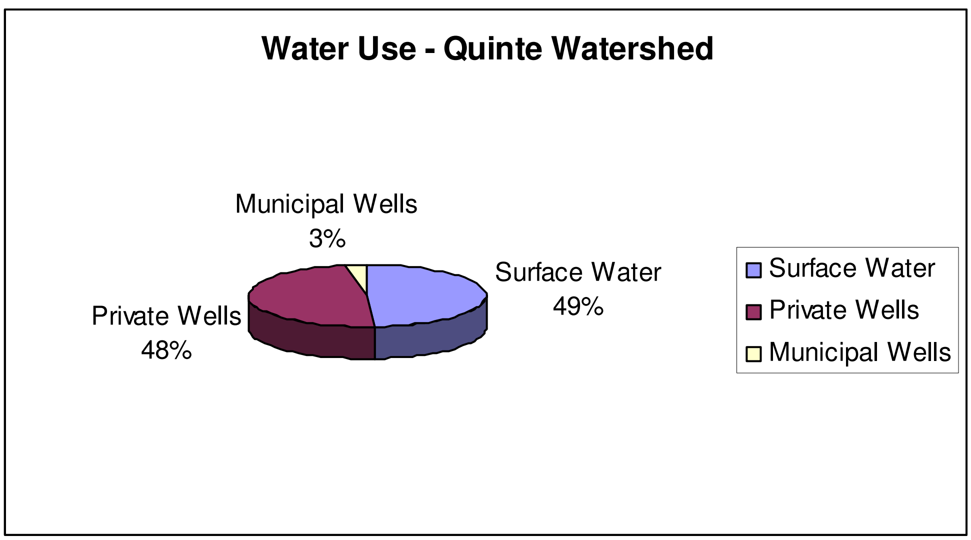
Figure 14: Groundwater Recharge Map

2.6 Water Use

Water in the QC watershed is used for potable water supply to municipalities and private homes. Other uses include irrigation, agricultural livestock watering as well as industry and manufacturing. To evaluate the sources of water that watershed residents are using, a review of the population distribution was completed for comparison with private and municipally serviced areas. This review determined that the proportions of population in the QC watershed may be divided approximately equally between those serviced by ground and surface water. This distribution is summarised by Figure 15 with approximately 51 % of the population being serviced by groundwater and the remaining balance on surface water.

The group of residents serviced by groundwater includes those residents on private wells as well as small communities on municipal groundwater supply systems in the Villages of Deloro, Tweed, and Madoc, and a small subdivision, referred to as Peats Point, in Prince Edward County. The majority of the population serviced by surface water, live in urban centres, and obtain supply from the Bay of Quinte or Lake Ontario. The exceptions are the Village of Ameliasburgh which uses Roblin Lake and the back up intake for the Town of Napanee on the Napanee River. The location of the municipal groundwater supply wells and surface water intakes are provided by Figure 16.

Figure 15: Water Use



A summary of the population distribution in the Quinte region with water use by each of the 18 member municipalities is provided by Table 7. A total of 11 or 61 % of the municipalities rely completely on groundwater for potable supply with only 3 municipalities having the majority of their water supply taken from surface water sources.

Figure 16: Municipal Groundwater Wells and Surface Water Intakes

Table 7: Municipal Population Distribution on Ground and Surface Water Supplies

Municipality	Total Population	Population Served			% Population Supplied by Groundwater		
		Municipal Groundwater	Surface Water	Private Wells	Total	Municipal Wells	Private wells
Tweed	5612	1539	0	4073	100	27.4	72.6
Belleville	45986	0	38306	7680	16.7	0	16.7
Tyendinaga	3769	0	0	3769	100	0	100
Deseronto	1796	0	1796	0	0	0	0
Stone Mills	7337	0	0	7337	100	0	100
Madoc	2044	0	0	2044	100	0	100
South Frontenac	3447	0	0	3447	100	0	100
Centre Hastings	3127	1730	0	1397	100	55.3	44.7
Addington Highlands	1056	0	0	1056	100	0	100
Greater Napanee	11667		7760	3907	33.5	0	33.5
North Frontenac	18	0	0	18	100	0	100
Central Frontenac	2096	0	0	2096	100	0	100
Marmora	527	50	0	477	100	9.5	90.5
Quinte West	3528	0	0	3528	100	0	100
Stirling Rawdon	465	0	0	465	100	0	100
Tudor & Cashel	319	0	0	319	100	0	100
Loyalist	238	0	0	238	100	0	100
Prince Edward	24901	50	9901	14950	60.2	0.2	60
Totals	**117933**	**3369**	**57763**	**56801**	**51**	**2.9**	**48.2**

2.6.1 Determination of Water Demand

To determine water demand, a variety of sources of information have been reviewed to establish total use of ground and surface water for the various categories itemised below. Sources of information included the MOE Permit to Take Water Database, the Rob de Loe agricultural water use study prepared for the MNR, Ontario Water Well Record data, and Canada Census population data. In this determination the maximum permitted water taking, as specified in the MOE Permit to Take Water data, was applied as opposed to an actual or average use. In many cases the permitted taking is expected to far exceed the actual water use, however, data on this use is not readily available. Use of the permitted taking is considered appropriate for the current level of study.

<u>Category 1</u>: Domestic and Commercial Use

Domestic and commercial use was determined utilizing well record and population census data (Canada Census, 2001). The number of records being utilised for domestic and commercial use were separated out of the water well record database and compared with the population for the individual municipalities. Based on correlation of the population with the number of water wells a factor of 3 persons per well was determined. A water usage of 175 litres per person per day was then applied to calculate the commercial and domestic water use. As regards to surface water any intakes located on the Great Lakes and connecting channels (Bay of Quinte) were not included for the purposes of this water budget. The exceptions are the intakes on Roblin Lake and the Napanee River.

<u>Category 2</u>: Industrial and Manufacturing:

MOE permit to take water data was used to determine this usage which includes the dewatering of quarries, aggregate washing and other similar activities.

<u>Category 3</u>: Livestock watering:

Agricultural water use data was taken from the Rob de Loe agricultural water use study prepared for the MNR. This data indicated ground water use by sub watershed which was distributed to the number of agricultural wells within the respective sub watershed.

<u>Category 4</u>: Irrigation

The MOE permit to take water data was used to determine this usage. This includes both agricultural and golf course demand which exceed 50,000 litres/day. Some takings less than this are considered under Category 3 through the Rob de Loe study.

<u>Category 5</u>: Public supply:

The MOE permit to take water data was used to determine this usage. This includes usage for campground and private developments where total daily demand exceeds 50,000 litres/day.

Category 6: Municipal Water supply

The MOE permit to take water data was used to determine this usage.

2.6.2 Groundwater Demand

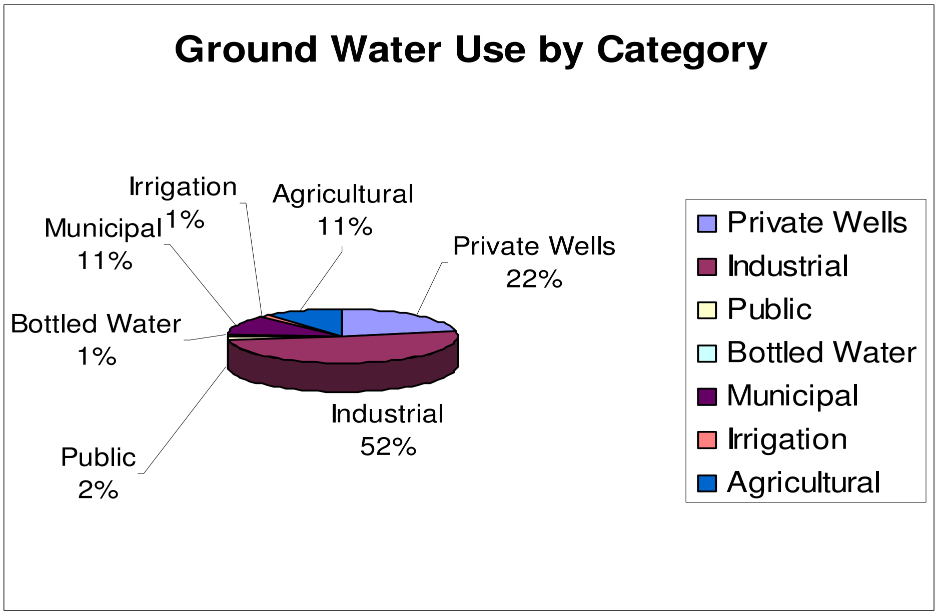
The estimated groundwater use for each of the categories was determined as listed in Table 8, at 16.4 million cubic metres per year. On a watershed basis this is the equivalent of 3 millimetres (rounded to the nearest millimetre) depth of water equally distributed over the region. The top 3 water uses, as illustrated by Figure 17, were first - Industrial (quarry dewatering), second - private wells, with agriculture and municipal needs both having the third highest demand. Please note that the industrial water use considered the maximum permitted use which is likely considerably higher than actual.

Table 8: Ground & Surface Water Demand (m^3/year)

Category	Surface Water *	% of Total	Groundwater	% of Total
Private Wells	0.00E+00		3.63E+06	22
Municipal	4.32E+06	33	1.81E+06	11
Irrigation	1.45E+06	11	2.41E+05	1
Industrial	7.50E+06	56	8.30E+06	51
Bottled Water	0.00E+00		1.75E+05	1
Agricultural	0.00E+00		1.86E+06	11
Public	0.00E+00		3.41E+05	2
Total	**1.33E+07**	**100**	**1.64E+07**	**100**

* The surface water demand does not include usage from the Bay of Quinte & Lake Ontario.

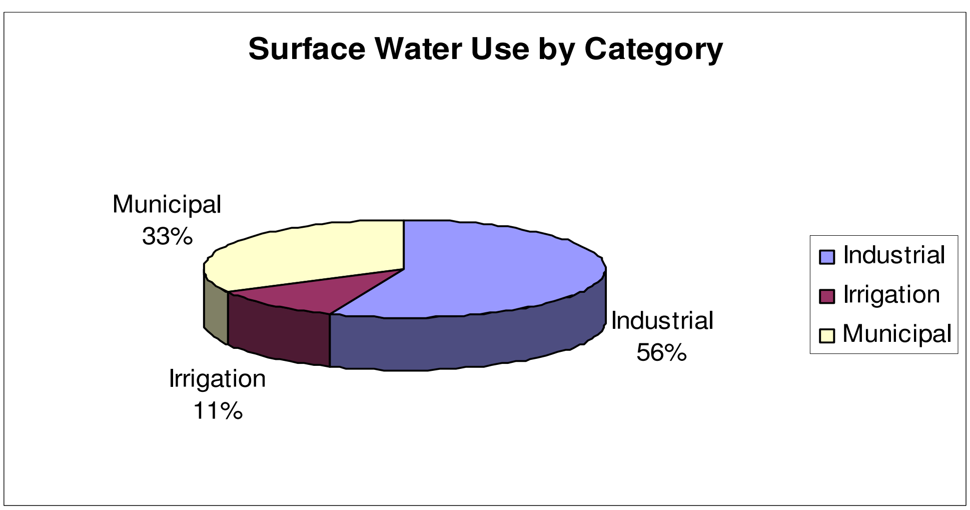
Figure 17: Groundwater Use



2.6.3 Surface Water Demand

The estimated surface water use for each of the categories was determined as listed in Table 7 at a total of 13.3 million cubic metres per year. On a watershed wide basis this is the equivalent of 2 millimetres of water depth equally distributed over the region. The 3 highest water uses, as illustrated in Figure 18, were first; Industrial (quarry dewatering), second - municipal, and third - irrigation. Similar to the groundwater the maximum permitted values were used with actual use expected to be lower.

Figure 18: Surface Water Use (not including Great Lakes)



3. Methodology & GIS Model

To assist in determining a water budget the watershed region a GIS model has been developed. The methodology for this process is provided below which generally involved three major components.

1.) Determination of the natural water budget across the study area,
2.) Partitioning of the surplus water between groundwater recharge (infiltration) and direct runoff (surface runoff) &,
3.) Evaluation of the water usage across the watershed to provide an indication of potential stress conditions.

This exercise was completed by imposing a 1 square kilometre gridded surface over the watershed boundaries in GIS and evaluation of the water budget for each grid based on climate, physical conditions and water use. This exercise was completed for an annual time period.

3.1 Determining the Natural Water Budget

Determination of the natural water budget involved consideration of four main parameters: precipitation (P), evapotranspiration (ET), Recharge (R) and direct run off. The latter two components are collectively known as *runoff* and combined a measurement can be provided from stream gauges. Precipitation is also a parameter that can be directly measured. Evapotranspiration is more difficult to physically measure, but may be calculated through empirical formulas such as the Thornthwaite formula or it may be derived as the unknown in a water balance equation using precipitation and runoff as physically measured in a given watershed.

The methodology presented below explains the data that was used in the assessment, how it was obtained and processed to cover the entire study area. The main data sets and sources used in this exercise are as listed in Table 9.

Table 9: Data Sources

Data set	Source	Use in this study
Climate Data	Canadian Forest Service , Environment Canada	Precipitation & Temperature
Soil Moisture Holding Capacity	Agricultural Canada & MOE	Calculation of Actual ET
Quaternary Geology	OGS	Runoff / Recharge Estimates & ET
Digital Elevation Model	MNR	Runoff / Recharge (slope calculations)
Land Cover	MNR	Runoff / Recharge
Stream Flow Data	Water Survey of Canada	Runoff & Derived ET
Permit to Take Water Database	MOE	Water Use
Ontario Water Well Records	MOE	Water Use
Agricultural Water Use	MNR (Rob de Loe)	Water Use
Canada Census'01	Canada Census	Water Use

3.2 Determining Climate

Climate conditions (precipitation and temperature) for the study area were determined through review of spatial climate models of Canada and North America for the period 1971 to 2000 as discussed earlier in section 2.1 of this report. The data was provided to QC in GIS format over a gridded surface of approximately 1 square kilometre. The QC watershed boundaries were then used to clip the area for which data was required. Longer term data, 1931 to 2000, was also reviewed to provide comparison over a greater period.

3.3 Determining Evapotranspiration

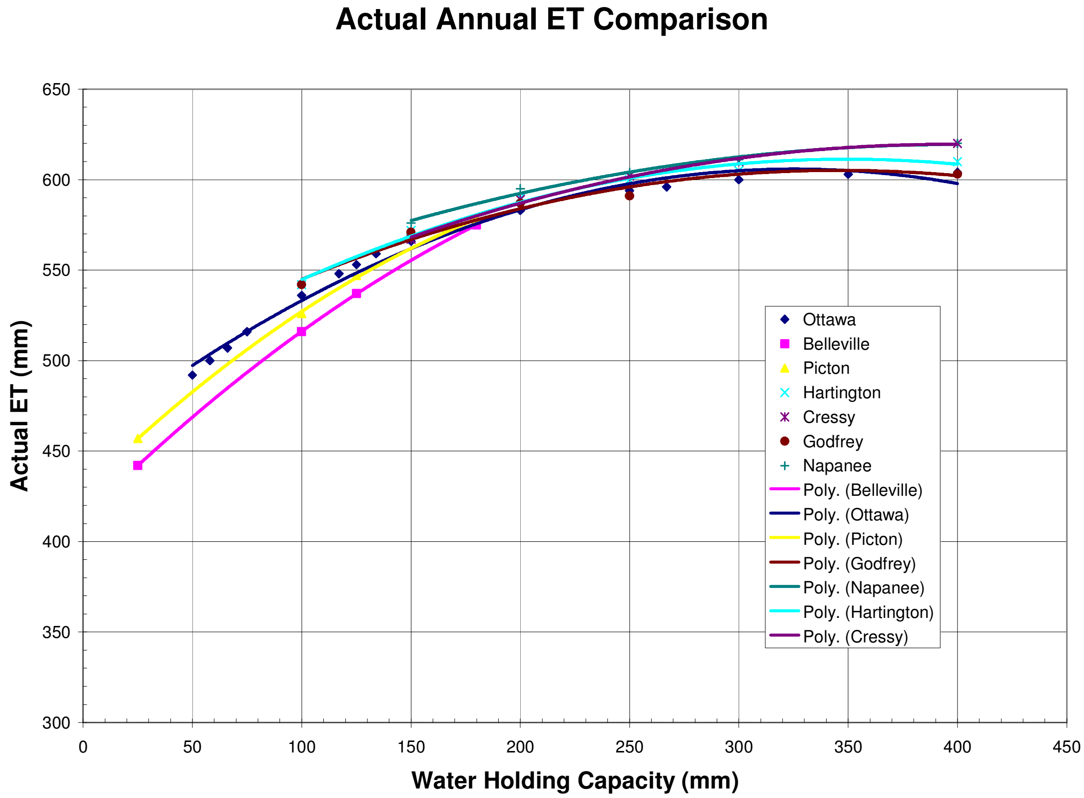
Evapotranspiration was calculated for each pixel in the gridded surface using the Thornthwaite Formula (1955). This method allows calculation of the potential evapotranspiration (PET) on a monthly basis utilizing mean monthly temperature data. A correction factor was also applied to compensate for the length of day light hours at the local latitude.

Following determination of the PET the actual evapotranspiration (AET) was calculated by finding the difference between the PET and the water available for evapotranspiration. This is the water that is received by the area for the same period in the form of precipitation and the water that is stored in the soil available for transpiration by plants. Available water holding capacities for the various soils throughout the study area were assigned in reference to Agriculture Canada (CANSIS-National Soil Database). In view of significant areas of shallow soil conditions over bedrock a value for such soils was also derived from An Assessment of the Groundwater Resources of Northern Ontario (Singer, 2002). The water holding capacities for the soil types encountered in the Quinte region are as follows:

- Shallow Soil over Rock 25 mm
- Sand, Sandy Loam 100 mm
- Clay loam 200 mm
- Clay 250 mm

Each of these values were assigned to the various soil types using surficial geology mapping in GIS. In addition to the above referenced values a review of soil water holding capacities was compared to AET as illustrated in Figure 19. This plot was developed based on various water holding capacities and AET as calculated by Environment Canada using the Thornthwaite method and specific climate station data. This relationship illustrated that AET tends to level out as the water holding capacity increases (i.e. enough water available to meet the PET with higher water holding capacities)

Figure 19: AET vs Water Holding Capacity



* Data as provided by Environment Canada (Meteorological Services) for climate stations at the locations listed in the legend (2006).

3.4 Partitioning of Surplus Water

Following the determination of the natural water budget the precipitation that is in excess of the evapotranspiration and soil moisture requirements is considered as available or surplus water. This water is considered, in simple terms, to be available for either groundwater recharge or direct runoff, collectively referred to as Runoff.

Partitioning of the surplus water between direct runoff and groundwater recharge was completed through application of MOE methodology (MOE Hydrogeological Technical Information Requirements for Land Development Applications April, 1995). This methodology was developed for determining groundwater recharge to predict impact at developments serviced by onsite sewage systems. For this phase of the conceptual water budget on a regional scale the methodology was determined to be acceptable.

Ground slope, land cover, and soil permeability have the greatest influence on the partitioning of surplus water to recharge or direct runoff. To estimate the spatial distribution of recharge and direct runoff, GIS coverage for the gridded surface was generated through application of the MOE methodology. This required determination of a partitioning factor based on 3 parameters: slope, soil permeability, and land cover. Each parameter was divided into subclasses based on their potential influence on groundwater recharge and factors as provided in the MOE methodology (1995). Following this methodology, a total partitioning coefficient is constructed by summing each factor for the three component parameters. This factor is then applied to the surplus water for determination of the percentage going to groundwater recharge and the balance to direct runoff. An outline of the methodology used for evaluation of the three main components (slope, land cover & soil permeability) is as follows.

3.4.1 Determining Slope Factor

A 10 m digital elevation model (DEM) was used for determination of the slope across the entire study area using GIS. The resulting surface was then divided into 3 slope categories: Flat Land, Rolling Land, and Hilly Land with slope ranges assigned as follows:

Category	Slope Range
• Flat Land:	0 - 1.5%
• Rolling Land:	1.5 - 3%
• Hilly Land:	> 3%

Each category was assigned a factor based on the MOE methodology (1995). However, given variability of the range of slope in the QC watershed compared with the ranges provided in the MOE Manual (1995), the coefficients were interpolated to cover the slope classes of the study area. For each slope category, the coefficient at the midpoint of the slope range was taken as representative of the entire category. In the case of hilly land, the midpoint was chosen between the slope values of 3 and 9%. The corresponding factor was then taken off the curve as illustrated by Figure 20 which shows graphically the relationship between slope and the factor.

Accordingly, the interpolated factors used in this study are listed below and were assigned their respective pixel areas in the GIS model.

Category	Recharge Factor
• Flat Land:	0.175
• Rolling Land:	0.125
• Hilly Land:	0.075

Figure 20: Slope Class Determination

3.4.2 Determining Soil Permeability Factor

The second component of the partitioning factor is soil type and permeability. The MOE methodology lists three classes of soil based on their permeability with respective factors as follows:

Soil Type	Recharge Factor
• Tight impervious clay:	0.1 (low)
• Medium combinations of clay and loam:	0.2 (medium)
• Open Sandy loam:	0.4 (high)

Based on the surficial geologic mapping of the study area, soil permeability factors were assigned to the individual soil types by simplifying the permeability values into high, medium and low.

3.4.3 Determining Land Cover Factor

Land cover is the third category for which a partitioning factor is assigned. Based on the MOE guidelines, 2 types of land use were adopted:

Land Cover	Recharge Factor
• Cultivated land	0.1 (low)
• Woodland:	0.2 (high)

Land cover mapping from the MNR was used to delineate areas for assigning the appropriate coefficients to areas of low and high cover.

3.4.4 Determining Recharge

Considering the three variables: slope, soil permeability, and land cover, one may apply 18 potential combinations (3 x 3 x 2) across the study area in the GIS model to establish 18 recharge classes. By summing the factors from each of the three components (slope, soil type, & land cover) an overall recharge factor was assigned to each pixel. The resulting layer is used to multiply the layer of "surplus water" calculated in Section 3.3 (Precipitation – Actual Evapotranspiration) to determine the volume of water that infiltrates into the ground as groundwater recharge. A thematic map was prepared showing the average annual recharge potential in the area based on combinations between the 18 subcategories of the three components. Such mapping could be used to assist in identifying areas of high groundwater recharge potential (MOE Water Budget Guidance Module # 2, April 2006).

Following this method the maximum and minimum coefficients were determined as 0.775 and 0.275 respectively. In respect of the long term annual runoff in the Moira River watershed at 366 mm (1931-2000) the maximum groundwater recharge could be calculated by this methodology as 283 mm/yr and the minimum at 100 mm/yr. Such rates are compared with a coarse sand and gravel at the high end and a clay or clayey silt on the low side (MOE, 1995).

Maps showing the spatial distribution of land slope, soil permeability and land cover were also prepared to provide the reader with a visual context of the selected watershed characteristics. The four maps have been included within Section 4 in the presentation of the results of the work.

3.4.5 Determining Direct Runoff

The amount of direct runoff was determined as the amount of surplus water remaining after groundwater recharge was partitioned out. The following mathematical operations were performed on the total recharge coefficient layer and the layer of surplus water:

Direct Runoff layer = (1 – total recharge coefficients layer) x layer of available water

As a quality assurance and control check, the different layers should satisfy the following equation:

Precipitation = Evapotranspiration + Recharge + Direct Runoff

3.5 Evaluating Potential Water Stress

A preliminary evaluation of water stress was completed for the study area based on the current water budget guidance documents (MOE Guidance Documents, 2006). In this section the methodology for evaluating water stress will be discussed with respect to both ground and surface water supplies.

3.5.1 Groundwater Use & Pumping from Water Wells

Prior to an evaluation of stress on groundwater supplies, a determination of groundwater use for each pixel in the GIS model was completed. Points of use were assigned to pixels based on the locations of wells derived from the Ontario Water Well Record database. Locations for each registered well are provided in UTM coordinates and were projected in NAD 83 for Zone 18. Water well records fall under two main categories: domestic and agricultural (livestock watering). Other categories include: not used, commercial, industrial, municipal and public supply. All of wells were imported into GIS according to the UTM coordinates.

The MOE permit to take water data was referenced in the assignment of usage for public, municipal, industrial, irrigation, and municipal categories to the relevant pixel according to the recorded location of use. Maximum permitted volumes were applied. However, private residential and small commercial annual consumption figures are not provided in either the well record or permit to take water databases. For an estimate of these uses the Canada Census data was considered.

For domestic and commercial wells, a correlation of the number of wells versus Canada Census 2001 population data for the various member municipalities was developed. Using this correlation, the population density was converted to 3 persons per well across the study area. Usage was assumed at 175 l/person or 525 l/well/day. The only municipality for which this factor did not apply was Prince Edward County. The difference was attributed to a high number of shore wells for residents living along the shorelines. To provide an estimate of use in Prince Edward County the same factor of three persons per well was also applied to represent use for registered wells .Use of surface water from shore wells along the Bay of Quinte and Lake Ontario shoreline was ignored.

Discharge from agricultural wells was estimated based on the Ministry of Natural Resources agricultural water use study by Rob de Loe. This study provided agricultural water use by subwatershed in reference to Canada Agricultural Census data. To assign usage to a pixel in the GIS model, the overall use was divided equally by the number of livestock wells, as reported in the well record category, within the respective subwatershed.

3.5.2 Surface Water Extractions

Surface water extractions were determined based on the Permit to Take Water data. Again, maximum annual permitted volumes were considered in the calculations. The permitted takings were assigned to the relevant pixels, however permits for non-consumptive takings from the Great Lakes (Lake Ontario and the Bay of Quinte), wildlife conservation projects (i.e. Ducks Unlimited) and Quinte Conservation dams were excluded.

3.5.3 Evaluating Stress

The stress on the groundwater supply was evaluated for each 1 square kilometre grid of the GIS model by calculating the percentage of groundwater use out of the total annual recharge. The percentage of annual use is compared to the prescribed criteria provided in the Provincial Water Budget Guidelines, 2006. Stress on surface water supplies will require assessment of the taking relative to mean annual flows in the water course. Results are discussed in the following sections of the report.

4. Water Budget Components

The movement and recycling of water between the atmosphere, land surface and underground is called the hydrologic cycle. Understanding the hydrologic cycle, and in turn the flux of water moving into and out of a study area, is critical in properly managing water resources. The hydrologic cycle consists of four main components; precipitation, evapotranspiration, surface water flow, and groundwater flow. Water on the ground surface, in streams or in lakes can return to the atmosphere as vapour through evaporation or by transpiration via vegetation. Collectively known as evapotranspiration, both evaporation and transpiration occur in greatest amounts during periods of high temperature, high wind, low humidity, and bright sunshine.

As rainfall infiltrates the ground, gravity pulls the water down until it reaches the water table. This groundwater then moves very slowly through pore spaces and fractures in a down gradient direction towards surface water features such as rivers, streams, and lakes. Precipitation is also returned to surface water rapidly as direct runoff or rapid runoff and can be seen as the early peak in the hydrograph.

Overall, the components of the hydrologic cycle can be expressed in the form of a water budget equation:

$$\text{Inputs} - \text{Outputs} = \text{Change in Storage} \qquad (1)$$

From this equation, equation 2 below is developed.

$$P + SW_{in} + GW_{in} + ANTH_{in} - ET - SW_{out} - GW_{out} - ANTH_{out} = \text{Change in Storage} \quad (2)$$

Where;

P	= Precipitation
SW_{in}	= Surface water flow in
GW_{in}	= Groundwater flow in
$ANTH_{in}$	= Human inputs such as waste discharges
ET	= Evaporation and transpiration
SW_{out}	= Surface water flow out
GW_{out}	= Groundwater flow out
$ANTH_{out}$	= Human removals or abstractions

This representation incorporates precipitation, evapotranspiration, runoff, and groundwater flows. An additional important consideration is the interaction between surface water and groundwater within the watershed. For the purposes of this present study and to assist with a conceptual understanding of the water budget components the time period under consideration is an average year. Thus, the change in storage is nil and with the representation presented by Equation 2, this interaction is cancelled out and is not considered explicitly. For this study, the partitioning of precipitation after satisfying evapotranspiration, to direct runnoff and groundwater recharge is represented in the following manner:

$$P = \text{Evapotranspiration} + \text{Surplus Water (Direct Runoff + Recharge)} \quad (3)$$

The flow components presented in Equations 2 and 3 are described and quantified in the following report sections.

An attempt was made to incorporate the greatest periods of record for the gauged data including precipitation, temperature and stream flow. At the time of preparation of this report the climate data that was processed by Natural Resources Canada – Canadian Forestry Service considered data from 1971 to 2000. This data was relied upon in the water budget calculations. However, climate may vary from year to year and over periods of time. Thus, common periods of record were selected for study. Only one station (Moira River at Foxboro) has a consistent stream flow record that spans the period from 1931 to 2000. While the Napanee and Camden East stations combined have a period of record dating back to 1915 there is a large gap in the record at the Napanee station from 1926 to 1946.

4.1 Precipitation

Precipitation received by the watershed region was previously discussed in reference to modeling of the Canadian Forestry Service for the period of 1971-2000. The annual average precipitation for the entire QC Region is 919 mm. For comparison the depths of average annual precipitation calculated by Environment Canada at local climate stations is presented below in Table 10. The values in this table are based on the entire periods of record for each station.

Table 10: Precipitation Data for Eastern Ontario

Station Name	Period of Record	Annual Precip (mm)
Peterborough	1968-2004	958
Cressy	1967-2001	948
Picton	1965-2004	926
Hartington	1968-2004	958
Belleville	1932-2004	865
Napanee	1991-2001	889
Godfrey	1985-2000	951
Ottawa	1940-2004	895
	Average =	**924**

4.2 Runoff

Runoff is determined using stream gauge data for four QC subwatersheds, as listed in Table 11. For consistency the gauge catchment areas found using the DEM in the GIS Model were used to determine both the total depth of precipitation as well as the depth of runoff. Runoff depth is calculated by converting the mean annual flow to m^3/yr then dividing by the catchment area in km^2 and then dividing by 1000 (conversion to mm). The mean annual flow is calculated directly from the stream gauging station data. Table 11 shows a summary of the results of these calculations for the stated subwatersheds.

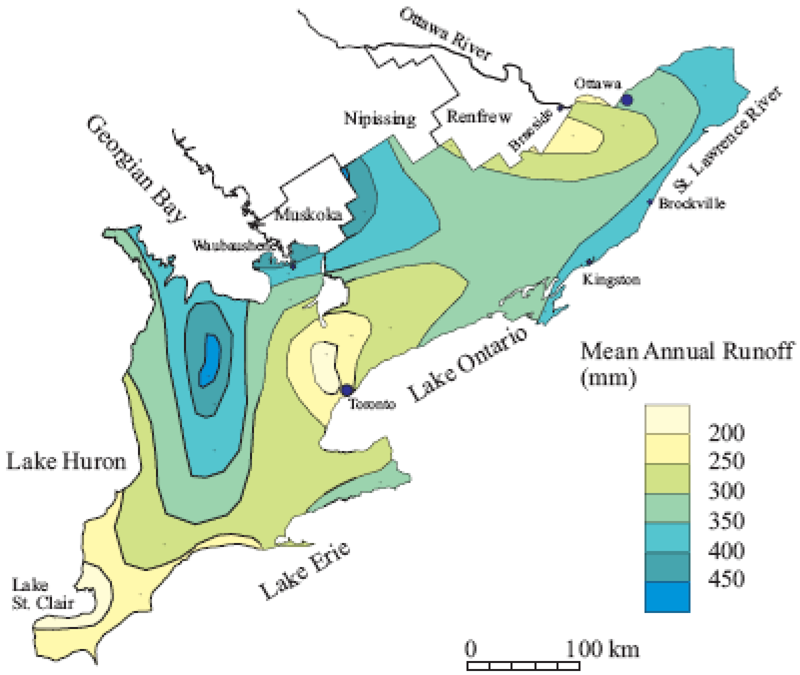
Table 11: Stream Gauge Station Summary

Station Name	Drainage Area (km^2)	WSC ID	Period of Record *	Mean Annual Flow (cms)	Runoff as mm/yr
MOIRA RIVER NEAR FOXBORO	2595	02HL001	1915 - 2005	32.3	**393**
SALMON RIVER NEAR SHANNONVILLE	909	02HM003	1958 - 2004	11.3	**392**
NAPANEE RIVER AT CAMDEN EAST	697	02HM007	1974 - 2004	8.75	**396**
CONSECON CREEK AT ALLISONVILLE	117	02HE002	1970 - 2004	1.48	**399**

* Runoff was calculated using only the period from 1971 – 2000.

The runoff at each of the gauging stations is between 392 mm to 399 mm annually. Essentially, for the region the annual runoff may be stated to be 395 mm. To compare the results of the calculations, reference was made to Figure 21 below excerpted from Singer 1997. The 1971 – 2000 runoff averages are higher than those reported in Singer where the 300 mm to 350 mm band predominates in the Quinte region.

Figure 21: Published Mean Annual Runoff Map



Investigation of the 1931 to 2000 data for runoff at the Foxboro station yielded a mean annual runoff of 370 mm and average rainfall of 860 mm. Both these values are below the precipitation and runoff recorded for the 1971 to 2000 period. It is important to note that the 1971 to 2000 period is included within the older data and the variation is thus more pronounced. Longer term data for the region indicates the latter period was wetter. This can be seen in the following table.

Table 12: Comparison of Flow and Precipitation to Period of Record

Subwatershed	Period of Record	Entire Record (mm)	1931 – 2000 (mm)		1971 – 2000 (mm)	
	(stream flow)		P	R	P	R
Moira	1915 – 2005	370	860	366	905	393
Salmon	1958 – 2004	371	874	NA	929	392
Napanee	1915 – 2004*	381	887	NA	934	396
Consecon	1970 – 2004	399	868	NA	925	399

4.3 Evapotranspiration (Calculated & Derived)

The average PET for the QC Region was calculated in the GIS model by the Thornthwaite method at 585 mm. The average AET was calculated to be slightly lower at 550 mm and in agreement with previous mapping of the area (MOE, 1974, Natural Resources Canada, 2006, Singer et al, 1997). The range in AET values was determined to be 455 mm in the north increasing to 617 mm in the south and the spatial distribution is illustrated by Figure 22. For ease of viewing, AET is reported in four classes on this map.

Figure 22: Annual Actual Evapotranspiration

To confirm the accuracy of the actual evapotranspiration determined using the GIS model, AET may be derived by rearranging equation 3 and subtracting runoff from precipitation. The equation is thus rewritten as:

$$\text{Derived ET} = \text{Precipitation} - \text{Runoff} \qquad (4)$$

The derived ET values may now be calculated by simple subtraction of the annual depths of runoff and precipitation. This has been completed for the four catchments represented by each of the gauging stations listed above and the values are captured in Table 13.

Table 13: Water Budget Summary for period 1971 – 2000

Station	Precip mm/yr	Runoff mm/yr	Derived AET (P –R) mm/yr	Calculated AET (From GIS)* mm/yr	Difference mm/yr
Moira	905	393	**512**	**517**	5
Salmon	929	392	**537**	**551**	14
Napanee	934	396	**538**	**561**	23
Consecon	925	399	**526**	**604**	78

* The GIS model uses the Thornthwaite method of determining AET using soil moisture content

The result of this analysis shows good agreement between the AET calculated by the GIS model and those derived from the gauged data using equation 4. Therefore, the GIS methodology to determine surplus water is considered to produce reasonably good results.

The water budget for the entire Quinte region for the 1971 – 2000 period would then be

Precipitation	– Evapotranspiration	= Runoff (Surplus)
919 mm	– 550 mm	= 369 mm (use 370 mm)

For comparison, the longer term evapotranspiration calculations for Moira subwatershed were completed for the period of 1931 to 2000 as follows:

Station	Precip mm/yr	Runoff mm/yr	Derived AET (P –R) mm/yr	Calculated AET (From GIS) mm/yr	Difference mm/yr
Moira	860	366	**494**	**508**	14

4.4 Partitioning of Runoff (Surplus)

The surplus water calculated in the GIS model was partitioned between direct runoff and groundwater recharge using the MOE methodology outlined in section 3. The results of the exercise are discussed in the following sections.

4.4.1 Land Slope Classification

The areas of the watershed within the three land slope categories were determined as listed below with spatial distribution of these classes as illustrated by Figure 23.

Category	% of Watershed Area
• Flat – 0 -1.5 %	39.1
• Rolling land – 1.5 – 3%	24.4
• Hilly land > 3%	36.6

4.4.2 Soil Permeability Classification

The areas of the watershed within the three soil permeability classes were listed as follows with spatial distribution of these classes as illustrated by Figure 24.

Category	% of Watershed Area
• Low permeability -	36.9
• Medium permeability -	53.9
• High permeability -	9.2

4.4.3 Land Cover Classification

The land cover was divided into two categories with individual watershed areas as listed below with mapping of the spatial distribution provided by Figure 25.

Category	% of Watershed Area
• Low	50.2
• High	49.8

4.4.4 Combined Recharge (Partitioning) Coefficient

The sum of the individual recharge factors was calculated for each of the 18 different combinations and divided into three ranges as listed below. These factors were grouped into the three categories of high, medium, low based on a simple division of the total coefficient into three equal ranges. The spatial distribution of these three ranges is illustrated by Figure 26. This mapping is useful in identifying areas of potential groundwater recharge. In accordance with MOE guidance document # 2 (MOE, 2006) areas with a factor of greater than 55% recharge are considered to be significant recharge zones.

Recharge Factor Range	% of Watershed Area
• 0.275 – 0.445 (low)	45.3
• 0.445 – 0.600 (medium)	48.2
• 0.600 – 0.775 (high)	6.5

Figure 23: Land Slope Classes

Figure 24: Soil Permeability Classes

Figure 25: Land Cover Classes

Figure 26: Groundwater Recharge Coefficient

4.4.5 Recharge & Direct Runoff

The volumes of recharge and direct runoff were determined by subtracting the AET from the precipitation to determine surplus water. The result (surplus water) is multiplied by the total groundwater recharge coefficient to determine ground water recharge with the difference between ground water recharge and the surplus water going to direct runoff. The average volume of groundwater recharge across the QC watershed was calculated at 168 mm. The direct runoff is the balance of surplus at 202 mm. The spatial distribution of the depths of average annual recharge and direct runoff is illustrated by Figure 27 and 28 respectively.

A summary of groundwater recharge depths for four catchments areas in the QC watershed is provided in Table 14 together with estimated base flows for these watersheds. These base flows were determined through application of a base flow index to the runoff measurements for each watershed. This base flow index was taken from the Unites States Geological Survey (USGS) as reported in their paper Base Flow in the Great lakes Basin – Scientific Investigations Report 2005-5217. This study provided a base flow index for various watersheds that allows estimation of the groundwater component of stream flow. This index was developed based on the geology of the given watershed in recognition of the fact that groundwater recharge is largely regulated by the capacity of the groundwater system to receive and transmit water.

A comparison of the calculated recharge rates with estimated base flow for the different watersheds indicates generally good correlation with the variation ranging from a minimum of 5% (8 mm) for the Moira watershed to a maximum of 20% (29 mm) for the Consecon watershed. This larger range for the Consecon watershed may be associated with potential uncertainty in the soil water holding capacity assigned to this watershed. This is to be evaluated in more detail in future water budget development work.

Table 14: Groundwater Recharge and Base Flow Summary

Station	Gauged Runoff mm/yr	USGS Groundwater Index BFLOW	USGS Groundwater Base flow mm/yr	Calculated Groundwater Recharge * mm/yr	Difference mm/yr
Moira	393	0.42	165	173	8
Salmon	392	0.40	156	175	19
Napanee	396	0.40	158	176	18
Consecon	399	0.44	176	147	-29

* Determined using the GIS model

Figure 27: Spatial Distribution of Average Annual Recharge

Figure 28: Spatial Distribution of Average Annual Direct Runoff

4.5 Water Use/Stress

The spatial distribution of groundwater use for the watershed was determined by applying water use numbers to each 1 square kilometre grid. This resulted in the production of Figure 29 a map of ground water usage. Water use on this map has been converted to a depth in mm averaged over each 1 square kilometre cell. This mapping indicates that there are isolated areas of high groundwater usage but for the majority the use of ground water over the watershed is low at depths of less than 1 mm. The distribution of the water use also reflects the population distribution within the watershed with areas of higher water use at the south.

The above generalization regarding ground water use may also be inferred from the Quinte Regional Groundwater Study (Dillon, 2004), which indicates that there is no indication of regional depletion of the aquifers as a result of over pumping. Localized areas of aquifer mining or interference caused by over withdrawal likely occur; however, these situations do not reflect widespread problems.

The total groundwater use over an annual period across the entire watershed region has been calculated at a depth of 3 mm on an annual basis. This represents less than 1% of the surplus (370 mm) or available water in the entire region. In consideration of groundwater recharge only, this percentage increases to just less than 2% (168 mm of recharge). For surface water the total annual use is 2 mm or also less than 1 % of surplus water.

Figure 29: Spatial Distribution of Annual Groundwater Usage

5. Discussion

The results of this investigation reveal that on an average annual basis of the 919 mm of precipitation received by the Quinte Region, 550 mm is lost to evapotranspiration. This leaves roughly 370 mm of surplus water available for division between ground water recharge and direct surface runoff. These two components were calculated in the GIS model at 168 mm of the 370 mm or 45% to groundwater recharge and the balance (202 mm) to direct runoff.

The calculated groundwater recharge would represent the available groundwater supply averaged over the watershed. Based on an inspection of Figure 26 (the spatial distribution of recharge coefficient), it is noted that higher recharge coefficients have been determined for the southern regions of the study area, while the northern areas have lower recharge coefficients. This observation is pronounced more notably in the northwest due to the predominance of low permeability of the Precambrian bedrock.

However, actual recharge, as seen in Figure 27, is lower in some areas in the south and higher by comparison in the northeast. While this appears contradictory, by inspection of Figure 5 and Figure 22 for mean annual precipitation and actual evapotranspiration, one sees that the total annual recharge is considerably impacted by the available surplus water. Therefore, while there is a higher potential for infiltration in Prince Edward County, there is less available surplus water due to the high AET and consequently lower annual recharge is indicated.

To confirm the accuracy of the separation between groundwater and direct runoff a review of various baseflow separation techniques was completed. The USGS, 2005 completed baseflow separations for historical gauged data including water courses within the study area. The various techniques provide estimates of 40% to 67% of flow measured at the gauge is from groundwater discharge for Moira, Salmon and Napanee rivers. Prince Edward estimates were for 44% to 71% of the streamflow comprised of groundwater discharge. Of all the techniques the BFLOW separation method appears to give results in line with those of this investigation indicating 40% to 44% of base flow as being contributed to by ground water.

The region has a maximum water usage of 5 mm of an available surplus of 370 mm (as determined by the GIS model). This represents approximately 1.4% of the surplus water. Little regional stress is suspected based on annual climate normals and maximum water use estimations.

5.1 The GIS Model

The GIS model provided surplus values that were in close approximation to the runoff measured at the large gauged watersheds in the region. Groundwater recharge calculated in the model also compares well with published estimates of groundwater base flow.

The simple GIS approach to the separation of the surplus water into groundwater recharge and direct runoff is considered to provide a reasonable basis upon which to estimate the present levels of stress on the resource. At this level of investigation, looking at water use over the entire watershed and recognizing little stress is indicated, further precision is not warranted.

5.2 Discussion of Uncertainty of the Results

With reference to Table 13, one sees very good agreement between the calculated AET and the derived AET for the Moira, Salmon and Napanee Watersheds. An exception is the Prince Edward station in Consecon that has a variation of 78 mm where the calculated AET is approximately 15% higher than the derived value. This is still considered good agreement and is within the level of uncertainty of the data.

Yet, in each subwatershed there is some measure of disagreement between the calculated and derived values for AET. 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. In the case of the precipitation data, the potential error was discussed by McKenney, 2005 and is conservatively estimated at 10%. Streamflow measurements are considered reliable to within 5%. The uncertainty also considers the standard error of the data. The total potential uncertainty within the water budget calculations is determined by taking the square root of the sum of the squares of the uncertainty for each value. This is summarized in the table below and presented in further detail in Appendix D.

Table 15: Quantification of Uncertainty

Watershed	Parameter	Depth (mm)	% Uncertainty	Uncertainty (mm)	Total Uncertainty
Moira	Precipitation	905	10.3	93.6	97 mm
	Runoff	393	6.0[1]	23.5	
Napanee	Precipitation	934	10.2	95.5	99 mm
	Runoff	396	6.1[1]	24.1	
Salmon	Precipitation	929	10.2	94.8	98 mm
	Runoff	392	6.1[1]	23.9	
Consecon	Precipitation	925	10.3	95.3	99 mm
	Runoff	399	6.3[1]	25.1	

[1]This value applies to long-term hydrometric stations subject to the following qualifications: 1) unbiased rating curve, that is zero systematic gauge error, and 2) minimal error in drainage area.

In all subwatersheds the difference in the calculated values for evapotranspiration is less than the maximum expected uncertainty. While an explanation for the comparatively larger difference at Consecon may not be required, some thought has been given to the potential for a gap in understanding of the Consecon Creek subwatershed. There is a predominance of Muck soil type in the vast marshy drainage area to which a water holding capacity of 250 mm has been applied. These muck areas have AET values very close to potential and as a result the entire subwatershed has noticeably higher actual evapotranspiration (see appendix A for more detail on AET and PET calculations). If a true value of water holding capacity for the muck soils is lower, less disagreement is observed. Since these soils are known to dry out in the summer months as evidenced by the prevalence of pathways cut through the marsh by both human activity and wildlife, this explanation may be valid. Also, by inspection of Figure 8 one notes the general trend in bedrock formations dipping to the south. It is possible that some regional movement of groundwater may be discharging in the Consecon subwatershed. Some further work would be required to provide a more substantiated explanation.

6. Data Gaps

6.1 Climate

Naturally, our understanding of the hydrologic cycle and how water is transferred from state to state or reservoir to reservoir is limited only by the ability of researchers to measure its presence or movement. In some cases actual measurements are possible as in the case of climate data and runoff, while other movements are less directly measurable such as groundwater flow and evapotranspiration. This section explores extents of available information upon which this conceptual water budget is based and suggests where 'gaps' in our understanding exist.

Precipitation and temperature information presented in this report was processed using a data set from 1971 to 2000. While the conceptual report is lacking in a complete record of climatic data for the conceptual report, older data is now available that spans back to 1930 and will be incorporated into further water budget work.

Evaporation and transpiration measurements are not readily available across the study area. Some evaporation pan data exists for Hartington and Morven (1968 to 1975) and some measurements of lake evaporation in the Moira watershed over the summer of 1970. While the GIS model is capable of calculating evapotranspiration as a surrogate for actual measurements using the Thornthwaite formula and the available climatic data, the calculated results may be improved with some field verification. There would also be some benefit in reviewing the pan evaporation data with the calculated evapotranspiration values.

6.2 Stream Flow

Flow data for the Moira, Salmon, and Napanee watersheds provides a good understanding of the hydrologic response of the respective watersheds to inputs. The data sets are relatively long (some over 90 years) and have few gaps in their record.

The Prince Edward Region, on the other hand, has only one current flow monitoring station on Consecon Creek, which has a period of record spanning 35 years. Two discontinued stations on each of Demorestville Creek and Bloomfield Creek provide some further data. These stations have seven and 22 years of record respectively. There is a knowledge gap in this area and some additional flow monitoring would be helpful. It is important to note that a new stream flow monitoring station was recently installed on the Black River in Prince Edward County which will enhance our understanding of this area in years to come.

Further, since Prince Edward County has several small discrete watersheds, most of which are ungauged, our knowledge of runoff is based largely on flow data from the Consecon Creek station. The lack of flow information on the remaining watersheds may be a significant gap that affects our understanding of the natural water cycle.

6.3 Groundwater

Available data for the characterisation of groundwater is limited. Information about groundwater in the Quinte region is largely interpreted from Ontario Water Well Records. However, some parts of the watershed do not have sufficient density of coverage to allow a high degree of confidence. In addition, the quality of the dataset is variable with many of the records of inadequate accuracy and not useful for characterization of groundwater movement.

Other readily available information includes groundwater level data for a network of monitoring wells throughout the watershed. These wells are part of the Provincial Groundwater Monitoring Network there is a short period of record in the groundwater monitoring wells from 2002 to present. Older data is also available for some wells in the Moira watershed, collected by the province in the late 1960's to early 1980's. With a longer period of record this network of monitoring wells can provide some excellent point information to help calibrate the GIS model.

6.4 Water Use

Water use is also a significant data gap in the present work. Estimates of usage were prepared based on census data and the permit to take water database. Actual usage is not known and what water is returned to the watershed and in what form is also not known.

7. Next Steps

The conceptual water budget work outlined in this report has provided an understanding of water movement within the Quinte Region. This understanding has provided the baseline for future water budget activities which will entail more detailed analysis of the quantities of water flowing within the watersheds. To proceed with this work the Province has provided a series of 4 screening questions which will be discussed below. In addition to this guidance we have identified some areas that will require attention in the future work as follows.

- Investigate the hydrologic water balance in Prince Edward County in more detail in an attempt to verify the conditions in this region and in particular the Consecon Watershed.

- Proceed with refining the GIS model to reflect the water budget across the Quinte region on a monthly time scale,

- Evaluate the effect of monthly water usage on the water budget using the GIS model. This will include limits for defining potential stress,

- Review and incorporate groundwater hydrographs into the water budget in an attempt to quantify groundwater recharge with actual water table levels,

- Use the model to predict changes in the water balance based on change in hydrologic conditions or increased water demand.

7.1 Screening Decisions

The initial water budget activities did not reveal significant water stress on an annual or regional watershed basis. However potential for localised stress conditions does exist. Future work will require focused attention on subwatersheds containing municipal ground and/or surface water intakes. The watersheds including these municipal intakes are listed as follows:

Watershed	Intake Type & Location
Moira	Village of Madoc Municipal Groundwater Wells (2)
Moira	Village of Tweed Municipal Groundwater Wells (2)
Moira	Village of Deloro Municipal Groundwater Well (1)
Napanee	Town of Napanee – Surface Water Intake (Napanee River)

Prince Edward	Peats Point – Municipal Groundwater Well (1)
Prince Edward	Village Ameliasburgh – Surface Water Intake (Roblin Lake)

The balance of the drinking water systems obtain supply from Lake Ontario and the Bay of Quinte and will not be considered in future water budget work.

Given low regional watershed stress conditions, a GIS spreadsheet model is proposed to enable the quantification of water and potential stress within localized areas. For this water budgeting activity the resulting GIS model will be a simple numerical approach; building on the work that has been completed for the conceptual stage.

The simple GIS model to be used for future water budget work is to consider both ground and surface water flows. Such a model will not be complex and does not require intensive numeric modeling. However, surface water flow models are in existence for the QC watersheds and will be used in future water budget work for calibration of the GIS Model and/or to assist in interpretation. Such work will also benefit the evaluation of potential water quality issues within the QC watershed dealing with nutrient rich surface water and/or contaminant loading from facilities such as the old Deloro Mine Site.

8. References

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APPENDIX A

30 Yr Climate Data Summaries

Table A1: Average Temperature, Precip, ET – Quinte Region – 1971 to 2000

Month	Average Temperature (°C)	Average Precipitation (mm)	Avg PE (mm)	Avg AE (mm)
January	-8.2	77	0	0
February	-7.2	60	0	0
March	-1.6	73	0	0
April	5.6	74	29	29
May	12.6	76	78	78
June	17.6	77	113	110
July	20.2	65	132	114
August	19.2	79	115	100
September	14.5	89	74	74
October	8.2	77	37	37
November	2.0	87	7	7
December	-4.9	83	0	0
		919	**585**	**550**

PE = Potential Evapotranspiration, AE= Actual Evapotranspiration
Calculated by Thornthwaite Method 1955

Table A2: Average Temperature, Precip, ET – Foxboro – 1971 to 2000

Month	Average Temperature (°C)	Average Precipitation (mm)	Avg PE (mm)	Avg AE (mm)
January	-9.0	73	0	0
February	-7.9	58	0	0
March	-2.1	71	0	0
April	5.2	72	28	28
May	12.4	76	78	78
June	17.3	78	112	108
July	19.8	66	130	96
August	18.7	82	113	94
September	14.0	88	73	73
October	7.7	76	35	35
November	1.4	84	5	5
December	-5.6	80	0	0
		905	**573**	**517**

PE = Potential Evapotranspiration, AE= Actual Evapotranspiration
Calculated by Thornthwaite Method 1955

Table A3: Average Temperature, Precip, ET – Shannonville – 1971 to 2000

Month	Average Temperature (°C)	Average Precipitation (mm)	Avg PE (mm)	Avg AE (mm)
January	-8.8	83	0	0
February	-7.6	59	0	0
March	-1.9	75	0	0
April	5.3	73	28	28
May	12.4	75	78	78
June	17.4	79	112	111
July	19.9	69	130	120
August	18.9	78	114	99
September	14.3	90	74	74
October	7.9	76	36	36
November	1.6	89	6	6
December	-5.3	82	0	0
		929	**577**	**551**

PE = Potential Evapotranspiration, AE= Actual Evapotranspiration
Calculated by Thornthwaite Method 1955

Table A4: Average Temperature, Precip, ET – Camden East – 1971 to 2000

Month	Average Temperature (°C)	Average Precipitation (mm)	Avg PE (mm)	Avg AE (mm)
January	-8.5	82	0	0
February	-7.3	60	0	0
March	-1.7	74	0	0
April	5.5	74	29	29
May	12.6	76	78	78
June	17.5	77	113	112
July	20.2	70	131	128
August	19.1	79	115	96
September	14.5	92	74	74
October	8.2	78	37	37
November	1.9	90	7	7
December	-4.9	84	0	0
		934	**584**	**561**

PE = Potential Evapotranspiration, AE= Actual Evapotranspiration
Calculated by Thornthwaite Method 1955

Table A5: Average Temperature, Precip, ET – Consecon Creek – 1971 to 2000

Month	Average Temperature (℃)	Average Precipitation (mm)	Avg PE (mm)	Avg AE (mm)
January	-6.4	78	0	0
February	-5.8	64	0	0
March	-0.5	75	0	0
April	6.5	78	32	32
May	13.1	75	79	79
June	18.1	73	114	114
July	21.0	60	135	135
August	20.1	77	119	115
September	15.5	89	78	78
October	9.2	79	40	40
November	3.2	90	11	11
December	-3.3	88	0	0
		925	**608**	**604**

PE = Potential Evapotranspiration, AE= Actual Evapotranspiration
Calculated by Thornthwaite Method 1955

APPENDIX B

70 Yr Climate Data Summaries

Table B1: Average Temperature, Precip, ET – Quinte Region – 1931 to 2000

Month	Average Temperature (℃)	Average Precipitation (mm)	Avg PE (mm)	Avg AE (mm)
January	-8.5	73	0	0
February	-7.6	60	0	0
March	-2.0	69	0	0
April	5.6	70	29	29
May	12.3	76	76	76
June	17.5	70	112	108
July	20.3	67	132	115
August	19.3	72	116	94
September	14.8	81	75	75
October	8.6	72	39	39
November	2.2	82	7	7
December	-5.3	78	0	0
		869	**587**	**544**

PE = Potential Evapotranspiration, AE= Actual Evapotranspiration
Calculated by Thornthwaite Method 1955

Table B2: Average Temperature, Precip, ET – Foxboro – 1931 to 2000

Month	Average Temperature (℃)	Average Precipitation (mm)	Avg PE (mm)	Avg AE (mm)
January	-9.2	71	0	0
February	-8.2	58	0	0
March	-2.5	67	0	0
April	5.3	68	28	28
May	12.0	76	75	75
June	17.2	71	111	104
July	19.9	69	130	98
August	18.8	71	113	86
September	14.3	82	74	74
October	8.1	70	37	37
November	1.6	80	6	6
December	-6.1	77	0	0
		860	**575**	**508**

PE = Potential Evapotranspiration, AE= Actual Evapotranspiration
Calculated by Thornthwaite Method 1955

Table B3: Average Temperature, Precip, ET – Shannonville – 1931 to 2000

Month	Average Temperature (°C)	Average Precipitation (mm)	Avg PE (mm)	Avg AE (mm)
January	-8.9	73	0	0
February	-8.0	60	0	0
March	-2.3	69	0	0
April	5.5	70	29	29
May	12.2	76	76	76
June	17.4	71	112	109
July	20.2	68	132	120
August	19.1	72	115	92
September	14.6	83	75	75
October	8.4	72	38	38
November	1.9	82	7	7
December	-5.7	79	0	0
		874	**582**	**544**

PE = Potential Evapotranspiration, AE= Actual Evapotranspiration
Calculated by Thornthwaite Method 1955

Table B4: Average Temperature, Precip, ET – Camden East – 1931 to 2000

Month	Average Temperature (°C)	Average Precipitation (mm)	Avg PE (mm)	Avg AE (mm)
January	-8.7	74	0	0
February	-7.7	61	0	0
March	-2.0	70	0	0
April	5.7	72	29	29
May	12.4	76	76	76
June	17.6	70	112	112
July	20.4	68	133	127
August	19.4	73	116	92
September	14.8	84	76	76
October	8.7	74	39	39
November	2.2	84	8	8
December	-5.4	80	0	0
		887	**588**	**557**

PE = Potential Evapotranspiration, AE= Actual Evapotranspiration
Calculated by Thornthwaite Method 1955

Table B5: Average Temperature, Precip, ET – Consecon Creek – 1931 to 2000

Month	Average Temperature (°C)	Average Precipitation (mm)	Avg PE (mm)	Avg AE (mm)
January	-6.8	76	0	0
February	-6.1	63	0	0
March	-0.9	70	0	0
April	6.4	71	31	31
May	12.8	74	77	77
June	18.1	66	114	114
July	21.0	62	136	136
August	20.1	72	119	112
September	15.7	79	79	79
October	9.5	71	41	41
November	3.3	85	11	11
December	-3.8	80	0	0
		868	**608**	**601**

PE = Potential Evapotranspiration, AE= Actual Evapotranspiration
Calculated by Thornthwaite Method 1955

APPENDIX C

Stream Flow Records for Selected Stations

Moira River at Foxboro

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1915	-	-	-	-	-	-	-	-	-	9.37	11.6	14.2	-
1916	32.6	56.3	29	163	69.3	107	32.5	7.47	3.86	3.07	4.4	10.1	42.9
1917	9.52	7.53	54.4	133	38.4	21.7	10.5	3.52	1.79	3.89	18.5	6.25	25.7
1918	2.05	4.22	66.8	130	37.1	17.4	11.5	4.57	6.38	15.6	38.3	50.4	32.1
1919	36.3	14.2	78	100	101	39.6	8.46	3.49	1.45	1.61	22	19.5	35.6
1920	5.45	4.8	66.5	75.7	33.4	8.03	6.5	2.79	0.942	1.55	4.47	20.2	19.2
1921	19.2	9.5	110	74.8	31.2	8.6	3.57	1.85	1.87	4.1	9.47	19.8	24.7
1922	9.04	6.85	64.7	156	49.1	17.6	5.3	2.64	1.22	0.929	1.14	1.05	26.3
1923	1.14	1.63	6.88	97.2	54.2	42.1	7.63	1.58	1.31	2.12	2.28	22.5	20
1924	23.6	25.1	52.2	108	58.4	22.4	5.83	3.47	2.88	10.4	5.63	7.28	27
1925	3.31	19.6	94.3	93.2	30.6	15.6	7	4.39	4.36	7.78	53.9	42.8	31.4
1926	18.8	13.2	23.3	146	75.8	22.7	7.66	4.58	6.34	15.1	82.4	41.7	38.1
1927	16.4	20.1	106	60.9	39.8	32.8	21.5	14.5	5.57	8.57	35.8	81.2	37.1
1928	45.9	23.6	71.5	170	51.5	27.2	23.3	38.4	15.5	69.7	70.9	54.3	55.2
1929	62.7	27.6	121	131	95.5	23.5	7.24	3.9	3.2	2.4	5.33	4.25	40.8
1930	42.2	31.4	68.7	97.2	46.3	16.4	6.73	2.75	2.43	2.62	1.89	1.59	26.6
1931	1.08	1.08	8.56	57.7	36.9	18.5	6	3.37	2.77	3.36	10.6	27.2	14.8
1932	78.4	62	32	147	46.2	11.8	5.11	4.66	2.38	5.38	34.7	44.2	39.2
1933	36.5	20	20	175	56.9	12.3	3.45	1.53	1.11	1.02	1.28	4.67	27.7
1934	6.88	4.62	34.9	162	38	14.1	5.65	1.99	2.6	2.07	3.48	14.1	24.2
1935	14.7	11.1	71.5	59.4	26	30.4	22.1	7.63	2.74	2.07	18.8	27.9	24.6
1936	10.9	9.09	145	163	49.2	13.3	3.68	1.73	1.56	5.99	26.1	13.8	36.9
1937	105	48.7	24.4	107	94.3	23.2	6.99	4.08	2.73	3.39	32.5	20.3	39.3
1938	12	47.6	96.2	87.6	31.1	12.1	4.4	3.6	3.81	5.21	5.33	5.78	26
1939	7.85	6.26	10.3	155	75.8	15.5	5.51	5.92	3.52	4.32	5.57	5.6	25
1940	3.57	1.81	2.78	144	92	68.6	13.2	4.59	3.17	2.79	8.45	23.5	30.6
1941	47.6	13.8	15.7	87.2	15.3	3.66	3.06	1.76	1.19	1.97	18	29.1	19.8
1942	29.4	12.2	96.3	73.3	40.9	31.2	6.41	2.05	2.57	3.33	36.7	21.4	29.7
1943	18.4	23.3	78.8	149	156	42.3	7.83	3.47	1.37	2.95	8.91	6.45	41.6
1944	3.07	3.13	14.4	71.5	62.2	16	8.45	2.88	1.94	1.85	1.14	2.82	15.8
1945	3.15	3.17	75.4	77.2	70.6	50.2	22.4	9.95	8.17	47.3	30.5	20.5	35.1
1946	24.1	15.3	94.8	41	22.2	14.3	4.06	2.08	1.63	1.91	6.69	23.9	21.1
1947	29.1	36.1	43.3	185	76.2	72.5	26	20.5	5.37	4	4.72	8.49	42.4
1948	7.68	9.1	111	115	66.9	27	9.9	3.6	1.82	1.92	4.89	9.54	30.7
1949	20.7	29.5	58.8	118	34.3	7.24	3.42	2.21	1.94	2.33	3.61	39.4	26.7
1950	84.5	33	39	157	38.4	13.4	4.53	2.9	2.46	1.9	4.27	20.6	33.4
1951	33.9	25.8	82.2	170	57.7	16.5	19.5	5.72	8.11	7.45	36.2	40.3	41.9
1952	40.2	45.4	54.9	167	44	21.7	4.83	3.2	2.74	2.05	2.2	15.9	33.5
1953	14.2	15.6	51.9	70.4	54	23.5	11.2	8.99	4.26	4.07	6.29	21.2	23.8
1954	13.3	25.9	77.8	128	48.4	11.9	3.71	2.67	5.25	21.6	35.1	32.2	33.7
1955	24.4	14	68	137	31.6	11.1	3.55	2.34	2.1	62.7	52.8	16.8	35.5
1956	13.5	7.22	13.1	141	102	59.1	9.35	5.91	6.91	3.68	4.87	15.6	31.8
1957	18.4	22	48.4	65.6	33.2	14	9.3	2.89	2.93	3.23	7.77	43.4	22.6
1958	32.3	12.7	34.5	88.7	35.6	9.37	3.35	1.81	3.06	1.96	3.66	7.1	19.5
1959	6.07	8.05	22.6	149	42.5	7.57	4.45	1.76	1.82	3.21	15.2	28.9	24.2

1960	14.8	25.2	22.5	216	69.6	19.8	6.31	3.06	0.859	0.795	1.58	2.07	31.6
1961	1.81	4.94	21.3	66.2	61.9	28.9	8.05	4.93	3.76	3.03	3.55	11.2	18.3
1962	7.05	5.32	30.8	102	28.6	8.23	2.7	2.38	2.11	3.86	23.5	23.4	19.9
1963	12	8.81	28.7	92.7	45	13.4	2.68	2.21	2.13	1.63	7.71	18.1	19.6
1964	18.6	19.5	44.3	67.7	42.6	11.7	2.7	1.31	1.87	1.62	2.05	8.91	18.5
1965	13.9	28.8	35.9	119	45.4	6.16	3.41	1.93	4.07	22.4	48.7	63.4	32.7
1966	37.3	19.7	80.6	48.7	27	16.8	1.99	1.23	1.49	1.52	20.3	86.1	28.7
1967	29.1	29.1	27.9	105	40.1	16.5	16.1	4.33	4.24	27.2	64.4	46	34.1
1968	25.4	31.1	65	68.1	20.9	24.7	15.6	3.59	3.68	4.56	13.1	26.6	25.1
1969	21.6	32.6	54.4	113	97.9	29.1	10.1	6.88	3.17	3.14	12.3	21.7	33.8
1970	10.8	14.1	24	103	49.9	14	8.24	3.32	3.12	3.66	18	27.5	23.2
1971	18.7	19.7	32.7	157	50.9	8.32	3.15	2.12	3.47	4.73	6.18	26.6	27.7
1972	24.1	18	22	151	81.7	23.8	21.1	16.8	6.59	13.6	44.8	44.2	38.9
1973	54.4	46	143	89.6	36.2	12.7	2.89	2.35	1.66	1.89	8.71	19.4	34.9
1974	31.3	32.6	73.4	127	82.8	19.7	6.57	2.75	2.49	4.74	11.9	19.9	34.5
1975	24	19.9	76.4	118	51.4	11.2	1.67	1.54	1.77	1.5	3.04	14.1	27
1976	15.3	32.2	115	144	33.5	9.96	4.01	2.54	2.2	4.24	6.74	7.73	31.3
1977	7.93	8.05	93.4	64.7	16.9	3.81	1.66	2.8	2.71	8.88	19.2	48.4	23.3
1978	51.7	41.7	40.9	163	56.5	9.14	2.02	1.75	1.9	2.83	11.6	19.9	33.4
1979	27.5	20.6	117	131	44.5	16.2	1.93	1.4	1.28	5.06	15.7	41.7	35.3
1980	42.8	13	82	96.8	44.5	13.1	5.55	3.19	3.53	7.47	20.6	34.9	30.7
1981	14	106	85.9	42.2	29.4	23.3	12	8.7	43.8	27.6	48	26.9	38.4
1982	19.7	14.1	34.3	149	40.9	21.5	5.99	3.69	4.14	5.25	25.3	68.9	32.7
1983	52.1	39.1	56.9	72.2	78.4	22.5	3.23	2.09	1.25	2.68	9.71	39.1	31.6
1984	20.8	76.7	67.9	149	65.6	17	7.38	6.94	5.69	2.66	9.89	18.8	37.1
1985	32.1	26.1	108	112	31.2	10.4	4.26	2.29	15.8	12	63.9	40.6	38.2
1986	34.3	28.6	69	80.4	26.4	29.9	11	13.8	29.1	63.2	30.7	38.4	37.9
1987	26.8	17	55.5	140	19	9.46	3.8	1.26	2.52	4.98	17.7	58.8	29.7
1988	29.1	35.4	54.1	103	26	5.09	1.32	1.15	1.92	4.8	12.7	15	24
1989	18.8	15.9	26.5	84.7	37	22.7	7.52	1.53	1.79	9.6	43.2	27.9	24.7
1990	27.6	35.5	85.3	89.2	46.7	14.2	5.8	3	1.13	6.34	15.1	56.1	32.2
1991	63.6	30	86.4	141	31.8	8.37	1.43	1.27	0.578	1.8	2.26	10.2	31.5
1992	12.6	9.99	44.5	127	48.9	6.87	2.62	3.86	24.3	17.7	73.2	48.6	34.9
1993	79.3	27.1	29.6	163	39.2	23.1	12.6	1.71	2.79	13	24	55.3	39.2
1994	16.1	14.3	28.6	97.8	46.4	22.6	7.66	7.42	3.2	4.67	9.14	23.6	23.4
1995	84.7	35.6	43.2	24.4	24.8	20.1	2.18	1.69	1.76	7.79	54.6	33.5	27.8
1996	50.5	72.3	60.2	88.1	80	22.7	6.9	5.21	19.8	31.1	53.8	64.4	46.1
1997	54.6	49.4	78	133	63	14.3	8.27	1.75	4.66	9.75	34.2	28.1	39.8
1998	54.1	26.7	73.3	100	10.6	5.17	7.22	2.4	2.76	3.58	6.92	13.3	25.5
1999	24.8	37.9	38.6	97.9	10.3	5.1	2.28	0.435	0.53	4.81	31.6	42.6	24.5
2000	31.6	19.7	47.3	57.9	67.3	47.1	38.9	15.8	5.8	6.6	14.5	38.3	32.7
2001	25.4	43.9	44.4	98.7	15	6.25	1.23	0.401	0.503	2.14	6.14	37.6	23.2
2002	29.4	26	56.7	87.8	74.4	67	21.6	3.03	1.24	2.43	7.86	10.3	32.3
2003	9.11	9.19	42.6	71.5	35.8	24.6	4.61	2.65	2.1	11.5	61.7	76.9	29.4
2004	54.2	19.4	54.4	69.6	45.4	21.8	7.26	8.21	19.7	7.83	21	60.7	32.5
2005	67.1	28.3	23.5	113	30.8	12.1	4.77	0.797	1.02	5.66	18.4	38.2	28.6
Mean	27.7	23.9	57.4	111	49.4	21.1	8.08	4.44	4.52	8.48	20.4	28.3	30.4
Max	105	106	145	216	156	107	38.9	38.4	43.8	69.7	82.4	86.1	55.2

Napanee River at Camden East

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1974	8.64	11.1	21	35.9	17	3.12	1.14	1.22	1.14	0.855	1.51	3.96	8.84
1975	9.45	6.98	21.7	31.5	10	2.69	1.22	1.26	2.28	1.31	2.53	6.74	8.12
1976	5.54	9.71	36.9	36.1	9.99	4.24	2.18	1.81	1.73	1.65	1.63	1.33	9.38
1977	1.16	1.28	25.8	19.9	5.83	2.31	1.4	1.89	1.66	3.02	5.43	10.1	6.69
1978	13	14.9	11.1	43.7	10.2	2.07	1.22	1.32	1.48	1.79	2.75	4.66	8.93
1979	5.55	4.59	32.1	30.1	9.23	4.47	1.54	1.62	2.16	2.98	4.24	10.7	9.13
1980	10.6	4.93	18.2	28.3	15.7	2.64	1.83	2.34	1.95	2.36	4.21	7.64	8.4
1981	4.35	23.6	24.4	7.64	5.66	6.25	3.13	3.79	19.8	13.7	15.1	9.32	11.3
1982	5.78	4.45	11.4	37.2	10.6	7.56	2.97	1.6	2.38	3.11	6.71	14.6	9.02
1983	14.2	11.2	14.5	18	20.5	5.44	1.39	1.51	1.3	1.69	6.14	20.3	9.68
1984	10.3	21.7	17.4	31.1	12.5	5.12	2.9	2.48	2.38	1.72	1.93	3.64	9.35
1985	4.84	6.29	27.4	20.2	3.84	1.87	1.56	1.18	4.24	4.25	13.9	10.9	8.37
1986	8.75	6.58	17.9	16.8	8.15	7.68	2.7	3.06	9.04	14	10.7	13.9	9.96
1987	9.95	5.7	16.4	27.6	4.79	5.18	2.6	1.43	1.98	1.83	5.5	20.5	8.62
1988	9.81	7.73	14.3	22	5.23	1.59	0.802	0.818	0.911	1.32	2.88	2.7	5.82
1989	3.35	4.04	8.84	23.2	11.1	4.09	1.45	1.17	0.625	1.26	5.59	5.19	5.81
1990	7.22	11.4	22.3	22.9	13.5	5.49	1.84	1.37	1.07	3.16	4.67	15.4	9.19
1991	19.5	11.1	24.2	30.8	11.8	2.77	1.02	0.628	0.262	1.15	1.7	2.13	8.9
1992	3.1	2.36	12.1	32	12.3	2.38	1.27	1.49	4.95	7.2	21	16	9.66
1993	20.5	12.5	11.4	42.2	12.6	5.37	2.6	1.51	1.47	3.86	6.66	16.3	11.4
1994	6.37	5.81	9.66	28.9	10.2	5.8	2.23	1.4	1.04	0.935	2.26	4.07	6.53
1995	18.9	11.6	14.6	6.34	4.25	1.67	0.727	0.619	0.788	2.84	12.7	9.65	7.04
1996	15	17.1	16	19	18.9	4.96	1.72	1.13	3.04	7.68	16.6	17.4	11.5
1997	16.3	12.6	23	34.9	15.8	4.2	1.85	1.04	2.03	3.18	10.3	10	11.2
1998	15.8	8.82	26.8	22.3	3.44	1.54	1.21	0.908	1.51	1.7	2.49	4.24	7.56
1999	10.1	14.5	16.5	29.2	4.04	1.18	1.14	0.742	0.91	1.52	3.17	7.83	7.5
2000	8.48	8.58	16.1	19.5	14.1	7.65	5.15	4.06	3.47	2.79	3.59	7.66	8.42
2001	7.06	8.37	13.7	25	5.1	1.28	0.628	0.543	0.683	0.798	0.906	6.11	5.82
2002	6.24	7.24	17.5	23.6	19.3	22.2	7.33	1.49	0.596	1.06	2.59	3.12	9.34
2003	3.48	3.55	13.1	21.5	9.32	6.26	1.98	1.24	1.13	2.72	12.2	23.1	8.3
2004	16.4	5.66	15	20.4	13	7.79	2.1	3.39	6.48	2.69	4.47	17.5	9.58
Mean	9.67	9.22	18.4	26.1	10.6	4.74	2.03	1.61	2.73	3.23	6.32	9.89	8.69
Max	20.5	23.6	36.9	43.7	20.5	22.2	7.33	4.06	19.8	14	21	23.1	11.5
Min	1.16	1.28	8.84	6.34	3.44	1.18	0.628	0.543	0.262	0.798	0.906	1.33	5.81

Salmon River at Shannonville

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1958	-	-	-	-	-	-	-	0.181	0.28	0.335	2.04	4.1	-
1959	3.73	3.88	15	50.6	14.2	1.32	0.702	0.171	0.229	2.19	8.46	14.6	9.58
1960	4.41	7.26	4.48	66.3	21	4.89	1.28	0.39	0.143	0.137	0.418	0.377	9.18
1961	0.27	2.95	11.1	24	20.6	9.88	2.82	1.02	0.606	0.315	0.628	2.71	6.41
1962	1.58	1.4	14	26.8	3.72	0.523	0.591	0.424	0.409	0.936	7.21	9.59	5.6
1963	5.25	3.76	15.9	28.7	14.1	7.98	2	0.807	0.292	0.282	1.24	8.37	7.39
1964	9.23	8.15	16.4	23.4	13.5	3.84	0.919	0.254	0.214	0.317	0.608	2.22	6.57
1965	4.44	13.5	17.9	36.7	14.4	2.11	0.974	0.307	0.78	6.38	21.1	23.7	11.8
1966	11.3	5.43	25.8	16.1	6.68	4.54	0.84	0.242	0.181	0.261	7.01	26	8.75
1967	11.1	10.5	11.6	33.1	12.9	4.73	3.02	0.968	0.347	5.12	20.5	15.4	10.7
1968	8.55	12.1	22.1	21.6	8.36	8.39	4.69	1.22	4.62	4.14	9.8	15.8	10.1
1969	8.35	12.7	21.1	38.5	31.8	13.4	3.71	2.08	0.465	0.388	4.79	9.75	12.2
1970	4.56	5.9	12.7	34.3	18.1	6.19	3.21	1	0.381	1.08	11.1	14.8	9.44
1971	8.48	8.18	15.9	52.2	20	3.71	0.967	0.266	0.22	0.635	0.665	9.85	10.1
1972	10.8	7.52	9.24	49.9	25.4	10.5	7.87	5.08	1.36	5.91	17.3	19	14.1
1973	21.7	17.8	43.2	32	13.6	5.76	0.993	0.281	0.125	0.158	2.98	8.43	12.2
1974	15.7	12.7	26.9	42.9	27.4	8.26	2.24	0.385	0.154	0.179	2.16	11.3	12.5
1975	9.3	9.42	26.9	39.6	21	3.76	0.566	0.164	0.129	0.391	0.848	6.78	9.89
1976	5.58	17.3	46.8	41.8	9.58	3.74	1.21	0.335	0.2	0.593	1.54	3.22	10.9
1977	2.55	2.59	38.5	23.4	7.16	1.76	0.302	0.244	0.413	2.65	6.77	19.1	8.84
1978	20.3	14.9	15.7	53.7	17.9	2.44	0.308	0.126	0.197	0.128	1.46	7.2	11.1
1979	15.3	8.42	43.3	43.2	14.9	5.68	1.11	0.21	0.189	0.79	5.75	17.1	13
1980	17.3	4.2	28.9	35.2	18.6	4.38	3.11	1.4	0.622	1.87	8.97	15.2	11.7
1981	4.98	36.3	29.1	13	9.49	8.78	3.89	2.38	21.5	11.9	18.2	8.08	13.8
1982	6.12	3.68	18.2	49.8	16.2	8.85	3.07	0.891	0.815	1.71	9.92	25.8	12.1
1983	19.1	15.3	20.6	29.2	28.3	7.88	1.17	0.49	0.377	2	8.62	24.8	13.1
1984	8.57	27.3	24	41.6	18.8	6.06	2.27	1.66	0.923	0.415	1.59	4.86	11.4
1985	7.93	10	35	30	7.57	2.51	0.657	0.096	2.46	3.71	19.1	11.2	10.8
1986	12.4	8.58	21.1	22.2	9.01	9.61	4.44	4.46	8.52	21.3	11	15.7	12.4
1987	8.22	4.51	20.6	41.3	6.23	3.22	1.44	0.294	0.269	0.647	6.22	23.5	9.71
1988	9.81	10.7	19	32.3	7.2	2.01	0.37	0.169	0.085	0.707	5.19	5.29	7.7
1989	6.86	5.74	12.2	28	13.7	5.95	1.47	0.371	0.044	0.238	10.2	8.89	7.79
1990	10.3	14.9	29.2	31.3	17.8	5.51	1.48	0.492	0.094	2.14	5.46	22.6	11.8
1991	20.8	11.7	31.9	40.4	13.4	2.73	0.406	0.038	0.025	0.082	0.139	1.87	10.3
1992	4.65	3.07	19.4	42.2	17.6	2.69	0.574	0.686	3.34	3.72	24.8	17.1	11.6
1993	29.4	12	14.6	53.4	15.5	6.9	2.34	0.537	0.434	2.94	9.51	21.1	14
1994	5.97	4.86	13.9	35.1	16	8.45	2.76	0.542	0.554	0.279	1.52	6.44	8.02
1995	27.4	14.2	14.9	9.66	7.66	3.67	0.789	0.357	0.228	2.41	19.3	12.2	9.37
1996	18.6	29.2	19.8	28.7	26.3	6.65	1.9	1.12	5.11	10.4	19.2	21.5	15.6
1997	19.7	19.4	32.9	48	27.4	5.97	2.68	1.19	1.43	2.93	15.6	10.3	15.6
1998	19.9	11.1	29.7	29.3	4.12	1.51	0.999	0.759	0.614	0.539	1.15	3.89	8.62
1999	9.76	17.5	19	32.9	4.58	1.38	0.851	0.224	0.23	0.931	5.3	13.1	8.73
2000	10.7	8.1	19.9	25.1	21.7	14.8	16	7.46	3.73	1.8	5.25	16.2	12.6
2001	9.39	15.9	19.3	30.5	5.98	1.95	0.367	0.065	0.054	0.454	1.14	13.5	8.15
2002	12	11.8	23.5	31.2	28.8	28.4	9.49	0.925	0.159	0.426	1.69	2.71	12.6

2003	3.11	2.98	17.6	26.8	14.6	9.34	2.35	1.31	0.334	2.21	20.4	30.2	11
2004	18.3	6.54	21.7	26.6	18.1	11.4	3.55	4.57	10.4	3.67	7.06	23.2	13
Mean	11	10.8	22	34.6	15.5	6.17	2.36	1.03	1.58	2.4	7.89	12.9	10.7
Max	29.4	36.3	46.8	66.3	31.8	28.4	16	7.46	21.5	21.3	24.8	30.2	15.6*
Min	0.27	1.4	4.48	9.66	3.72	0.523	0.302	0.038	0.025	0.082	0.139	0.377	5.6

Consecon Creek at Allisonville

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1969	-	-	-	-	-	-	-	-	-	-	-	-	-
1970	0.224	0.513	5.78	3.71	1.25	0.126	0.143	0.032	0.006	0.021	1.66	1.57	1.26
1971	0.511	0.544	4.08	11.2	1.1	0.149	0.006	0	0	0.001	0.002	0.214	1.47
1972	0.58	0.486	2.15	7.99	1.22	0.535	0.184	0.121	0.017	0.762	2.93	2.75	1.64
1973	2.58	2.14	6.36	3.37	1.37	0.316	0.017	0.001	0.001	0.007	0.136	0.67	1.41
1974	3.23	1.05	2.99	5.27	2.62	0.362	0.03	0.003	0.002	0.004	0.098	1.06	1.4
1975	2.61	2.25	5.67	3.19	0.766	0.293	0.004	0	0.005	0.009	0.09	1.2	1.34
1976	0.612	4.71	7.84	2.59	1.83	0.301	0.168	0.055	0.022	0.129	0.276	0.328	1.56
1977	0.206	0.201	8.34	2.35	0.515	0.014	0.002	0.002	0.033	0.531	2.26	3.34	1.5
1978	3.23	1.28	3.12	10.8	0.948	0.068	0.008	0.003	0.004	0.011	0.095	0.715	1.68
1979	1.65	1.35	8.68	3.76	1.11	0.045	0.005	0.002	0.009	0.095	1.68	3.26	1.81
1980	0.897	0.128	6.08	3.27	1.25	0.271	0.671	0.165	0.04	0.337	1.09	1.9	1.35
1981	0.309	8.44	1.45	1.13	0.886	0.224	0.121	0.075	2.58	0.988	1.33	0.541	1.45
1982	0.618	0.372	7.4	4.78	0.611	1.46	0.416	0.066	0.036	0.304	2.02	2.61	1.73
1983	1.01	1.05	2.79	3.35	2.96	0.423	0.006	0.001	0.001	0.011	0.853	2.24	1.23
1984	0.369	3.87	2.46	6.27	1.57	0.352	0.022	0.012	0.006	0.005	0.014	0.166	1.24
1985	0.196	1.03	5.96	2.28	0.269	0.041	0.008	0.004	0.005	0.009	1.79	0.918	1.04
1986	1.95	0.646	5.89	1.9	1.33	0.409	0.031	0.111	1.87	3.29	1.7	4.98	2.03
1987	1.21	0.608	5.2	5.06	0.413	0.034	0.005	0	0.001	0.006	0.176	2.83	1.3
1988	0.474	0.76	4.95	2.65	0.462	0.04	0.005	0.001	0.002	0.016	0.1	0.085	0.796
1989	0.307	0.315	3.33	3.93	1.87	0.496	0.036	0.001	0.001	0.025	2.04	0.442	1.07
1990	2.16	2.34	6.14	4.4	3.76	0.547	0.117	0.014	0.004	0.019	0.169	5.03	2.06
1991	1.82	2.62	7.22	4.08	1.18	0.029	0	0	0	0.001	0.006	0.063	1.41
1992	0.363	1	4.94	7.96	2.17	0.209	0.006	0.007	0.11	0.16	3.73	1.63	1.85
1993	5.74	0.736	3.67	7.62	0.751	1.12	0.109	0.001	0	0.013	0.606	2.42	1.9
1994	-	-	-	6.24	1.8	0.154	0.014	0.007	0.001	-	-	1.42	
1995	3.36	0.206	2.66	0.87	0.839	0.071	0	0.002	0.005	0.995	3.54	1.01	1.14
1996	3.1	2.78	1.5	3.6	3.27	0.716	0.093	0.004	0.333	1.32	2.33	2.58	1.8
1997	2.21	2.9	5.4	3.97	1.28	0.147	0.033	0.012	0.019	0.12	1.05	0.919	1.5
1998	3.66	2.11	5.16	1.5	0.345	0.391	2.99	0.017	0.007	0.014	0.057	0.213	1.38
1999	1.57	2.57	5.07	2.35	0.17	0.01	0.06	0.009	0.002	0.174	0.595	1.03	1.13
2000	0.722	1.91	2.82	3.83	1.21	2.01	1.11	1.39	0.686	0.355	1.88	1.94	1.65
2001	0.905	1.57	5.26	3.38	0.092	0.023	0.002	-	-	0.017	0.043	0.702	-
2002	2.33	2.55	3.53	2.95	3.68	1.95	0.067	0.005	0	0.001	0.128	0.62	1.48
2003	0.483	0.576	7.64	2.54	1.48	0.731	0.055	0.019	0.001	0.026	2.6	2.97	1.6
2004	1.56	0.384	4.83	2.92	1.96	0.446	0.105	0.58	2.66	0.087	1.18	3.89	1.72
Mean	1.55	1.65	4.89	4.2	1.38	0.415	0.19	0.08	0.249	0.29	1.13	1.66	1.48
Max	5.74	8.44	8.68	11.2	3.76	2.01	2.99	1.39	2.66	3.29	3.73	5.03	2.06

APPENDIX D

Uncertainty Calculations

Uncertainty in the Data

For the annual watershed average conditions that have been determined using the 1971 – 2000 period the very small percentage of water use (less than 2% of available water) suggests that reliance on the quantity estimates of available determined at this level of study is satisfactory. However, if one were to anticipate the need for greater reliance upon the calculated water availability some level of confidence in the data would be of assistance. For this reason Table 15 contains a synopsis of the uncertainty in the data used to derive the Actual Evapotranspiration (AET).

Since AET is calculated as the difference of two data sets each having some degree of uncertainty associated with the measurements of precipitation or runoff, there will be a combination of uncertainties in the derived value.

From where does the uncertainty arise?

Uncertainty in the data is comprised of both sampling error and measurement error. For example, in order to represent the mean annual flow conditions for a particular drainage area one must consider the sampling error of the population as well as the error associated with measuring each data point. Flows are calculated by a conversion of recorded water levels through what is known as a rating curve. The rating curve is constructed by taking many measurements of both flow and water level in the same reach of the river over time. With more measurements a more reliable curve can be developed. Water level can be measured with good precision, but flow measurements have a higher degree of error associated. It is suggested that the measurement error of flow by this method is within 5%.

Simple statistics of the reported means for Moira as an example will show that the mean annual flow is calculated to be 30.4 cms for the period of record between 1915 and 2005. This is calculated as a mean of the mean annual flows. The standard deviation of the means over the 90 years of record is 7.39 cms. Knowing these values one can determine the standard error (SE) of the mean to be:

$$SE = \frac{\sigma}{\sqrt{n}}$$

$$SE = \frac{7.39}{\sqrt{90}} = \frac{7.39}{9.48} = 0.78cms$$ or 0.8 cms

This is 2.6% of the calculated mean for the period.

For the period between 1971 and 2000 the mean and standard error are 32.3 cms and 1.1 cms respectively. The standard error is 3.3% of the mean. This represents the distribution of the sample means around the average mean.

Precipitation data uncertainty is also a combination of both sampling error and measurement error. Measurement errors arise in undercatch of the precipitation gauges and in the spatial transference of the values over the area said to be represented by the gauge. The latter may be considered more of a systematic error. The measurement error may be considered to be about 10%.

Considering the Belleville station, the mean annual precipitation for the period between 1971 and 2000 is calculated as 895.0 mm with a standard error of 22.7 mm. This is 2.5%. The precipitation value reported in Table 15 was determined using the Natural Resources Canada – Forestry Services model for each watershed. So for the Moira the average annual precipitation is 905 mm.

The combined influence of the sampling and measurement errors is considered in the following manner:

Runoff

$$Error_R = \sqrt{SE^2 + ME^2} = \sqrt{3.3\%^2 + 5\%^2} = 6\%$$

Precipitation

$$Error_P = \sqrt{SE^2 + ME^2} = \sqrt{2.5\%^2 + 10\%^2} = 10.3\%$$

Uncertainty in Derived AET

Since AET is derived from the two values above, the uncertainty in the AET value is determined in the following example calculation for the Moira watershed:

$$Error_{AET} = \sqrt{Error_P^2 + Error_R^2} = \sqrt{93.6^2 + 23.5^2} = 96.5mm$$ or 97 mm

Similarly the uncertainty for each of the Napanee, Salmon and Consecon watersheds are determined using the Hartington station for the Salmon and Napanee and the Picton station for Consecon. The final figures for the uncertainty calculations are contained in Table 15 in the report.