CONCEPTUAL UNDERSTANDING OF THE WATER BUDGET

PRELIMINARY DRAFT
(APPROVED BY PEER REVIEW TEAM AND PROVINCE)

MISSISSIPPI-RIDEAU SOURCE
PROTECTION REGION

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List of Acronyms

ΔS	Change in Storage (surface water and ground water)
ANTH	Anthropogenic
BGS	Below Ground Surface
CA	Conservation Authority
CANSIS	Canadian Soils Information System
ET	Evapotranspiration
GW	Groundwater
MNR	Ministry of Natural Resources
MOE(E)	Ministry of Environment (& Energy)
MRSPR	Mississippi-Rideau Source Protection Region
MVCA	Mississippi Valley Conservation Authority
P	Precipitation
PTTW	Permit To Take Water
R	Runoff (depth of runoff)
RVCA	Rideau Valley Conservation Authority
SLC	Soils Landscape of Canada
SOLRIS	Southern Ontario Land Resource Information System
SW	Surface Water
WHC	Water Holding Capacity (soils)
WCR	Watershed Characterization Report

List of Units

ha	hectares
km	kilometres
L, l	litres
Lpcd	Litres per capita per day
m	metres
masl	metres above sea level
mm	millimetres
m^3	cubic metres
m^3/s	cubic metres per second
m/s	metres per second
m^3/yr	cubic metres per year
s	seconds
yr	year

1.0 Introduction

This document, entitled the “Conceptual Understanding of the Water Budget”, has been prepared for the proposed Mississippi-Rideau Source Protection Region (the MRSPR) in conjunction with the “Draft Water Budget and Water Quantity Risk Assessment Technical Direction Version 5.0” (Province of Ontario, September 2006). This report is being submitted to Conservation Ontario and to the Province with the understanding that all comments received from the peer review team have been included in the peer review record and have been addressed.

1.1 Source Water Protection and Water Budgets

On December 5, 2005 the Government of Ontario introduced the *Clean Water Act*, known as Bill 43, for the purpose of protecting municipal drinking water supplies in Ontario from contamination and overuse through the creation of science-based, locally-developed source protection plans. The Clean Water Act received Royal Assent on October 19, 2006 at which point it became law.

Under the current legislation, source protection planning will be completed on a watershed basis by the Conservation Authorities across Ontario. Conservation Authorities have been grouped into 19 Source Protection Regions. Each Region will be required to complete a Technical Assessment Report and a Source Protection Plan. To date, the Technical Assessment Report includes the following seven modules:

- Guidance Module 1 - Watershed Characterization
- Guidance Module 2 - Municipal Long-Term Water Supply Strategies
- Guidance Module 3 - Groundwater Vulnerability Analysis
- Guidance Module 4 - Surface Water Vulnerability Analysis
- Guidance Module 5 - Threats Inventory and Issues Evaluation
- Guidance Module 6 - Water Budget and Water Quality Risk Assessment
- Guidance Module 7 - Water Budget and Water Quantity Risk Assessment

The proposed MRSPR is currently working on Guidance Module 1 – Watershed Characterization (separate document) and Guidance Module 7 – Water Budget and Water Quantity Risk Assessment.

For Guidance Modules 7, each Region is required to initially produce a conceptual understanding of the water budget (the report herein) to describe how water moves throughout the hydrologic cycle in the Region. After the conceptual understanding, each Region will move on to a Tier 1 water budget using a ‘simple’ (spreadsheet or GIS based) model that will quantify the movement and storage of water on a watershed/subwatershed basis. Using the Tier 1 model, each Region will complete a water quantity risk assessment to determine if there is any risk that the drinking water supply will not meet future water demands. Depending on the level of stress, the Region may or may not proceed to more complex numerical modeling in Tier 2 and Tier 3. The complex models used in Tiers 2 and 3 would assess the cause of the water supply shortfall and would have major implications on the remaining portions of the Technical Assessment Report.

At a minimum, all Regions are required to complete the Conceptual Understanding and Tier 1.

1.2 Purpose

The overall objective of developing the water budgets is to help protect the quantity of drinking water sources in Ontario. The aim of the conceptual understanding is to provide an overview of how surface water and ground water interact and move throughout the watershed. The Tier 1 analysis will then estimate the hydrologic stress of subwatersheds in order to screen out areas that are unstressed from a water quantity perspective.

1.3 Report Objectives

Each assessment in the development of the water budget will address the following questions:

- Where is the water (i.e. where are the reservoirs)?
- At a conceptual level, how does the water move between those reservoirs? (i.e. what are the pathways through which water travels)?
- What and where are the stresses (i.e. where are the water takings)?
- What are the trends (i.e. observed changes in climate, stream flows, well levels, etc.)?

These are the overall objectives of the entire water budget process however this reports only deals with assessing these aspects at a conceptual level. To completely answer the above questions, an assessment of the various elements that affect the movement and storage of water is required. These elements include: climate, geology, land cover, groundwater, surface water, and water use.

1.4 Scope of Work

This report includes the review of existing data and information related to the elements of the hydrologic cycle in and around the MRSPR and provides preliminary estimates of water budget elements on an average, annual basis for the major watershed regions.

For this report, the following tasks have been completed:

- Review available climate data, information from previous studies and climate patterns (precipitation, temperature, rain, snow, evaporation, evapotranspiration),
- Calculate evapotranspiration,
- Determine representative values for climate data,
- Review existing land uses in the MRSPR,
- Review available information on geology and physiography,
- Review available information on groundwater,
- Describe groundwater-surface water interactions at a conceptual level,
- Review surface water systems and control structures,
- Prepare an inventory of hydrometric station data,
- Estimate streamflow and runoff in the MRSPR,
- Estimate baseflow in the MRSPR,
- Identify and locate major water uses,
- Collect and assess municipal drinking water use data,
- Calculate average annual water budgets and on regional basis,
- Estimate average annual potential groundwater recharge, and
- Compare the magnitude of water demands to water supply at the watershed level.

There is relatively more data available for climate and surface water elements than for groundwater elements thus enabling the climate and surface water systems to be more easily visualized and quantified than the groundwater systems. Thus, certain sections of this report will be more focused on quantification of the climate and surface water components to estimate the annual water budget at the watershed level and sections related to groundwater will be more at a conceptual level.

Prior to any groundwater numerical modeling a well developed 3-D conceptual understanding of the geology and the groundwater system is required. To assist with this task all spatial and temporal data associated with geology and hydrogeology is being assembled into a database format for use with electronic software (SiteFX and Viewlog). This software will facilitate an organized method of maintaining a continuously updated database in the future as more data becomes available. Much of this work is described separately in the Watershed Characterization Report.

1.5 Report Structure

The climate and land cover data are presented first, followed by a summary of the geology and groundwater characterization, and a summary of the surface water systems and major water uses in the MRSPR. More detail on the characterization of the geology and ground water can be found in the Watershed Characterization Report. Average annual estimates of water budget components and baseflow/groundwater recharge follow the data summary, which is then followed by a preliminary review of regional water demand and stresses on water supplies.

All tables, graphs and figures are located in sections following the main body of the report.

A glossary of terms used in the report is provided in Appendix G.

1.6 Study Area

The study area, the proposed MRSPR, includes the boundaries of the Mississippi Valley Conservation Authority (MVCA) and the Rideau Valley Conservation Authority (RVCA). It is bordered by the Ottawa River and Quebec to the north, Cataraqui Region to the south, Quinte Region to the south-west, and South Nation-Raisin Region to the east. The largest rivers in the MRSPR are the Mississippi River and the Rideau River, which both discharge to the Ottawa River. The Carp River, located in MVCA, and some smaller tributaries, also discharge to the Ottawa River. The jurisdiction of the Ottawa River subwatersheds is split between MVCA and RVCA.

A base map of the other Eastern Ontario Source Protection Regions (Raisin Region/South Nation, Cataraqui, and Quinte) is given in Figure 1.6-1. A base map of the MRSPR is given in Figure 1.6-2. The watershed areas within the MRSPR are given in Table 1.6-1.

2.0 The Water Budget

2.1 Components of the Hydrologic Cycle

The hydrologic cycle (see Figure 2.1-1) begins with water evaporating from surface water bodies such as lakes, wetlands, streams, and rivers into the atmosphere. As moist air rises, the water vapour in it condenses and turns into precipitation in the form of rain or snow depending on temperature. Precipitation falls to the ground and either runs off directly into surface water bodies or it infiltrates into the soil where it adds to soil moisture. Where it infiltrates, water either gets taken up by vegetation (i.e. transpiration) or it travels through the unsaturated zone as interflow before discharging back to a surface water body. The remainder of the infiltrated water percolates past the water table into the saturated zone and recharges the groundwater aquifers or will travel even deeper underground from basin to basin.

A water budget is the amount of water in each of the components of the hydrologic cycle. It is a measure of the supply and demand of water in a control volume, typically a watershed or subwatershed. A water budget consists of inputs, outputs, and changes in storage. The inputs are precipitation, surface water inflows, groundwater inflows, and anthropogenic inputs such as wastewater discharges. The outputs are evapotranspiration, surface water outflows, groundwater outflows, and anthropogenic outflows such as drinking water takings. Changes in storage may occur with changes in surface water levels (lakes/reservoirs and snow pack) and in groundwater (aquifers).

2.2 Water Budget Equation

The components of the hydrologic cycle for a control volume can be expressed in the form of a water budget by the following equations:

2-1 Inputs = Outputs + Changes in Storage

2-2 $P + SW_{in} + GW_{in} + ANTH_{in} = ET + SW_{out} + GW_{out} + ANTH_{out} + \Delta S + \text{Diversions}$

Where:

P = precipitation
SW_{in} = surface water flow in
GW_{in} = groundwater flow in
$ANTH_{in}$ = human inputs (e.g. wastewater discharges)
ET = evapotranspiration (evaporation and transpiration)

SW_{out} = surface water flow out
GW_{out} = groundwater flow out
$ANTH_{out}$ = human removals (e.g. drinking water takings)
ΔS = change in storage (surface water and groundwater)
Diversions = water taken out of the control volume (e.g. watershed)

Over the long-term (i.e. 30 years), changes in storage (above, on and below surface) are negligible so the ΔS from equation 2-2 above can be ignored. Net consumptive use, largely from gains from wastewater discharges and losses to drinking water takings, is also assumed negligible over the year so anthropogenic inputs and outputs ($ANTH_{in,out}$) can also be ignored. Groundwater flow in and out of the system is treated as equivalent over the year so this term ($GW_{in,out}$) is ignored. There are no known major diversions in the MRSPR so this term can be ignored. The remaining elements include precipitation (P), surface water flow ($SW_{in,out}$), and evapotranspiration (ET). All terms are in consistent units, first in terms of volume (in m^3), and then for convenience these volumes are often expressed as equivalent depths (in mm) over the watershed area.

Over the long-term, the annual water budget equation (2-2) can be reduced to:

2-3 Precipitation – Runoff – ET = 0

2.3 Scale and Approach

The water budget can be completed at various temporal and spatial scales depending on the objectives of the exercise. For the conceptual understanding, estimates for a long-term (average), annual water budget for the major watersheds (Mississippi and Rideau) and the entire MRSPR will be completed. Computing a water budget on an average annual basis will provide an understanding of the inputs and outputs in the study area but may mask the effects of storage and stresses as changes in storage (surface water and groundwater) are assumed negligible. A monthly water budget will reveal more of the effects of stresses and the influence of surface water storage and the seasonal changes in water levels, particularly during the low flow periods, which will give a better indication of the effects of water takings on existing water supplies.

3.0 Physical Description of the MRSPR

3.1 Regional Overview

The MRSPR is located in Eastern Ontario. The major watersheds in the MRSPR include the Mississippi River and the Rideau River plus some smaller subwatersheds on the Ottawa River. The population of the MRSPR is 786,000 persons. The majority of the population resides within the urban portion of the City of Ottawa (including the urban areas outside of the Greenbelt). Most of the land in the MRSPR remains undeveloped.

Most of the MRSPR's population relies on municipal systems for its drinking water. There are twelve municipal drinking water systems in the MRSPR including five surface water systems (three on inland rivers and two on the Ottawa River) and seven municipal wells. Approximately 99% of all municipal water in the MRSPR is taken from surface water (Ottawa River, Mississippi River, Rideau River, and Tay River). This includes the MRSPR's two largest drinking water plants in the City of Ottawa, Britannia and Lemieux, which take from the Ottawa River and account for approximately 94% of all municipal surface water takings.

Excluding the Ottawa River plants (Britannia and Lemieux), it is estimated that 80% of municipal drinking water is from surface water (includes the inland rivers: Mississippi River, Rideau River, and Tay River) and 20% is from groundwater. Including private well consumption, it is estimated that 60% of all drinking water is supplied from groundwater and 40% is from surface water (excluding the Ottawa River plants). Of the groundwater takings, it is estimated that 83% is from private wells and 17% is from municipal wells. Bedrock aquifers supply groundwater to approximately 95% of the domestic water supplies and approximately 5% of other (i.e. municipal, commercial, industrial, institutional etc.) water supplies, compared to unconsolidated overburden deposits, which supply water for approximately 90% of domestic and 10% of other purposes.

In summary, the majority of the MRSPR's drinking water is supplied by the two City of Ottawa plants that take from the Ottawa River however, excluding the two Ottawa plants, it is estimated that approximately half of total drinking water consumption is from municipal facilities and the other half is from private wells. In terms of municipal facilities only (excluding private wells), the largest source (80%) of drinking water is from surface water. For all drinking water demands, the majority (60%) of drinking water is supplied by groundwater (excluding the Ottawa River plants).

Details on the MRSPR's water use are discussed later in Section 3.7. A summary table of average annual regional drinking water use is given in Appendix E.

3.2 Climate

The climate of eastern Ontario can be described as humid continental (MNR, 2005). The Great Lakes modify the climate in the Great Lakes St. Lawrence region, promoting milder winters and cooler summers due to the thermal inertia of the large masses of surrounding water and promoting increases in precipitation especially in winter. Precipitation in the region is caused also by the intersection of cold polar air from the north and warm moist air from the United States.

An inventory of all climate stations in the MRSPR found seven active stations (four in the Mississippi Valley and three in the Rideau Valley) and 103 historic stations in the MRSPR. The location of the climate stations in and around the MRSPR is given in Figure 3.2-1. Lists of active and historic climate stations in and around the MRSPR with details of data availability at active stations are given in Appendix A. In addition to these stations, there are 12 rain gauges in the MRSPR operated by the Conservation Authorities (eight in the Mississippi and two in the Rideau). The list of these stations is given in Appendix A. All the active stations have rainfall, snowfall, precipitation, and temperature records. A few of them record snow depth, as well.

Snow depth and water equivalent is also collected by the Conservation Authorities and by Parks Canada in the MRSPR. Within the Mississippi Valley, 14 snow course sites are operated by the Mississippi Valley Conservation Authority, among 11 snow course sites in the Rideau Valley, five are operated by the Rideau Valley Conservation Authority and six by Parks Canada (location map is given in Figure 3.2-2, and the list of snow sites is given in Appendix A).

In order to improve consistency in defining climatic conditions across the MRSPR, precipitation and temperature maps were reproduced for the MRSPR through a GIS approach from the "Great Lakes Forestry Centre" study (GCS NAD, NRR Can 1983). Canada-wide and North America-wide climate 'normals' for 1971-2000 were modeled in this study by Natural Resources Canada-Canadian Forestry Service using smoothing spline algorithms of ANUSPLIN and GIS (McKenney et al., 2006). Precipitation and temperature data received from this study were clipped to the boundary of the MRSPR, buffered by ten kilometres. The values were weighted over the MRSPR to get an average value for each of the major watersheds and for the MRSPR. Annual precipitation, and average minimum, maximum, and mean temperature surfaces for the MRSPR are given in Figures 3.2-3 to 3.2-6. Long-term annual precipitation for the region ranges from 840 to 1000 mm, with an average for the MRSPR as 912 mm. According to another study by MNR (MNR, 2005), the mean annual precipitation in the MRSPR ranges from 800 mm to 1000 mm. The average minimum, maximum, and mean monthly temperatures in the MRSPR are in the ranges of -1.5 to -20°C, 9.5 to 12°C, and 4 to 7°C, respectively.

There are only twelve years (1994-2005) of data available in common for the active climate stations in the MRSPR. These are summarized in Table 3.2-1. The average precipitation for the Mississippi and the Rideau watersheds are observed to be 902 mm and 912 mm, respectively with an average precipitation of 907 mm for the MRSPR. This is slightly low, but comparable to 912 mm observed in 1971-2000 period by Great Lakes Forestry study. During the last 10 year period, general pattern in the precipitation in the region from west to east and south to north are weak; however, highest (945 mm) and lowest (870 mm) values were observed in the southwest and in the middle of the MRSPR, respectively. There is an increase in the mean temperature from southwest to northeast of the MRSPR (Table 3.2-1).

For the climate pattern discussion, 50 year mean values of precipitation (including rainfall and snowfall) and temperature at two centrally located climate stations in each CA (Drummond Centre in the Mississippi Valley and Kemptville in the Rideau Valley) are used and summarized in Table 3.2-2. To provide 50 years of data, Drummond Centre data was combined with Chats Falls while Kemptville data was extended with Ottawa Airport data using a ratio for the 2001-2005 period data because this station had been replaced with an automatic gauge after 2000. Annual snowfall and rainfall values are high in the Rideau, as compared to those in the Mississippi. Rainfall and snowfall (water equivalent) account for 77% and 24% of the average annual precipitation in the MRSPR (Table 3.2-2). The highest snowfalls occur in December, January and February (water equivalent of 44, 42, and 38 mm [Mississippi] and 45, 42, and 37 mm [Rideau], respectively). The wettest months occur in April through December, with only 12 to 13 mm variability in monthly precipitation. The lowest precipitation is observed in February (55 mm in Mississippi and 60 mm in Rideau), and the highest precipitation is observed in September (81 mm in Mississippi and 85 mm in Rideau). Observed average annual precipitation of 848 and 898 mm, respectively, in the Mississippi and Rideau are in accordance with the values obtained from the Hydrological Atlas of Canada and studies done by MNR (1984), Moin & Shaw (1985), and Canadian Forestry Service (2002) [Appendix A]. Minimum temperatures are 1°C less and maximum temperatures are 1°C more in the Mississippi than in the Rideau. The mean temperatures in both watershed regions are the same. Although the precipitation is evenly distributed throughout the year, there is not enough precipitation to meet high rates of evapotranspiration in the summer months (May through August).

3.2.1 Precipitation Pattern

Precipitation varies with changes in the annual cycle, geographic location, and elevation. Graphs 3.2-1 and 3.2-2 show the annual total precipitation, rainfall, snowfall (water equivalent) and 5 year moving average of precipitation occurring at the Drummond Centre and Kemptville climate stations, respectively, tabulated over a period of 50-years (1954-2003). Average precipitation (snowfall and rainfall) totals in both regions are lower during the first 20 year period (1954-1972) than those in the last 30 year period (1973 to 2003). In both regions, for the last 30 year period, trends in rainfall, snowfall, and precipitation were weak; however, there does appear to be a slight decrease in the amount over the last 10 years. The driest period took place between 1957 and 1970, and the wettest between 1973 and 1987. The maximum and minimum precipitation occurrences in the MRSPR are shown in Table 3.2-3. Average monthly distributions of precipitation occurring at Drummond Centre and Kemptville for the period of 1954-2003 are given in Graphs 3.2-3 and 3.2-4, respectively. The histogram shows the contribution of rainfall and snowfall (water equivalent) to total monthly precipitation. Maximum precipitation occurs in the summer months, when all of it occurs as rainfall, while in the winter, 20 to 72 % of the total precipitation is in the form of snow.

3.2.2 Temperature Pattern

Similar to precipitation, temperature also varies with change in the annual climate cycle and geographic locations. Monthly distributions of average daily minimum, maximum, and mean temperatures at the Drummond Centre and Kemptville stations are shown in Graphs 3.2-5 and 3.2-6, respectively. Maximum temperatures (>10°C) occur between mid-April and mid-October, and begin to significantly decrease in September. Minimum temperatures (<0°C) occur between November and March. Generally, monthly maximum temperatures in winter and summer are -2 to -5°C, and 22 to 27°C and the minimum temperatures are -8 to -15°C and 10 to 13°C, respectively.

Graphs 3.2-7 and 3.2-8 show the time series of annual minimum, maximum, and mean monthly temperatures occurring at Drummond Centre and Kemptville climate stations, respectively, for the 50-year period (1954-2003). Over the 50-years period, the maximum daily temperature of 37.5°C occurred at Drummond Centre on August 3rd, 1988 and 37.8°C at Kemptville on August 1st, 1955; whereas, the minimum daily temperatures of -36°C and -39.4°C occurred at these stations respectively on January 27th, 1994 and February 3rd, 1971.

3.2.3 Evaporation Pattern

Lake evaporation is calculated using the observed daily values of pan evaporative water loss, the mean temperatures of the water in the pan and of the nearby air, and the total wind run over the pan. None of the climate stations in Ontario are currently measuring pan evaporation. Some historic data is available in the MRSPR. The Ottawa CDA and Kemptville climate stations have evaporation data for 25 years (1974-1998) and 22 years (1974-1995) respectively. Using this data, lake evaporation values at Ottawa CDA and

Kemptville stations were calculated as 612 and 559 mm per year, respectively. Average monthly (May through October) lake evaporation values range from 42.3 to 140 mm and 46.6 to 125 mm, at Ottawa CDA and Kemptville, respectively. Average monthly evaporation at these stations is shown in Graph 3.2-9. According to the Canadian Climate Normal's (1971-2000), the average annual lake evaporation at Ottawa CDA is 610 mm. The small difference between the two Ottawa CDA values can be attributed to the different periods of record. A Climate Normal's value was not obtained for Kemptville because there were gaps in the monthly data.

3.2.4 Calculated Evapotranspiration

Evapotranspiration (ET) is water loss due to a combination of evaporation (direct water loss to the atmosphere) and transpiration (water loss to the atmosphere via plant stomata). It generally comprises the largest loss in the rainfall-runoff sequence (Viessman and Lewis, 1996). The rate of ET depends on various factors including climate, soil, and land cover. Transpiration can be influenced by the type of vegetation and the depth of the root. Larger rooted vegetation such as trees will have longer transpiration rates than shallow rooted plants such as grasses and crops.

ET can be calculated with continuous climate data using various methods (Thornthwaite and Mather, Priestley-Taylor, Penman, Turc, Hargreaves, Blaney-Criddle, etc.). For this study, mean annual ET was calculated using the Thornthwaite and Mather (1955) approach with two different data sets described below.

ET was calculated using data from the Great Lakes Forestry Study (McKenney et al., 2006). This data set included 30 years of precipitation and temperature data from 1971-2000. Average annual evapotranspiration has been mapped for the MRSPR with this data in Figure 3.2-7. ET was also calculated using 30 years of data from a slightly different time period (1974-2003) from the AES Ottawa MacDonald Cartier International Airport (Ottawa Airport) climate station as it had the longest continuous period of record in the MRSPR. ET was calculated for various soils water holding capacities (the capacity of the soil to retain and supply water to plants (Agriculture Canada, 1995)). The soils water holding capacities in the MRSPR were determined for various soil textures and root depths with guidance from Table 3.1: Hydrologic Cycle Component Values from the "MOE Stormwater Management Planning and Design Manual" (MOE, 2003). Land cover was classified according to root depth (shallow, moderate, moderate to deep, and deep). Soils texture data was extracted from CANSIS (Agriculture Canada, 2002) and overlaid with the land cover data (MNR, 1991-1998) to determine the WHC. The soil water holding capacities assigned to the various land covers and soils textures found in the MRSPR are summarized in Appendix A.

The results of the ET calculations show little difference in average annual ET by using the two data sets described above (2% difference for the MRSPR (5% for Mississippi and

1% for Rideau). When ET was calculated using the Forestry Study data (1971-2000) it was found to be 575 mm for the MRSPR (570 mm for the Mississippi and 581 mm for the Rideau). Using the Ottawa Airport data (1974-2003), ET was found to be 587 mm for the MRSPR (598 mm for the Mississippi and 576 mm for the Rideau).

The calculated ET values compare well to previous studies although tend to be somewhat high but not significantly. As an example, the derived ET for the Rideau watershed was found to be approximately 560 mm (see Section 5.1 below for Derived ET). Philips (1976) calculated annual ET at the Ottawa Airport (1941-1970) for two WHC's as follows: 538 mm (WHC = 100 mm) and 566 mm (WHC = 200 mm). In the study herein, ET was calculated for the same WHC's for the same station but for a different period of record (1974-2003) and was found to be: 545 mm (WHC = 100 mm) and 594 mm (WHC = 200 mm). The average of these four values is approximately 560 mm (+34 mm, -22 mm), which, coincidentally enough, is the same as the derived ET for the Rideau. The derived ET is essential equal to the calculated ET for the same WHC. For a constant WHC, the variation in the calculated ET values can be attributed to the different periods of record with the climate data. As mentioned above, the calculated ET values for the Rideau were as follows: i) 576 mm using the Ottawa Airport from 1974-2003, and ii) 581 mm using the Great Lake Forestry data from 1971-2000 (McKenney et al., 2006). The average of these two calculations is approximately 580 mm, which is somewhat higher (3%) than the 560 mm. The main difference is due to the variation in water holding capacities (a weighted value for the Rideau versus 100 mm or 200 mm). The WHC for the Rideau watershed was 251 mm (256 for the MRSPR and 261 for the Mississippi). The ET value calculated over the Rideau watershed (580 mm) is reasonable in comparison to the lake evaporation values for Ottawa CDA (610 mm) (although some would suggest that a 30 mm difference between actual ET and lake evaporation may not be large enough).

The calculated ET values are concluded to be reasonable for the purposes of this study. It should be noted that for future subwatershed work, the calculated ET numbers may be a bit on the high side. The Thornwaite and Mather model is a conventional approach to calculating ET. If ET needs to be modeled for future stress assessments consideration could be given to a more modern approach.

3.2.5 Summary of Mean Temperature, Precipitation, and Evapotranspiration

The mean monthly temperature, precipitation and evapotranspiration averaged over the MRSPR are graphed in Graph 3.2-10 and tabulated in Appendix A. Temperature and precipitation data are from the Great Lakes Forestry data (McKenney et al., 2006) and are averaged over a 30-year period (1971-2000). Evapotranspiration was calculated using the Thornthwaite and Mather approach (Section 3.2.4) with the temperature and precipitation data as input parameters. The Forestry data (McKenney et al.) will be used for water budgeting purposes in this study because it is more advanced and better suited to the regional analysis than data from a single climate station.

3.3 Land Cover

The land cover in a study area can affect the water budget in a variety of ways. Land cover is an important factor in determining the amount of water that runs off of the land or infiltrates into the ground. Land cover can influence the water holding capacity of the soil. Water will mainly run off surfaces with low permeability such as pavement. Softer, more permeable surfaces such as cultivated land and woodland will infiltrate water more easily and potentially reach the ground water table and recharge aquifers or will move further downstream in the unsaturated zone and discharge back to surface water. Open water bodies will store water in depressions or provide a pathway for flow down rivers and streams. Land cover will affect the amount of water that lost to evapotranspiration. Forests may transpire more water than shallow fields because of the deeper roots. The amount of water consumption also varies with land use. Certain land uses may use more water as well such as agriculture, which uses water for crops and livestock.

Good land cover data is essential to the water budget. In Ontario, land cover has been classified by the MNR (1991-1998) into 28 categories. These categories can be broadly lumped into several smaller categories including aggregate, agriculture, aquatic & wetlands, development, forest & plantation, and other natural areas. Most of the land in the MRSPR is undeveloped. More than half (52.8%) of the MRSPR is classified as forest and plantations, which includes various types of coniferous, deciduous and mixed forest, coniferous plantations, and recent cutovers. Agriculture land represents the second largest land use (26.8%), and the combination of water and wetlands represents the third largest (16.2%). Only 2.4% of the total MRSPR is classified as settled and developed.

The land cover data for the MRSPR is presented in Figure 3.3-1. The land cover percentages are summarized in Table 3.3-1.

3.4 Geology and Physiography

The following sections briefly describe the conceptual geologic setting of the MRSPR to assist with the development of this conceptual water budget. A more detailed discussion of geology, physiography and hydrogeology can be found in the Watershed Characterization Report.

The MRSPR can be divided into two distinct geological environments: [1] the western half of the MRSPR (i.e. approximate area west of a line drawn between Arnprior, Carleton Place and Portland) where the Canadian Shield is exposed at surface, and [2] the eastern half of the MRSPR which is part of a larger physiographic region known as the Central St. Lawrence Lowland basin and where the Precambrian bedrock is overlain by sedimentary bedrock units and overburden deposits. Figure 3.4-1 shows the approximate extent of the Central St. Lawrence Lowland Basin and also where the Precambrian Shield is exposed at surface within the MRSPR. The western portion of the MRSPR is characterized as being higher in elevation compared to the eastern portion, hilly and little to no overburden sediments above the Precambrian bedrock unit. The eastern portion of the MRSPR is generally characterized as flat lying with sedimentary bedrock units overlying the Precambrian bedrock and localized areas with significant overburden thickness above these sedimentary bedrock units.

Following the Precambrian Era, an ancient ocean from the east flooded the Precambrian Shield within Eastern Ontario during the Middle Ordovician and Late Ordovician time (> 400 million years ago). During this time, known as the Paleozoic Era, the ancient ocean retreated and re-flooded many times, which resulted in, the erosion of the Precambrian landmass followed by the deposition of conglomerates, sandstone and carbonate-rich fine-grained sediments. The deposition of these sediments formed the many layers of sedimentary bedrock (sandstones, limestones, dolostones and shale) that now exist above the Precambrian basement rocks. More recent geologic events involving erosion of bedrock formations and the deposition of these sediments (clays, silts and sands) provide localized pockets of unconsolidated overburden material within the northern portion of the MRSPR.

The following sections provide a brief description of the topography, overburden geology, and bedrock geology within the MRSPR.

3.4.1 Topography

Topography within the MRSPR is highly variable and generally slopes from the west towards the east with a total relief of approximately 420 m. Figure 3.4-2 shows the ground surface topography throughout the MRSPR which can generally be divided into two regions: [1] the western half of the MRSPR where Precambrian bedrock outcrops and ground surface elevation is generally greater than 175 metres above sea level (masl), and [2] the eastern half of the MRSPR where Paleozoic bedrock overlies Precambrian bedrock and ground surface elevation is generally less than 175 masl. The highest ground surface elevation within the MRSPR is at the extreme western tip the MRSPR, south of Denbigh where ground surface is approximately 470 masl and the lowest ground surface elevation is along the shores of the Ottawa River where ground surface is approximately 40 masl.

3.4.2 Overburden Geology

A discussion of depositional history for the overburden sediments in Eastern Ontario and a detailed description of sediment types and their occurrence within the MRSPR are included in the Watershed Characterization Report (WCR).

Figure 3.4-3 shows the distribution of overburden materials throughout the MRSPR. With the exception of the northern and eastern portions of the MRSPR, bedrock generally outcrops throughout the study area resulting in very sparse and disconnected overburden deposits found in localized bedrock depressions.

Figure 3.4-4 shows the interpreted thickness of overburden materials based on information provided in the MOE water well records as presented in the Regional Groundwater Study (Golder et al., 2003). Generally, the overburden thickness within the MRSPR is thin to non existent (< 1 m) with the exception of areas in the northern portion of the MRSPR where bedrock valleys near the Ottawa and Rideau Rivers allow the accumulation of 10-30 m of clays and sands. East of the MRSPR, as the top of the Paleozoic bedrock drops in elevation and where the deepest portions of the former Champlain Sea were located, overburden thickness is much greater. Table 3.4-1 summarizes the types of sediments and the location of significant deposits of these sediments within the MRSPR.

3.4.3 Bedrock Geology

Figure 3.4-5 shows the generalized distribution of bedrock stratigraphy throughout the MRSPR. Generally, the bedrock geology comprises Precambrian-aged igneous and metamorphic rocks overlain by Paleozoic-aged sedimentary rocks. The Precambrian Shield exists throughout the entire MRSPR; it outcrops over the majority of the western portion of the MRSPR and is covered with Paleozoic-aged sedimentary rocks (sandstone, limestone, dolostone and shale) east of Perth and Almonte. Figure 3.4-6 shows three regional cross sections through the MRSPR and the generalized regional bedrock distribution. The locations of these cross sections are shown in Figure 3.4-5.

3.4.3.1 Precambrian Bedrock Geology

The geology of Precambrian bedrock within the MRSPR is extremely complex with many faults, folds, and a mixture of rock types including: crystalline limestones, gneisses, quartzites, intruded, deformed and metamorphosed by bodies of granite, syentite and other igneous rocks (Wilson, 1946).

Precambrian bedrock predominantly outcrops as a dome-shaped highland area, in the southwestern portion of the MRSPR, and is known as the Frontenac Arch. The Frontenac Arch connects the Precambrian bedrock of the Canadian Shield in Ontario to the Adirondack Mountains in New York. In addition to the western portion of the MRSPR, Precambrian bedrock is exposed at surface as a narrow band extending southeast from Galetta towards Carp and the City of Ottawa. This Precambrian bedrock ridge is locally known as the Carp Ridge and is formed as a result of a historic fault, known as the Hazeldean Fault that runs northwest to southeast, on the north side the Carp River.

3.4.3.2 Paleozoic Geology

The Paleozoic sedimentary bedrock formations within the Central-St. Lawrence Lowlands are categorized based on similar lithology and characteristics which are influenced by the age of deposition and depositional environment. Three groups of Paleozoic bedrock formations exist with the MRSPR, which include the Potsdam, Beekmantown, and Ottawa Groups. Table 3.4-2, modified from Golder et al. (2003), provides a description of age, thickness and lithology for each formation of each Paleozoic Group that exists within the MRSPR. The table is organized by depositional history; therefore the oldest bedrock formations are shown at the bottom and are overlain (where the bedrock units exist) by the younger bedrock formations, which are listed higher in the table.

3.4.3.3 Bedrock Faults

Following the formation of these Paleozoic rocks, ongoing shifting of bedrock masses due to continental tectonic forces resulted in a period of extensive faulting. Bedrock faults, fractures and joints are structural geology features that may provide a preferential pathway for groundwater movement. A simplified version of this fault network is shown in Figure 3.4-5, which only indicates the major faults within the MRSPR. The major faults within the MRSPR that are characterized by a vertical displacement exceeding 200 m include the Pakenham, Hazeldean, Gloucester and Rigaud faults and the Ottawa River fault series.

The Ottawa-Bonnechere graben, a down-dropped block of the earth's crust resulting from extension or pulling of the crust, is located within the northern portion of the MRSPR and is the most significant fault zone within the MRSPR. This graben was formed approximately 175 million years ago after the Paleozoic Era and therefore penetrates all of the bedrock formations within the Ottawa-St. Lawrence Lowland region resulting in abundant exposures of faults and fault zones, especially in the northern part of the MRSPR. The total displacement or down-drop of this feature is approximately 300 m as evidenced by the abrupt rise in Precambrian bedrock north of the Ottawa River (Chapman and Putnam, 1992). This graben is approximately 60 km wide and 700 km long.

The end result of these faults is the vertical displacement of bedrock units which is shown in three regional bedrock cross sections (Figure 3.4-6). This is important because the bedrock aquifer and aquitard units on either side of the fault will not necessarily be continuous and the bedrock within a fault zone typically dips towards the down-thrust side of the fault block, therefore causing complications in groundwater flow patterns.

3.5 Groundwater and Hydrogeology

The following sections briefly describe the conceptual hydrogeologic conditions within the MRSPR to assist with the development of this conceptual water budget. A more detailed discussion of groundwater flow and aquifer/aquitard units is included in the Watershed Characterization Report.

3.5.1 Groundwater Flow Direction

3.5.1.1 Shallow and Deep Groundwater Flow Systems

Overall the regional groundwater flow pattern represents a subdued representation of the topography and is heavily influenced by the elevation of surface water bodies (lakes, rivers, streams, etc.). Within the MRSPR, shallow groundwater flows from the regional recharge area of the Precambrian Highlands (in the southwest) towards the regional discharge area of the Ottawa River (in the north-northeast). Figure 3.5-1 shows the regional distribution of shallow water table elevations that depicts a regional groundwater flow from the southwest towards the Ottawa River in the north-northeast portion of the study area. This map was modified from the Regional Groundwater Study (Golder et al., 2003) and is an interpolated surface (kriged) using a combination of surface water elevations plus static water level data from wells that were completed to depths less than 15 m bgs.

Local groundwater flows are influenced by local topography and generally flow from higher elevations towards low lying areas, which are sometimes evidenced by surface water features (Mississippi River, Rideau River, major lakes, wetlands, etc.) as shown in Figure 3.5-1. Local variation in geology also influences groundwater flow where groundwater connection is typically through the higher permeability units.

All bedrock units are conceptualized to be hydraulically connected through fracture networks however the presence of less fractured and lower permeable bedrock layers may result in local flow barriers. The orientation of the local fracture and joint structural pattern will greatly influence the groundwater fracture flow pattern.

Deeper groundwater flow is less influenced by surface features and more influence by connectivity of aquifer material (i.e. fractured bedrock or sand and gravel units) and therefore may flow underneath smaller surface water features that act as minor discharge features for shallow groundwater flow. Figure 3.5-2 shows the regional distribution of the deep groundwater potentiometric surface, which appears similar compared to the shallow water table elevations. This map was modified from the Regional Groundwater Study (Golder et al., 2003) and is an interpolated surface (kriged) using the static water level data from wells that were completed to depths greater than 30 m bgs. The similarity between these two maps is expected since both maps are controlled by topography (water level measurements from ground surface) and the fact that many of the water elevation readings likely incorporate open fractured bedrock boreholes which may connect the shallow and deep bedrock aquifers.

Based on water levels measured in wells completed deeper than 30 m below ground surface, deep groundwater flow within the Nepean sandstone unit is conceptualized as flowing east-northeast across the boundary with South Nation Conservation. Assuming a horizontal gradient of approximately 0.001 m/m across this boundary, a hydraulic conductivity for the Nepean sandstone of approximately $1x10^{-4}$ m/s, and a total thickness of Nepean sandstone of 40 m, a groundwater flux of approximately $4x10^{-6}$ m^3/s per m length is conceptualized across this boundary.

3.5.1.2 Long Term Groundwater Elevation Monitoring - PGMN Well Network

The behavior of static water levels over time was studied by looking at hydrographs for 22 PGMN wells. Hourly static water levels readings have been recorded at these locations (Figures 3.5-1 and 3.5-2) using dedicated dataloggers since 2003. These hydrographs are reproduced in Appendix B and do not indicate any significant increase or decrease in static groundwater levels over this time period. Although this is an indication that groundwater mining is not occurring at these locations, three years is not sufficient time to conclude any trends in long term water level behavior. Analyses of longer term static water level trends should be continued as more data is available.

The locations and average static groundwater level of all Provincial Groundwater Monitoring Network (PGMN) wells that have been continuously monitored with a datalogger since 2003 are plotted on Figures 3.5-1 and 3.5-2. As can be seen in these figures, the three-year average static water levels at these locations support the regional groundwater flow directions shown.

3.5.2 Hydrogeology

The hydrogeology of the MRSPR is conceptualized as consisting of 12 hydrostratigraphic units (8 aquifers and 4 aquitards) as summarized in Table 3.5-1.

3.5.2.1 Aquifer and Aquitard Distribution

Figure 3.5-3 shows the general distribution of domestic water taking from each of the eight aquifer units described above. The lowest hydrostratigraphic unit that the well intersects as described in the MOE well records or golden spike information was considered to be the aquifer of choice for that particular well. The interpreted extent of each water supply hydrostratigraphic unit was constructed by drawing a boundary around clusters of MOE well records that were assumed to draw water from similar aquifers. This map is an approximation of aquifer usage based on reported geology within MOE water well records. Although variations in bedrock description are evident in the MOE well records database, a general trend of bedrock formations pumped correlates with the limits of the shallowest aquifer of choice.

The MRSPR contains a mixture of confined and unconfined aquifers. Sometimes there is both a shallow and deep aquifer such as in the central portion of the MRSPR where the overlying Oxford-March Formations provide a shallow unconfined water supply and the underlying Nepean Sandstone provides a deeper confined water supply. Figure 3.5-4 shows a conceptual distribution of confined and unconfined aquifers as they relate to the domestic water takings (Figure 3.5-3).

Generally, domestic groundwater supply is obtained from the following aquifers: [1] the western portion of the MRSPR uses the unconfined Upper Precambrian Bedrock aquifer, [2] the central portion uses the unconfined Nepean Sandstone, confined Nepean Sandstone and the unconfined Oxford-March aquifers, [3] the north and extreme east portions use a mixture of unconfined and confined overburden (sand and gravel) and bedrock (limestone and shale) aquifers.

The Nepean Sandstone aquifer unit is the most desirable bedrock aquifer from a quantity and quality perspective within Eastern Ontario. It provides the highest sustainable yield of high quality potable groundwater and is therefore targeted by large commercial and municipal systems (Almonte, Munster, Richmond, Merrickville, Kemptville, and Westport) unless a sufficient water supply is obtainable from an overburden esker deposit (Carp).

The Oxford and March Dolostone aquifer is the most highly used domestic water supply aquifer in the MRSPR where the Nepean Sandstone aquifer is deep (i.e. high cost of drilling deeper) and a sufficient overburden aquifer (sand or gravel) does not exist. This type of aquifer is most common East of Smiths Falls and Appleton. Alternatively, where sand and gravel deposits are extensive and interconnected, they form esker deposits and lateral moraines, which prove to be highly significant aquifers around the south and east of the City of Ottawa.

Figure 3.5-5 shows the location and extents of all completed source-water-protection related groundwater studies within the study region as well as the location of five conceptual cross section views that are drawn through each municipal groundwater supply aquifer within the MRSPR. The conceptual cross section views are shown in Figures 3.5-6 through 3.5-10.

3.5.3 Groundwater Recharge and Discharge

Groundwater recharge features are found where the dominant vertical groundwater flow direction is downwards near ground surface. Areas of significant groundwater recharge typically exist on topographic high elevations or where a porous surficial sand cover exists in a flat lying area, which allows the precipitation to infiltrate into the deeper groundwater aquifers. Conversely, groundwater discharge features are found where the dominant vertical groundwater flow direction is upwards near ground surface and where ground surface elevation dips below the water table elevation (wetlands, lakes, rivers, etc.) and are a significant source of water for wetlands and some lakes, streams and rivers.

3.5.3.1 Potential Recharge Areas Based on Vertical Gradients

Another method for determining recharge areas is to look at vertical gradients. Figure 3.5-11 shows interpreted areas of potential recharge and discharge as determined by Golder et al. (2003). Potential recharge conditions were assumed to exist in those areas where the potentiometric groundwater elevation in deep wells (Figure 3.5-2) is at least 5 m lower compared to the shallow water table elevation (Figure 3.5-1), therefore indicating a higher possibility that a downward gradient may exist. Similarly, potential discharge conditions were assumed to exist in those areas where the deep potentiometric elevation (Figure 3.5-2) is at least 5 m greater than the shallow water table elevation (Figure 3.5-1), therefore indicating a higher possibility that an upward gradient may exist. As expected, the areas of potential recharge generally correspond with topographically high areas in the western portion of the study area and in areas of local topographic highs throughout the remainder of the region. Similarly, the discharge areas typically correspond to low lying river valleys such as the Mississippi and Rideau as also shown by the locations of flowing well conditions. Although the distribution of recharge and discharge areas is variable within the western portion of the MRSPR where Precambrian bedrock outcrops, it corresponds to the highly variable ground surface elevations within this area.

Although this approach is useful for identifying potential recharge and discharge area at a regional scale, there are two limitations identified with it: [1] this approach assumes that the deep wells are connected to the unconfined aquifer, where it is common that confined wells or deep bedrock wells are not hydraulically connected; and [2] by looking at the distribution of vertical gradients without taking into account the geologic structure and hydraulic conductivity of the material lying in the unsaturated zone, the areas identified in Figure 3.5-11 cannot be considered more than “potential” recharge and discharge areas.

3.5.3.2 Groundwater - Surface Water Interaction

Groundwater and surface water interaction is a highly complicated and potentially variable relationship (both spatially and temporally) that is not well understood in most watersheds. For example, a stream can have both groundwater discharge and groundwater recharge features over a short reach, which depending on the seasonal fluctuations in water levels will change throughout the year. Although surface water features are typically associated with discharge features, surface water features may also be associated with recharge features or areas with no net discharge or recharge. For example, the numerous wetlands (or bedrock depressions) situated on top of the poorly drained, shallow bedrock area of the Precambrian Shield in the western portion of the MRSPR may recharge the underlying groundwater aquifer and therefore be a source of water for domestic water supplies in the area. On the other hand, these wetlands (and bedrock depressions) may not interact with the groundwater significantly and therefore act as temporary reservoirs. An example where surface water may be recharging the underlying groundwater flow systems is where surface water bodies are situated on top of, or within, permeable bedrock formations (i.e. Mississippi Lake on top of Nepean Sandstone). This lack of understanding highlights that recharge and discharge is a complicated process that relies heavily on local site specific information and forms a data gap that should be addressed in future studies.

3.5.3.3 Shallow versus Deep Recharge

It is important to recognize the difference between the confined and unconfined groundwater flow systems, whereby the shallow recharge areas may not actually recharge the deeper confined aquifer. Therefore, different approaches to define significant recharge areas for shallow groundwater flow systems and deeper groundwater flow systems are warranted. The MOE (1995) approach to calculate recharge rates based on topography, soil permeability and land cover was used to define significant recharge areas for the shallow groundwater flow system, as discussed further in Section 5.2. Deeper, confined aquifer recharge areas are defined in a more conceptual discussion below.

Within the MRSPR, confined aquifers exist where sand, gravel and bedrock aquifers exist below a less permeable covering layer. For example, [1] sand and gravel aquifers overlain by a surficial clay layer such as in the northern portion of the MRSPR, and [2] where the Nepean Sandstone aquifer is covered by lower permeable bedrock units (i.e. limestone, dolostone), in the central and east portions of the MRSPR, east of Carleton Place. In these areas, groundwater is likely recharged partially from the overlying units but also from unconfined aquifers that are hydraulically connected to the confined aquifer. For example, the water recharging the deeper confined Nepean Aquifer for the Merrickville and Kemptville municipal supplies is conceptualized to partially originate a significant distance west of these communities where the Nepean Aquifer outcrops (Figure 3.4-5). Similarly, where a low permeability surficial soil (i.e. clay) is covering a deeper aquifer material (i.e. sand), the recharge area for this sand aquifer is conceptualized to largely come from "windows" in the overlying confining layer and from areas further away where the confining layer does not exist. Although conceptualizing confined and unconfined aquifers attempts to simplify the understanding of groundwater recharge and discharge areas, more complicated situations exist involving multiple aquifers as well as the more common and perhaps more realistic conceptualization involving leaky aquitards and semi-confined zones.

3.5.3.4 Recommendations for Additional Work

Additional methods to help understand the concepts of deep groundwater recharge, that are considered beyond the scope of this conceptual water budget report but may prove useful during Tier 1 water budget analyses include: [1] differentiating groundwater chemistry of shallow and deep groundwater using isotopes to date groundwater, and [2] observation of static groundwater levels in response to precipitation events for different aquifers (shallow and deep), and [3] overlying information in GIS layers pertaining to hydraulic conductivity, depth to water (thickness of unsaturated zone), and vertical gradient to better determine significant recharge areas. A better understanding the recharge and discharge areas will ultimately result in a better understanding of infiltration into the municipal well aquifers and therefore a more accurate municipal well water budget.

Golder et al. (2003) looked at the isotope composition (^{18}O, ^{16}O, ^{3}H, ^{2}H, and ^{1}H) of groundwater collected during 2002 from eleven wells to help determine groundwater age. They demonstrated that some groundwater in deeper sandstone aquifers appeared to show longer residence times compared to shallow groundwater. Although this suggests that shallow recharge from younger water is not significant and that the deeper aquifer may be confined (i.e. not hydraulically connected to the shallow groundwater flow system), no correlation was possible between groundwater age and depth of well. One possible explanation for the poor correlation of groundwater chemistry with depth is that the deep groundwater wells are completed as open bedrock wells, therefore allowing cross-connection to occur resulting in a blended chemistry between shallow and deep water bearing zones. Further literature review or investigations would be beneficial in understanding deep aquifer groundwater recharge.

Detailed analyses of static groundwater fluctuations in response to precipitation events may provide understanding of the difference between recharge rates for shallow and deep aquifers. As an example the static groundwater elevation of PGMN well ID # 260, completed in Precambrian bedrock and situated in the western limits of the MVCA area, was plotted with daily precipitation data from the closest climate station (Appendix B) during 2005. A second, more detailed plot during the time period of June and July 2005 shows that there is a varied response to precipitation events (magnitude and time lag) depending on volume of precipitation and duration of precipitation event. For example, starting on June 13 a significant precipitation event over 5 consecutive days (total precipitation of approximately 96 mm over 5 days) resulted in an increase in water level in the borehole of 18 cm after a lag time of approximately 4 to 7 days. Another, smaller precipitation event on July 17 (28 mm over 2 days) does not show much of an increase in water level. One explanation for the variability in levels of response to various precipitation events is that the rain recorded at the gauge may be different from the rain actually falling at the monitoring well. Further analyses of water levels in wells responding to precipitation events at different times of the year, and comparing responses in wells completed in different hydrostratigraphic units (or geographic locations) during the same precipitation event would be beneficial in understanding groundwater recharge in different hydrostratigraphic units and geographic locations.

Groundwater vulnerability within the MRSPR is being studied as part of this source water protection work and includes Intrinsic Susceptibility Index (ISI) calculations. ISI calculations incorporate the hydraulic conductivity and the thickness of each unsaturated geologic layer about the water table. When the regional compilation of unsaturated zone thickness and K values is completed in a GIS form, this information could be studied along with vertical gradients, slope and vegetative cover to establish a better understanding of significant recharge areas.

3.5.4 Limitations with Groundwater Data

There are several potential sources of error associated with the interpretation of the groundwater elevations for the purpose of groundwater flow direction, vertical gradients and recharge. Potential sources of error, listed in order of concern, associated with the interpretation of the groundwater flow direction and with this method of mapping recharge and discharge features include:

1. Static water levels in large “open” boreholes completed in bedrock represent a hydraulically diluted (average) water elevation (blended head) due to intersecting multiple fractures;
2. Errors associated with static water level measurements in MOE records – each water level was recorded immediately following drilling and therefore may not have equilibrated. In addition, each reading was collected at various dates spanning decades;
3. Regional groundwater elevations are being interpolated over large areas where the data is sparse (i.e. western area in Addington Highlands);

4. Regional ground surface elevation is taken from a Digital Elevation Model (DEM) with a grid spacing of 25 m; and,
5. Location errors associated with MOE wells (UTM coordinates) – most UTM coordinates were selected from an Ontario Base Map and therefore are not overly accurate.
6. Uncertainty is well drillers reported lithology that is used to determine unconfined/confined conditions and aquifer unit.

Overall the confidence in the flow directions is relatively high on a regional scale. These potential sources of errors will become more of a concern in areas where data is sparse such as in the western portion of the MRSPR, or if this data was used to predict groundwater elevations on a local scale.

Similarly, the source of error associated with determining groundwater elevations for both shallow and deep aquifers using these methods is carried through into the delineation of potential recharge and discharge features. These maps should only be used as a general regional interpretation and should not be relied on for local conditions.

3.6 Surface Water

The surface water in the MRSPR features many lakes, rivers, and wetlands. The upper portion of the MRSPR, underlain by Canadian Shield, is speckled with deep glacial lake systems. The lower portion is dominated by large riverine systems. Flows and levels on many of these systems are controlled by hydraulic structures. Hydraulic structures including dams, lock gates and generation stations control much of these systems. Many are continuously measured by a network of hydrometric stations.

3.6.1 Rivers and Reservoirs

The MRSPR is divided into two major watersheds: the Mississippi River watershed in the west and the Rideau River watershed in the east (Figure 3.6-1). For planning purposes, the watersheds are sub-divided into subwatersheds. Both watersheds are roughly the same size, the Rideau being the larger of the two, while the Mississippi is much longer and flatter, and discharge into the Ottawa River. The MRSPR also includes the much smaller Carp River, which is located within the jurisdictional boundaries of the Mississippi Valley Conservation Authority, and some smaller tributaries that all drain to the Ottawa River. The drainage areas of the major watersheds and the subwatersheds in the MRSPR are listed in Appendix C.

The Mississippi River runs from an upstream elevation of 325 metres above sea level for 212 kilometres to a downstream elevation of 73 metres, for a total drop of 252 metres or an average slope of 0.1%. The main tributaries to the Mississippi River include the Clyde River, the Fall River, and the Indian River.

The Rideau River runs from an upstream elevation of 163 metres above sea level at Burridge Lake for 160 kilometres to a downstream elevation of 40 metres at the Ottawa River, for a total drop of 123 metres an average slope of 0.1% slope. The main tributaries on the Rideau River include the Tay River, Jock River, and Kemptville Creek. The Rideau River is part of the Rideau Canal, a major navigation route between Ottawa and Kingston. The Rideau Canal splits at Newboro. From here it flows north along the Rideau River to the Ottawa River (and south into the Cataraqui River). The principal flow control point on the Rideau Canal is at Poonamalie, which regulates levels in Big Rideau Lake and Lower Rideau Lake, thereby affecting flow to the downstream reaches.

Most of the storage in the MRSPR is held in lakes in the upper half of the watersheds, which is underlain by Canadian Shield, for navigation, recreation and hydroelectric power generation. Hydraulic control structures are operated/owned by Parks Canada (for the Rideau Canal), Ministry of Natural Resources, the Conservation Authorities, and power generation companies. There are approximately 30 water control structures in the Mississippi Valley including 25 dams and 5 power generating stations. Twelve of these structures were identified through the Mississippi River Water Management Plan (MVCA, August 2005) as having a significant affect on flows and water levels on the Mississippi River. There are 46 control structures in the Rideau Valley including 24 dams, 19 locks (on the Rideau Canal) and three power generating stations. The locations of the surface water control structures are shown in Figure 3.6-2. Characteristics of the major reservoirs (as defined in the Watershed Characterization Report) in the MRSPR are given in Appendix C.

3.6.2 Streamflow and Runoff Patterns

Streamflow is the combination of direct runoff and shallow and deep groundwater discharge. It is the flow we see in the lakes, creeks, rivers and streams. Streamflow is measured at hydrometric stations located on surface water bodies throughout the MRSPR. Streamflow data has been obtained from HYDAT (WSC, 2003), from Parks Canada (for the Rideau Canal) and from the Mississippi and Rideau Valley Conservation Authorities. The locations of the active stations are shown on Figure 3.6-2. A detailed data inventory of all active and historic (e.g. discontinued) stations in the MRSPR is given in Appendix D.

Fourteen of the active stations in the MRSPR have been selected for further analysis in this study. Seven of these stations are in the Mississippi watershed, and seven are in the Rideau watershed. The 14 stations are operated by Water Survey of Canada (WSC) except for three of the Rideau stations, which were originally operated by WSC but are now operated by Parks Canada on the Rideau Canal. These 14 stations gauge approximately 90% of the MRSPR's total area. Twenty percent of the Mississippi River watershed remains ungauged as its most downstream station is at Appleton. The most downstream station on the Rideau River is at Ottawa, which leaves only about 1% of the area ungauged. The names and drainage areas of the 14 selected stations are given in Table 3.6-1. The locations of the stations are shown on Figure 3.6-2.

To see the pattern in a long-term streamflow record for the most recent period, data from 1974-2003 was selected to form a 30-year period (data from 2004 was not available in time for this report). Five of the 14 selected stations had 30 years of complete data (i.e. no missing data). Three of these stations were in the Mississippi (Mississippi River at Appleton, Clyde River at Lanark, Carp River at Kinburn), and two were in the Rideau (Rideau River at Ottawa and Jock River at Richmond). Kemptville Creek and Indian River at Blakeney had few data gaps. The Tay River at Perth has a lot of missing data in this period, mainly prior to 1993.

Streamflow correlations were completed at each station to fill in missing data. Stations in the Mississippi and Rideau watersheds were treated separately. Correlations were done for a common period of records. Degree of correlation evaluated based on correlation coefficient and slope and intercept of the best-fit line. The station which best correlated with the station having missing data were selected as the representative station for data infilling. Correlations were repeated for the missing months. Monthly correlation equations were generated from the representative stations, and were used to fill data gaps to form a complete 30 year data sets from 1974 to 2003. An inventory of the data and the data infilling approach for stations from 1974 to 2003 are given in Appendix C.

Because the station on the Tay River at Perth is missing almost 20 years of data, streamflow correlations were not completed here. For now, the seven years of data from HYDAT will be used. For future water budgeting work, estimates of streamflow may require advanced modeling.

Mean annual streamflow (in m^3/s) was calculated from 1974-2003 (Table 3.6-1). The highest flows occur at the station on the Mississippi River on Appleton (as it's the most downstream station). The largest flows on tributaries to the Mississippi River occurred in order on the Clyde River, the Fall River, the Carp River, and finally the Indian River (Table 3.6-1). The highest flows on the Rideau River occur at Ottawa (the most downstream point). The largest tributary flows occur on the Tay River (only 7 years data), followed by the Jock River and then Kemptville Creek (Table 3.6-1).

Mean annual and monthly runoff (in mm) at the stations have been calculated for a 30 year period (1974-2003). Depth of runoff was calculated by multiplying the mean streamflow at the station with the time step (to get volume), and dividing by the drainage area. Long-term annual runoff at each station is also given in Table 3.6-1. Long-term annual and monthly runoff and mean monthly streamflows at different gauges in each watershed region are shown in Graphs 3.6-1 through 3.6-4.

Monthly flows peak in the spring (April) during snowmelt. The lowest monthly flows occur in July, August, and September (Graphs 3.6-3 and 3.6-4). Eight of the 14 stations had the lowest annual runoff occurred in the year 1989 (Graphs 3.6-1 and 3.6-2). All of these stations are located in Mississippi, except for Jock River (Rideau). Four stations, Rideau River at Ottawa, Manotick, and Merrickville and Tay River, had 2001 as the lowest annual flow year, and two other, Marble Lake and Smiths Falls, show 1977 as the lowest annual flow year. Kemptville Creek shows lowest annual flow in the year 1995. A preliminary comparison of the years in which lowest streamflow and lowest annual precipitation occurred does not show any correlation.

The mean annual runoff from 1974-2003 for the MRSPR was estimated as 364 mm/yr (area-weighted average of runoff at all the stations) with 365 mm/yr in the Mississippi and 364 mm/yr in the Rideau. The mean annual runoff at the stations ranged from 328 to 446 mm/yr from 1974-2003. These numbers appear reasonable when compared to long-term annual runoff values from previous studies (Hydrological Atlas of Canada, 1978; MNR, 1984; and Moin and Shaw, 1985). The Hydrological Atlas of Canada (1978) values range from 300-400 mm. The MNR (1984) values range from 200-350 mm per year, which is somewhat lower than the station data but more or less comparable. The Moin and Shaw (1985) values range from 325-500 mm, which is also comparable. The mean annual runoff from the selected stations is concluded to be representative of the MRSPR. Any differences between the station data and the previous studies are likely largely due to differences in the periods of record. Mapping from the previous studies is given in Appendix C.

A comparison of annual historical flows at the oldest stations with longer period of records (>50yrs) in the MRSPR is given in Table 3.6-2. The flows are compared using all available data to flows from the last 30 years only (1974-2003). The results indicate less than 8% difference between the two periods. The mean annual runoff at Appleton (340 mm) over the entire period of record (1918-2003) and that at Ottawa (327 mm) over entire period of 1949-2003 appear low when compared with their mean annual runoff from 1974-2003 period (357 mm at Appleton and 352 mm at Ottawa). The rating curve may have changed at these stations thereby changing the flow data. Further studies on the historical flows at these stations are recommended. Runoff at the most downstream stations, Appleton and Ottawa, over 30 years are very similar. These are large neighbouring river basins with similar weather and geologic conditions; and when averaged over a common long-term period they will show similar flows, although local conditions will vary.

3.6.3 Baseflow Data

Baseflow is the component of streamflow that is mainly from ground water discharge to surface. Low flow measurements taken in streams and creeks during the summer are traditionally used to approximate baseflow. There is no baseflow data for the MRSPR so it will be estimated using a hydrograph separation method. Hydrograph separation is a procedure used to separate a streamflow hydrograph into baseflow and direct runoff components. This technique divides a streamflow hydrograph into two major components: baseflow and surface runoff (Sloto and Crouse, 1996; Winter et al., 1998). Interflow is the lateral movement of water in the unsaturated zone during and immediately after a precipitation event, and the water moving as interflow discharges directly into a surface water body (Fetter, 1980). Interflow is usually ignored in hydrograph analysis because its amounts are relatively small compared with the portion of direct runoff and baseflow.

3.6.3.1 USGS Baseflow Index (BFI) Method

Baseflow indices (BFI) from a study entitled “Base flow in the Great Lakes Basin” done by USGS (Neff et al., 2005) were used in the baseflow estimation for the watershed. The study used the geology (G) model to assess the groundwater component of streamflow and BFI. The BFI was approximated using proportions of surficial-geology classes (e.g. Bedrock, Tills, Organic sediment, Coarse-textured sediment, Fine-textured sediment) within the areas that are upstream of the hydrometric stations (Neff et al., 2005).

The BFI values ranged from 0.42 to 0.70 in the Mississippi watershed and 0.40 to 0.65 in the Rideau watershed. Out of the six models, the BFLOW model predicted the lowest BFI values and HYSEP1 model predicted the highest. The average BFI was 0.60 for the Mississippi and 0.55 for the Rideau. The average BFI for the MRSPR was 0.58, which was calculated by taking an area-weighted average of the BFI values from the Mississippi and Rideau. These values are comparable to indexes of 0.30 to 0.79 found in the Moin & Shaw mapping for the Region (see Appendix C). The BFI values for the Mississippi and Rideau watershed regions and the calculated values for the entire MRSPR are given in Table 3.6-3.

When multiplied by the annual runoff, the baseflow indexes provide an estimate of annual baseflow (same approach used in the Regional Groundwater Study (Golder et. al. 2003). Long-term annual baseflow was estimated by taking the average BFI value from the six groundwater models for each watershed and multiplying it by the long-term annual runoff from 1974-2003. The resulting baseflow estimates for 1974-2003 are given in Table 3.6-4.

3.6.4 Reservoir Level Data

Hydrometric stations have been established to measure water level data at the major reservoirs in the MRSPR. All stations measuring water levels on the reservoirs in the Mississippi are operated by MVCA. All stations in the Rideau measuring water levels on the reservoirs are operated by Parks Canada (formerly by WSC). The locations of the stations are shown in Figure 3.6-2. An inventory of all stations in the MRSPR that collect water level data (active and historic) is given in Appendix D.

The available reservoir level data was inventoried over a 30 year period of interest (1974-2003) for selected reservoirs. This data will be used for future monthly water budgeting computations in Tier 1. Any missing data can be in-filled using reservoir rule curves where available. Where rule curves are not available the average of the available data can be used. A summary of the selected stations and the proposed data infilling approaches is given in Appendix C.

3.6.5 Wetlands

Wetlands cover approximately nine percent of the MRSPR. They can have a major influence on surface water storage depending on the size of the wetland, the type (marsh, fen, bog or swamp), its location within a catchment (adjacent to lakes/rivers, isolated, etc.), the soils in the area (clay versus organics), the underlying geology, and the elevation of the water table. There are various types of wetlands in the MRSPR. The inland marsh is probably the most influential in terms of hydrology as it likely holds the most water. Inland marsh covers 0.6% of the area, which is not significant to the MRSPR but may be more significant at the subwatershed level. The storage capacity of the wetlands in the MRSPR is unknown. There is no known water level data on wetlands either. These factors would have to be evaluated to gain an understanding on how the wetlands contribute to surface water storage (and also their effects on groundwater). Influence on the water budget is unknown at this time. Some of the larger wetlands may need to be modeled with advanced modeling techniques to see their effects on the water budget in the MRSPR. The distribution of the wetland coverage in the MRSPR is given in Table 3.6-5.

3.7 Water Use

Water is used in the MRSPR in a variety of ways including for drinking water (drinking water plants, municipal wells and private wells), for agriculture, industrial / commercial / institutional processes as well as for groundwater remediation etc. Water use data is summarized below. A summary table of average annual drinking water uses (municipal and private) broken down for the MRSPR is given in Appendix E.

3.7.1 Permit to Take Water Database

The Ontario Permit to Take Water (PTTW) database tracks permitted water takings in Ontario. The database lists only the permitted taking (not the actual taking) so it is of limited use at this time. According to the most current version of the database (October 2006), there are a total of 331 permits in the MRSPR including 112 permits in the Mississippi and 219 permits in the Rideau. The largest number of permits is issued under “Miscellaneous” followed by “Water Supply”. The total volume of permitted water takings in the MRSPR is more than 31 million cubic metres per day including more than 8 million cubic metres per day in the Mississippi and 23 million cubic metres per day in the Rideau. The highest volume of permitted takings is for “Remediation” (e.g. groundwater remediation). The PTTW locations are shown in Figure 3.7-1. A detailed summary of the PTTW’s in the MRSPR is given in Appendix E.

3.7.2 Municipal Drinking Water Takings

There are twelve municipal water supply systems in the MRSPR including five drinking water plants that take from surface water (three on inland rivers and two on the Ottawa River) and seven municipal wells that take from groundwater. The two plants that take from the Ottawa River (Britannia and Lemieux) are the largest surface water systems. They are owned and operated by the City of Ottawa. The three inland river systems include Carleton Place, Smiths Falls, and Perth, and take from the Mississippi River, the Rideau River, and the Tay River respectively. The seven municipal wells take include Almonte, Carp, Kings-Park Richmond, Munster Hamlet, Kemptville, Merrickville, and Westport. The locations of the municipal drinking water systems in the MRSPR are shown in Figure 3.7-2.

Historical daily drinking water data has been obtained from pump records from the municipalities. An inventory of the data collected to date is given in Table 3.7-1. This data was used to calculate average drinking water takings from municipal systems in the MRSPR.

Average takings from surface water account for 80% of the total municipal takings in the MRSPR (excluding Britannia and Lemieux). The largest municipal surface water taking from an inland river is from the Rideau River for Smiths Falls. The largest municipal well is at Almonte. Average municipal takings have been calculated for a common period (2000-2005). Average takings for each facility are given in Table 3.7-2. The total regional municipal taking is the sum of the average takings from the inland river plants and the municipal wells. Takings from Britannia and Lemieux are shown in the footnote. They have been excluded from the total water takings summary as they take from the Ottawa River and are not on inland rivers.

3.7.3 Municipal Sewage Discharges

There are seven municipal sewage treatment facilities that discharge in the MRSPR, six of which discharge sewage to inland rivers and one, which discharges sewage to the Ottawa River. These sewage facilities include two facilities in the Mississippi Valley at Almonte (Mississippi Mills) and Carleton Place, which discharge to the Mississippi River, and four facilities in the Rideau Valley including Kemptville, Merrickville, Smiths Falls, and Perth each of which discharge to the Rideau River except for Perth, which discharges to the Tay River.

R.O.P.E.C. (Robert O. Pickard Environmental Centre) (also known as “Green’s Creek”) is the City of Ottawa’s sewage treatment facility. It discharges its sewage to the Ottawa River. It services the sewage discharge from the City of Ottawa (areas connected to the Britannia and Lemieux water supply plants) plus some surrounding areas such as Carp. Both Munster Hamlet and Richmond, including the areas on a municipal well in King’s Park and the remainder of Richmond on private wells, discharge its sewage via forcemain to R.O.P.E.C. Richmond has discharged to R.O.P.E.C. for a long time while Munster recently (i.e. in the last 5 years) switched from having its own lagoon to discharging at R.O.P.E.C.

Sewage discharge data has been collected from each of the inland river systems. Average annual sewage discharge rates have been calculated based on data from 2000-2005. The locations of the municipal sewage discharges in the MRSPR are shown in Figure 3.7-3. The data collected to date and the average annual discharge rates are shown in Table 3.7-3.

Municipal drinking water takings from surface water may not be significant to water budgeting as they take their water from surface water and discharge sewage back to surface water and the overall net consumption would be assumed as zero, particularly at the larger time scales (annual). At the smaller time scales (monthly and daily) the differences between the takings and the discharges may be greater and thus more significant to the water budget. Municipal wells are more significant to water budgeting as they take from groundwater and discharge to surface water. None of the municipal drinking water systems in the MRSPR discharge back to septic. The significance to water budgeting is summarized in Table 3.7-4.

A preliminary comparison of drinking water takings and sewage discharges is presented in Table 3.7-5. Differences in the taking and discharge vary upwards to 35%, which is fairly significant. Sewage discharges may be more significant to seasonal/monthly water budgeting computations. For an annual water budget, the difference between the water takings and the sewage discharges will be assumed negligible.

3.7.4 Private Well Consumption

Private well consumption (i.e. water takings from private domestic wells) in the MRSPR is estimated as significantly greater than takings from municipal wells and approximately equivalent to all municipal takings combined. Private well takings across the MRSPR are estimated at 9.2 million m^3/yr (3.1 million m^3/yr in the Mississippi and 6.1 million m^3/yr in the Rideau). Consumption estimates were prepared based on the number of private wells in the MRSPR, an estimated 2.85 persons per well, and a typical consumption rate of 200 Lpcd.

Private well locations were obtained from the MOE Wells Database (excluding all monitoring wells) and are shown in Figure 3.7-4. The average number of persons per well was estimated to be 2.85 based on 4 years of population data (1986, 1991, 1996, and 2001) for five townships fully enclosed within the MRSPR (Montague, Merrickville, Tay Valley, Beckwith, and Drummond/North Elmsley). For each of these townships and years, the number of wells was divided by the unserviced population (i.e. not on a municipal system) obtained from MUD (Municipal Water Use Database) (Total Population – Population Serviced) and from Statistics Canada.

Several sources of information were reviewed before selecting a consumption rate of 200 Lpcd. The City of Ottawa recommended using a value between 180 and 220 Lpcd (personal communication with Michel Kearney, 2006). The Regional Groundwater Study (Golder et al. 2003) found typical consumption to be 175 Lpcd. The average water use per person per day in Montague Township was found to be 160 Lpcd. Montague was chosen as a sample municipality as it is considered a “tight” water system (i.e. minimal losses). The average consumption rate was calculated as total annual metered water / 560 persons in Montague (assumed constant) based on ten years of metered data (1989-1997 and 2001). Estimates of private well consumption are given in Table 3.7-6.

3.7.5 Agriculture Water Use

Annual agriculture water use data was obtained from the MNR (de Loe, 2002) by quaternary watershed based on the estimated number of farms. Water use data is given for livestock and crops. Water uses for livestock include: animal drinking, washing, cooling, washing barns, washing equipment and spillage losses. Water uses for crops include irrigation, crop spraying, harvest water use, equipment washing, on-farm processing, and other minor uses such as washing or keeping products moist following harvest. According to the MNR data, approximately 55% of agricultural water use is used for livestock and 45% is used for crops in the MRSPR. The data does not distinguish between surface water or groundwater takings however, the majority of takings likely come from groundwater (Personal communication with Dick Cootes, January 2007). The ratio of surface water to ground water takings in the PTTW database indicates that most come from surface water but this is only for permitted uses and is not representative of the majority of all farms in the MRSPR. On average, the majority of agricultural takings are non-permitted. Most farms would have their own private wells. The water use data is mapped by subwatershed for the MRSPR in Figure 3.7-5 and is summarized in Table 3.7-7.

3.7.6 OMYA

OMYA, a calcite processing plant in the Rideau Watershed, takes water from the Tay River just upstream of Perth. It is the largest (and only) industrial water taking and discharge (and diversion) in the affected streamflow areas on the inland rivers. Monthly water consumption has been computed using data reported from 2004 and 2005. Water takings varied from 0.02% to 0.36% (average 0.08%) of the total monthly flows measured upstream in the Tay River. Water consumed by OMYA is small compared to the total flow measured in the Tay River just upstream of the plant as shown in Table 3.7-8. A graph of monthly water consumption at OMYA is given in Appendix E.

4.0 Data Quality and Quantity

4.1 Data Sources

Different data is required depending on the temporal scale (e.g. annual or monthly) of the water budget. Some data (e.g. PTTW) will not be used for annual water budgeting or requires modifications to be used. A summary of the data sources is presented in Table 4.1-1. Some data is not listed here including soil water holding capacity data and land cover data but has been used to develop other data sets (e.g. ET). Data quality and quantity is discussed in the individual sections below.

4.2 Precipitation and Temperature Data

Precipitation and temperature data from Great Lakes Forestry study (McKenney et al., 2006) was used in climate mapping, evapotranspiration estimation, and water budgeting; whereas data from Ontario Ministry of Natural Resources and Environment Canada's Atmospheric Environment Service (AES) was used for reviewing long-term climate patterns.

There are more than 100 climate stations in the MRSPR; however most of them are no longer in service. At present, there are only twelve stations collecting climate data, four of them in the Mississippi and three are in the Rideau. The Drummond Centre station located near the centre of Mississippi has more years of data, and was chosen as representative for the Mississippi region for the long-term climate analysis of climate patterns. Kemptville, Ottawa CDA and Ottawa Airport stations in the Rideau have 75, 117 and 68 years of data, respectively. As both the Ottawa stations are located in the north end, the Kemptville station, which is located near the middle, was chosen as the representative station for the Rideau region for reviewing long-term climate patterns.

There are missing data in precipitation and temperature for all climate stations operated by Atmospheric Environment Service (AES) (given in Appendix A). Simple statistical analysis of data showed similar precipitation and temperature at different climate stations in the MRSPR. Hence, data from nearby stations were used in missing data filling for each Mississippi and Rideau representative station. Some spatial differences may associate with this kind of data filling; accordingly a certain percent of error might associate with the results.

Great Lakes Forestry data (McKenney et al., 2006) was the output of the model with Canada 'normals' for 1971-2000 (AES) using smoothing spline algorithms of ANUSPLIN and GIS (McKenney et al., 2006). In the Great lakes Forestry study a reasonable mean absolute error of 20–40% was found for precipitation, and 0.5–1.5 °C for minimum and maximum temperatures (McKenney et al., 2006). Uncertainty in precipitation is due to measurement error [up to 50% for snow conditions (Sevruk, 1982)], spatial variability [higher errors in the summer months], and location. The calculated error is for the entire North America region with larger errors along large water bodies (Hutchinson, 1991). Minimum error of 20% in precipitation is reasonable at any location away from a station; however an error in the average precipitation for a watershed basin should be less than that. The study did not show any specific error/uncertainty for the MRSPR therefore an error of 10% in precipitation will be assumed for the MRSPR.

4.3 Evapotranspiration Data

Evapotranspiration (ET) is not measured; rather it is calculated using various methodologies. For the MRSPR, ET was estimated on a GIS platform using Thornthwaite and Mather (1955, 1957) with 30 years of precipitation and temperature data (1971-2000) from the Great Lakes Forestry study (McKenney et al., 2006). The resulting calculated values will be compared to a “derived” value (Section 5.1) using long-term precipitation and streamflow data in the annual water budgeting estimates discussed more below. ET was also calculated using 30 years of long-term data from Environment Canada’s Ottawa Airport (1974-2003). Results showed minimal differences between both calculations, however, for water budgeting computations, the Forestry data will be used. More discussion on calculated ET is in Section 3.2.4.

4.4 Streamflow Data

Streamflow data from the selected hydrometric stations is required to calculate depth of runoff for water budgeting. Two different periods were used in the streamflow data analysis. The most recent 30 year period, from 1974 to 2003, used in the streamflow pattern analysis; whereas, an earlier period, from 1971 to 2000, will be required for the water budget to coincide with the climate parameters’ data periods. For water budgeting, in order to reduce uncertainty in the data, data sets without any data gap filling were used; however in the streamflow pattern analysis missing data was correlated with best-fit correlation equations with nearby stations (refer to Section 3.6.2 for detailed methodology and results). Six of the selected stations in the region have full data from 1974 to 2003 period (no data gaps). The other four stations used correlated data from representative stations to fill gaps in streamflow data where gaps are minor or seasonal. The Tay River at Perth station has the largest data gaps. It only has seven years of complete annual data in this period. Correlated data was not representative for this station, so, only seven years of data was used for this station in the streamflow pattern analysis (3.6.2).

4.5 Baseflow Data

Baseflow is not measured at WSC or at the Province, therefore no measurements are available. Instead, baseflow was calculated for each hydrometric station using the baseflow index method. The average of the baseflow indices was taken from the USGS study (Neff et al., 2005) done for the Great Lakes basin. Baseflow data is not required for annual water budgeting computations. It will be used for approximating groundwater recharge (Section 5.2).

4.6 Groundwater Data

The limitations in groundwater data is discussed above in Section 3.5.4.

4.7 Water Use Data

Water use data can be used to measure the magnitude of regional water demand versus supply. Water use data will be used to refine the stress evaluations at the subwatershed level in later tiers. Sources of data supporting water demand estimations are outlined in Appendix D “PTTW Demand Assessment” of the guidance document (MOE, September 2006). This tool will be used in Tier 1 subwatershed stress assessment. It is not required for the conceptual understanding. Maximum water taking data from permitted water uses can be obtained from the PTTW database. Because the PTTW database contains only the permitted (maximum) water taking data, and not actual takings, demand estimates will be conservative; however a tool has been provided in the provincial guidance documents to modify the maximum takings to estimate consumption water demand. Additional limitations of this database are discussed in the provincial guidance documents.

Water takings data has been obtained from municipal pumping records for all municipal water supply systems in the MRSPR. This data should override the PTTW and consumption factors. This data can be used for regional water demand estimates and water budgeting activities.

Estimates of private well consumption have been made based on the number of wells from the MOE wells database, an estimate of the number of persons per well using population data from Stats Canada and serviced population data from the Municipal Water Use Database, and a gross assumption about the consumption rate per person (200 Lpcd) (Section 3.7.4). These estimates can be used for water demand calculations and monthly water budgeting.

Agriculture water use data (de Loe, 2002) is limited as the source of the taking, whether it is from groundwater or surface water, is unknown. Agriculture takings will be assumed to come from groundwater and can be used to support preliminary estimates of stress in the region. Agriculture water use data can be used for regional water demand calculations (Section 3.7.5).

Reported water consumption data (2004 and 2005) from OMYA has been obtained and will be used for regional water demand calculations.

Industrial water demands will be estimated using the PTTW database in Tier 1 with user surveys where possible.

Sewage discharge data has been collected for all municipal treatment systems in the MRSPR. This data can be used for monthly water budgeting as a return to surface water. It is not required for annual water budget estimates as it is assumed to be negated by the drinking water takings.

5.0 Water Budget and Groundwater Recharge

Long-term (average), annual, regional values have been used to estimate water budget components and to provide bulk estimates of groundwater recharge and baseflow for the Mississippi and Rideau River watersheds and for the MRSPR. Long-term values have been computed by taking the average of values over a 30-year period (1971-2000). The limitations and uncertainty of these estimates is discussed in later sections.

5.1 Water Budget

Long-term, annual, regional values of water budget components including precipitation, depth of runoff, and evapotranspiration have been estimated and are presented below.

Long-term, annual precipitation data (1971-2000) was obtained from the Great Lakes Forestry data (McKenney et al., 2006). The mean annual precipitation in the MRSPR was determined to be 912 mm/yr with 898 mm/yr in the Mississippi and 926 mm/yr in the Rideau.

The mean annual depth of runoff (flow per unit area) was estimated with complete 30-year data sets from 1971-2000 at the most downstream stations on the Mississippi and Rideau River, namely the “Mississippi River at Appleton” and the “Rideau River at Ottawa” respectively. The mean annual runoff in the MRSPR was estimated to be 366 mm/yr and is about the same for the Mississippi and the Rideau. An area-weighted average of runoff at these two stations was used to calculate the annual runoff of the entire MRSPR. The runoff values were comparable to those from previous studies (Hydrological Atlas of Canada, 1978; MNR, 1984; and Moin and Shaw, 1985). The Hydrological Atlas of Canada (1978) shows annual runoff values ranging from 300-400 mm. The MNR (1984) values range from 200-350 mm per year, which is somewhat lower but more or less comparable. The Moin and Shaw (1985) values ranges from 325-500 mm. Any differences between the station data and the previous studies are likely largely due to differences in the periods of record. Mapping from these studies is given in Appendix C.

Using the precipitation and runoff data from 1971-2000, evapotranspiration was then derived from the long-term annual water budget equation (refer to Equation 2-3 in Section 2.2) as follows:

5-1 Derived ET = Precipitation – Runoff

The derived ET estimates are representative on an average, annual, regional scale. They are not really applicable to smaller time scales (e.g. monthly) or to smaller areas (e.g. subwatersheds). The annual long-term regional water budget estimates are summarized in Table 5.1-1.

Evapotranspiration can also be calculated. ET calculations have been completed (Section 3.2.4) using Thornthwaite and Mather (1955, 1957) with long-term precipitation and temperature data (1971-2000) (McKenney et al., 2006).

As an approximate test, the calculated ET values were compared to the derived ET values. The calculated values compare well to the derived values for the MRSPR. The overall difference between the calculated and derived values for the MRSPR is low (5%). The derived ET value for Mississippi is somewhat low, likely due to low precipitation as the depth of runoff appears reasonable (Table 5.1-1). The calculated and derived ET results are summarized in Table 5.1-2.

5.2 Groundwater Recharge

Two approaches have been used for estimating long-term, annual groundwater recharge in the Mississippi-Rideau Region and major watersheds. The first method is the USGS 2005 approach (Neff et al., 2006) (introduced in Section 3.5). The second method is the MOE 1995 approach (see Appendix F for detailed methodology), which is recommended in the Province’s guidance documents (MOE Sept. 2006) and has been modified to the MRSPR. Average data from a common 30-year period was used for both methods.

5.2.1 USGS 2005 Baseflow Estimates

The USGS 2005 method was used to estimate groundwater recharge assuming that baseflow is equivalent to groundwater recharge over the long-term (i.e. 30 years). Long-term baseflow estimates can be used to approximate groundwater recharge assuming that all baseflow is from groundwater; however, in reality, some recharge will go to evapotranspiration (e.g. plants whose roots reach the water table) and some baseflow (smaller amounts) is from surface flow that has a long time of concentration within the watershed (e.g. takes a long time to run off the watershed and discharge into the stream).

The annual baseflow for the MRSPR is estimated as 150 mm/yr and was similar for the Mississippi and the Rideau watersheds (154 mm/yr in the Mississippi and 146 mm/yr in the Rideau). The USGS baseflow was estimated by taking the annual depth of runoff on the Mississippi and the Rideau Rivers (Section 5.1.1) averaged from 1971-2000 and multiplying it by the USGS baseflow index for the BFLOW (groundwater) model, one of six models used to predict baseflow by the USGS (Section 3.6.3). The BFLOW model had the lowest index of the six models and produces the most reasonable results for the MRSPR. The baseflow indices from the remaining five models were too high.

5.2.2 Modified MOE 1995 Groundwater Recharge Estimates

The MOE proposed a methodology for determining groundwater recharge in a report entitled “Hydrogeological Technical Information Requirements” (MOEE, 1995) for assessing the impact of on-site sewage systems. This methodology was originally introduced in “Guidelines for the Preparation of a Rural Servicing Report for Development to be serviced by On-Site Sewage Systems” (MOE, 1989). Based on this methodology, groundwater recharge was estimated using a set of infiltration factors for land cover, soil permeability, and slope of the ground. The sum of these infiltration factors (the combined infiltration coefficient) is multiplied on a pixel by pixel basis by the “water surplus” (in mm) to determine the groundwater recharge volume (in mm). The “water surplus” is defined in the MOE methodology as the amount of precipitation that is available after evapotranspiration. Parameters in the MOE methodology have been modified to suit the MRSPR. A detailed methodology is given in Appendix F.

The results from the above methodology indicate that groundwater recharge is 132 mm/yr for the MRSPR, with 122 mm/yr in the Mississippi and 142 mm/yr in the Rideau (see Table 5.2-1) based on long-term (1971-2000) data. The combined infiltration coefficients were estimated as 0.41 for the MRSPR (0.39 in the Mississippi and 0.43 in the Rideau). Higher recharge may occur in the Rideau than the Mississippi because there is less bedrock outcrop and more permeable soils.

Results of the potential groundwater recharge estimates based on the modified MOE 1995 methodology have been mapped in Figure 5.2-1.

5.2.3 Comparison of Baseflow Estimates and Groundwater Recharge Estimates

There is good agreement between the modified MOE 1995 groundwater recharge estimates and the USGS 2005 baseflow estimates. The variation between the two estimates is 12% (18 mm) for the MRSPR with 21% (32 mm) in the Mississippi and 3% (4 mm) in the Rideau. The higher variation in the Mississippi estimates may have been due to uncertainty in the calculation of the soils water holding capacity in this area, mainly in the bedrock (shallow soils) areas. The MOE results may be lower than the USGS baseflow results because the infiltration factors assigned to bedrock, specifically Precambrian bedrock, may be considered by some as too low. A higher factor would take into account depression storage and infiltration. Results of groundwater recharge estimates for both methods are compared in Table 5.2-1.

5.3 Limitations and Uncertainty

The limitations and uncertainty of the approaches and resulting estimates are described below. These will become more refined in the upper tiers of water budgeting work.

5.3.1 Limitations

5.3.1.1 Limitations of Long Term, Annual, Regional Values

Long term (average), annual, regional values do not necessarily apply to individual years or to individual subwatersheds. The temporal average is not applicable to specific years and the spatial average is not applicable to specific watersheds.

The long-term (average), annual values for watershed regions cannot be applied to individual years as some years are wetter or drier than others. For the long-term, average annual water budget, changes in storages are negligible when compared to precipitation over 30 years however for an individual month or an individual year the changes in storage cannot be assumed to be zero. Groundwater recharge will vary on a seasonal and monthly basis because recharge is higher in the spring and lower in the summer.

The regional spatial averages for water budget estimates and also for recharge estimates are not necessarily applicable to individual subwatersheds. For example, recharge in a forest will be different than recharge in a swamp. ET will also vary spatially depending on soils and land cover. Recharge will also vary from subwatershed to subwatershed across the MRSPR.

5.3.1.2 Limitations of Modified MOE 1995 Methodology for Groundwater Recharge Estimates

Although the MOE 1995 methodology may be effective at quantitatively partitioning the portion of precipitation that will infiltrate into the groundwater, the methodology falls short in a few areas, such as outcropping bedrock land cover and shallow soils; confined aquifers; and urban areas.

One of the three parameters used in the modified MOE 1995 methodology is a soil classification that categorizes soil cover into three groups of unconsolidated material (clay, clay and loam, and sandy loam) and does not account for areas where bedrock is outcropping at ground surface. With a large portion of the MRSPR having exposed bedrock at ground surface, additional soil classifications for bedrock have been incorporated for this study. These additional infiltration factors are further explained in Appendix F.

This MOE methodology may be more suitable for determining the amount of infiltration to shallow, unconfined groundwater aquifers, rather than to deeper, confined groundwater aquifers. Two examples of this is in the central portion of the study area where the Oxford Formation dolostone overlies the Nepean Formation sandstone aquifer and in the eastern portion of the study area where a significant layer of clay overlies deeper, sand or fractured limestone aquifers. In both of these situations, a portion of the precipitation that falls in these areas may infiltrate into the shallow soils but the percentage of precipitation that actually reaches the underlying aquifer will be less than the partitioned volume using the above methodology. In these cases, the confined aquifers are partially recharged from the overlying units; however a significant portion of the recharge will come from areas further up-gradient where the overlying confining layer does not exist.

The method does not take into account depression recharge in the bedrock areas, where water sits in depressions for long periods of time because of the poor drainage. While the permeability of the rock is low, these depressions may act as local significant water recharge areas.

For the purpose of this conceptual water budget, it is assumed that the estimates of water infiltrating into the ground will reach the groundwater table and the MOE methodology is valid, taking into account the additional soil classifications.

Future work may include back-calculations of the infiltration factors to improve results for bedrock and shallow soils.

Healy and Cook (2002) provide a method for estimating infiltration values using long term water level data. By reviewing the maximum water level fluctuations during annual and season changes and assuming a porosity value for the aquifer material, the amount of infiltration is estimated. This approach should be investigated to independently check the infiltration values determined as part of this conceptual report during Tier 1 water budget activities.

The MOE recharge calculations may not apply very well in urban areas because hard surfaces such as pavement and buildings have not been taken into account. Hard surfaces contribute less to groundwater recharge. The MOE recharge methodology is based on infiltration factors applied to land cover, soil and slope but none of these factors account for hard surfaces. These factors are combined and applied to the water surplus to estimate the amount that will be partitioned to recharge. The remainder is assumed to go to direct runoff.

The infiltration factor for land cover in urban areas has been reduced to account for some of the recharge lost to hard topping by pavement and buildings however it does not consider an overall reduction in recharge due to percent imperviousness. Conversely, in many urban areas, especially subdivisions, infiltration is enhanced by roofs where rainfall is discharged to lawns. A more in depth analysis is recommended for Tier 1, particularly in subwatersheds with municipal wells. A suggested approach would be that the combined infiltration factor in urban areas be adjusted by multiplying the recharge factor by the percent perviousness. This approach will require a good estimate of percent imperviousness in the urban area. This data is not currently available but will eventually be available through SOLRIS. Results of annual recharge in urban areas can be verified or improved through a review of urban watershed studies completed in the MRSPR and/or from infiltration rates determined by other Regions.

Groundwater recharge estimates are preliminary and should be used with caution until refined with better data and information.

5.3.2 Uncertainty

5.3.2.1 Uncertainty in Water Budget Estimates

Each component of the water budget estimates (precipitation, streamflow, and evapotranspiration) are measured (or derived) with a certain amount of uncertainty (error).

Precipitation is measured with a fairly high level of certainty. For the precipitation data, there was no specific measurement of uncertainty for the MRSPR (McKenney et al., 2006). An uncertainty of 10% in precipitation will be assumed for the MRSPR. A more detailed explanation of the uncertainty in this study is in Section 4.2.

The streamflow data from the Water Survey of Canada is measured with a relatively higher degree of certainty. A 5% error is generally accepted for streamflow data (Water Survey of Canada).

ET is not measured, rather it is derived (or calculated). The uncertainty in derived ET can be approximated by taking the square root of the precipitation uncertainty squared plus the runoff uncertainty squared. Given that the precipitation and streamflow are measured with a fairly high degree of certainty, ET can be assumed to have a medium to high level of certainty as well. The resulting uncertainty for the water budget estimates are calculated in Table 5.3-1.

5.3.2.2 Uncertainty in Groundwater Recharge Estimates

The USGS baseflow data has an average standard error of 10% (Neff et al., 2005). In the USGS study, six models were tested to estimate BFI values for individual gauges in North-America. Error functions were minimized by comparing calculated and estimated BFI for surficial-geology classes and parameters in the attenuation function were minimized. Percentages of BFI model predictions for gauged watersheds were within 10-

20% of BFI values from hydrograph-separation analyses. The average standard error of 0.1 in this study falls within the range of standard error for other studies by Mazvimavi et al., (2004), Mazvimavi (2003), Nathan and McMahon (1992), Gustard et al., (1989), Bullock (1988) (from 0.08 to 0.19) [Neff et al., (2005)]. Various factors limited the accuracy of model results such as accuracy of total runoff estimates (total runoff estimates were based on area-runoff ratios) [Neff e al., (2005)].

Given the 10% uncertainty in the baseflow estimates, the USGS results are within range of the MOE estimates for the Rideau recharge estimate and lie just outside of the range for the MRSPR and for the Mississippi. There is no information available on measuring or quantifying the uncertainty in the MOE recharge methodology as it is only an estimate with no measured value; however, it is reasonable to assume that with a certain amount of error the MOE results would fall within range for the MRSPR and the Mississippi. The uncertainty in USGS baseflow estimates is quantified in Table 5.3-2.

6.0 Regional Water Demand and Water Quantity Stresses

6.1 Regional Water Demand

6.1.1 Long-Term, Annual, Regional Estimates of Water Demand

The average, annual water demand is estimated to represent less than one percent of the average, annual water supply (P - ET) in the MRSPR (see water uses listed in Table 6.1-1 – excluding Ottawa River drinking water plants). Of this, approximately two thirds of the demand is from groundwater and one third is from surface water. For municipal systems only (municipal plants and municipal wells) surface water demands are greater than groundwater demands. Of all the drinking water demand (municipal plus private), private well consumption is equivalent to municipal consumption (excluding Ottawa River plants). Average, annual water demand was calculated by taking the total water takings in the Region divided by the average amount of water supply. Water supply was calculated by subtracting evapotranspiration from precipitation using long-term, annual values from 1971-2000 (Section 5) for precipitation and evapotranspiration. Water demand was calculated by taking the total of surface water and groundwater takings from public drinking water systems (2000-2005), private wells, agriculture (2001), and OMYA (2004-2005) while excluding other uses for now. Water taking and supply estimates are shown in Table 6.1-1 for the Mississippi, Rideau and the MRSPR.

6.1.2 Limitations of Regional Water Demand Estimates

The average, annual values may not give a complete understanding of the level of stress. The above results indicate that there is plenty of drinking water available in the MRSPR on a regional, average, annual scale however this will vary temporally and spatially. The regional, annual values mask any seasonal trends or spatial differences. Temporally, the long term values do not apply to individual years. Water supply will vary from year to year, from season to season, and from month to month. The extreme periods such as periods of drought may reveal different conclusions. Seasonal and monthly supplies will change at the drier times of the year such as in the summer. Water demand will also vary (but less so than supply). Spatially, supply and demand will vary across the MRSPR. Water availability will change depending on location. This type of analysis can be done at smaller scales (monthly, subwatershed basis) in Tier 1 to see more detail.

The above analysis also does not account for a reserve amount in the water supply. The reserve amount would include water requirements for ecological habitat, recreational uses, or flow control purposes. Further evaluation in Tier 1 will be needed to determine how this affects water supply.

The above estimates are from water use data available to date and do not account for all water takings in the MRSPR so this analysis likely under estimates the total water use in the MRSPR. There may be other water takings located outside of the municipalities (or are not an agriculture taking). A tool will be provided by the Province in Tier 1 to help estimate consumptive water demand.

This analysis ignores the effects of storage. Reservoir storage plays a key role in the amount of water available. The Mississippi and Rideau Rivers are both heavily controlled for a variety of reasons but mainly navigation, hydroelectric power, and recreation. The changes in water levels will affect the amount of water available for drinking water. The impact of flow control on the supply of drinking water would be more easily understood with advanced modeling techniques.

From a groundwater perspective, the above values show an abundance of water available over the year however the Shield has a low storage capacity and stresses in groundwater supplies may occur during short-term events. This is discussed more below.

6.2 Water Quantity Stresses at Municipal Drinking Water Plants

Water quantity stress on surface water supplies has been estimated by determining the percent demand by taking the maximum monthly takings at the inland river drinking water plants and comparing these to the lowest recorded monthly streamflow at the nearest hydrometric stations. The three inland river plants are located at: Carleton Place on the Mississippi River, Smiths Falls on the Rideau River, and Perth on the Tay River. The hydrometric stations that are located nearest the plants include (periods of record are shown in brackets): the Mississippi River at Appleton station (1918-2003), Tay River at Perth (1994-2003), and the Rideau River at Smiths Falls (1970-2003).

The percent water demand for surface water has been calculated as follows:

6-1 PERCENT WATER DEMAND = Q DEMAND / Q SUPPLY * 100%

Where:

Q DEMAND = Water Taking (drinking water takings measured at the plant)
Q SUPPLY = Water Supply (stream flow measured at nearest hydrometric station)

The percent water demand calculated using the above equation does not account for a reserve amount, prescribed in the Provincial Guidance documents. The Provincial Guidance (see Section 3.1.1 of the guidance documents for water supply estimation) requires that the water demand calculation subtract a "reserve" amount from the water supply. The reserve amount is required to account for a minimum flow rate for other water uses (e.g. ecological needs, recreation, flow control, etc). A reserve amount will be accounted for in Tier 1. For the conceptual understanding, reserve will be ignored when defining percent demand.

The maximum recorded monthly drinking water takings at the inland river drinking water plants were found to range from 4 to 10% of the minimum monthly stream flow on record. In other words, the percent water demand ranges from 4 to 10%. Based on the Provincial definition of stress, there are no surface water quantity stresses as the provincial guidance documents categorizes "Low" stress as a maximum water demand of less than 20% (Provincial Guidance [September 2006], Water Budget Section 3.2.1). Percent water demand results for each of the plants are given in Table 6.2-1.

6.3 Water Quantity Stresses on Groundwater Supplies

Golder et al. (2003) attempted to acquire information concerning which aquifers/areas typically experience low yield or dry conditions by surveying 12 local water well drilling companies. The responses identified the following areas: Ottawa Formation in West Carleton and Panmure as well as Precambrian granite in Carp and Denbigh. Further attempts to obtain historical information indicating which areas typically experience water shortages or stressed conditions from drilling companies, municipalities, water haulers; etc might assist in identifying areas to focus future water budget studies.

No significant water quantity issues were identified in this regional water budget analysis or any of the Well Head Protection Area (WHPA) studies completed for the municipal groundwater supplies. However, all of these studies looks at annual average conditions and therefore does not take into account transient, localized seasonal conditions or aquifer specific yield and storage.

The capacity of a geological unit to store groundwater is an extremely important concept that must be taken into account when trying to determine the ability of a groundwater system to withstand water quantity stresses. This is especially important when the groundwater storage of an aquifer is low, such as the case for the majority of the MRSPR where bedrock is near ground surface and the overburden aquifer material is not significant (i.e. Precambrian Highlands). Precambrian bedrock has a very low bulk porosity (in the order of less than 1%) which corresponds to a very low storage capacity for groundwater. Practically speaking, this relates to a large drawdown when pumping occurs (approximately 1 m drawdown to yield 1 cm of water) which therefore requires a larger spacing of domestic wells to prevent groundwater interference problems.

Therefore, although this study has not identified any water quantity issues for domestic water supply aquifers on an annual basis, local conditions exist that may exhibit groundwater quantity issues for transient precipitation events. For example, in areas with low storage capacity likely demonstrate lower infiltration rates and higher degree of surface runoff, therefore precipitation over shorter time periods (weekly or monthly) may result in the aquifer overflowing (localized flooding or significant runoff). Likewise, short time periods without much rain in the summer may result in the water level dropping quickly as a result of low specific yield for the unconfined Precambrian aquifer (localized short term droughts).

Based on the geology distribution within the MRSPR, all of the municipal wells are located in highly permeable and yielding aquifers and therefore these issues are not evident in this study. However, domestic supply wells in areas with poor yielding aquifers (Precambrian bedrock in western portion of MRSPR) may be susceptible to water quantity issues during periods of low recharge or high aquifer use and are therefore considered vulnerable with respect to water quantity issues.

7.0 Summary

7.1 Conclusions & Recommendations

Most of the climate and surface water data has been collected and evaluated for the MRSPR. Long-term (average), annual estimates for various components of the water budget (precipitation, depth of runoff, and evapotranspiration) have been estimated over a 30-year period from 1971-2000 for the Mississippi and Rideau River regions and for the combined MRSPR. Evapotranspiration was derived from average precipitation and runoff data (Precipitation – Runoff). Evapotranspiration was also calculated using Thornthwaite and Mather (1955, 1957). Calculated ET values compared well to derived ET values.

Long-term, annual, regional values were also used to estimate baseflow and groundwater recharge. Regional ground water recharge estimates from the MOE 1995 methodology (customized to the MRSPR) compared fairly well to estimates from the USGS 2005 BFLOW method. Preliminary drinking water low flow stress evaluations and water demand calculation have also been completed.

Based on a limited review of the data, no drinking water stresses have been found on an average, annual, regional scale. Average, annual, regional demand for water represents less than one percent of the water supply in the MRSPR. Demand estimates included takings from public systems, private well consumption, agriculture, and OMYA. Supply was estimated as the amount of water available from precipitation after evapotranspiration. Supply and demand will vary temporally and spatially across the MRSPR. Monthly estimates of water demand at the subwatershed level in Tier 1 may reveal considerable vulnerability to seasonal fluctuations and spatial effects (drought conditions will not be assessed until Tier 2). It should be noted that the supply amount did not account for a reserve amount for other water uses (ecological, recreational, flow control, etc.). A reserve amount will be calculated in Tier 1. Conclusions from this study apply only on an average, annual, regional scale. Long-term, annual, regional values do not apply to individual years or to individual subwatersheds. Estimates will vary temporally and spatially across the MRSPR and will be refined more in Tier 1.

Potential groundwater recharge estimates have been completed for the MRSPR using the 1995 MOE approach modified to the MRSPR (Appendix F). The results appear reasonable although the approach still presents some limitations. The approach may be more suitable for determining infiltration to shallow unconfined aquifers rather than deeper confined aquifers. Further work is required to confirm infiltration values in shallow bedrock and in urban areas.

Long-term, annual regional baseflow estimates have been prepared using the USGS BFLOW method (Neff et al., 2005). Baseflow will vary by month and by season, and so, changes in seasonal/monthly indices have to be considered for monthly water budgeting in Tier 1. Tier 1 work can be completed with available data however beyond Tier 1, if warranted, a field program could be established to measure baseflow and help identify recharge/discharge areas.

Potential recharge and discharge areas were identified conceptually using multiple methods, however further work is necessary to better determine where these features are considered to be significant. In addition, further work is necessary to determine the long term groundwater levels in both monitoring wells and municipal wells. The overall interaction between surface water and ground water lacks understanding and therefore also requires further study.

7.2 Screening Decisions for Tier 1 Modeling

The Provincial Guidance document provides a series of screening questions in order to determine how to proceed to Tier 1. Interim direction was recently provided with advanced screening criteria.

Based on the guidance and criteria mentioned above, drinking water intakes on the Ottawa River (Britannia and Lemieux) will be excluded from Tier 1 as there are no water quantity issues.

The remaining intakes: Carleton Place, Smiths Falls, and Perth are located on inland rivers including the Mississippi River, Rideau River, and Tay River respectively. Water budgeting will be necessary for these watersheds.

In addition, water budgeting will be required for the remaining subwatersheds (including Ottawa River subwatersheds) as they contain a significant number of private wells.

For Tier 1 modeling, a simple “steady-state” spreadsheet approach to water budgeting will be used. GIS will be used where necessary. Water budget components will be estimated on a monthly basis for each subwatershed in the MRSPR. The key outcome of the Tier 1 will be water budget estimates used to undertake the Water Quantity Risk Assessment, which will evaluate existing water supply (and reserve amounts) and existing and future water demands. Water quantity issues will be identified in Tier 1 before determining if it is necessary to proceed to Tier 2.

A map of the Tier 1 water budgeting locations and municipal water supplies is given in Figure 7.2-1. Water budgeting will be done on the drainage areas to the streamflow gauges. Water budgeting may be done for the drainage areas to the inland river water plants. Ground-watersheds may be treated separately from surface-watersheds. Water budgeting for municipal wells may be based on an estimated groundwater aquifer contributing area. This will be considered further in Tier 1.

7.3 Considerations for Tier 2 Modeling

Subwatersheds experiencing a moderate or significant stress identified in Tier 1, and containing a municipal water system, will move forward to Tier 2, which will involve complex modeling at the watershed/subwatershed scale. Subwatersheds that do not contain a municipal system will not move forward to Tier 2.

Reservoirs in the upstream parts of the MRSPR are needed for maintaining downstream flows in the Rideau Canal (controlled by Parks Canada) and for hydroelectric power generation on the Mississippi (controlled by various agencies). The implications of flow control on drinking water issues in the MRSPR are unknown at this time. One area of concern may be the Tay River, which is controlled by the federal government solely for navigation purposes. Flows may be reduced substantially without storage upstream at Bob’s Lake.

At this time, it is not anticipated that a regional complex groundwater flow model will be required.

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Table 1.6-1 Summary of watershed areas in the Mississippi-Rideau Source Protection Region (MRSPR)

Jurisdiction	**Watershed/Subwatershed**	**Area (km^2)**
Mississippi Valley Conservation Authority	Mississippi River	3,747
	Carp River	300
	Ottawa River	287
Rideau Valley Conservation Authority	Rideau River	3,872
	Ottawa River (East & West)	385
Mississippi-Rideau Source Protection Region		**8,591**

Table 3.2-1 Average annual precipitation and mean temperature at active climate stations in the MRSPR (1994-2005)

Station	**Annual Average Precipitation (mm)**	**Annual Average Temperature (°C)**
Ompah	944.8	5.3
Ompah-seiz	924.7	6.1
Drummond Centre	870.0	6.4
Appleton	869.1	6.3
Kemptville	915.9	6.6
Ottawa Airport	920.1	6.3
Ottawa CDA	901.1	6.6

Table 3.2-2 Monthly average climate data for Drummond Centre (Mississippi) and Kemptville (Rideau) [1954-2003]

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Drummond Centre													
Precipitation (mm)	61	55	59	65	73	76	75	77	81	74	80	71	848
Snow water equivalent (mm)	42	38	30	9	1	0	0	0	0	2	16	44	181
Rainfall (mm)	19	17	29	57	72	76	75	77	81	72	64	27	667
Temperature (°C)													
Min.	-15	-14	-7	0	7	11	13	12	8	2	-3	-10	0
Max.	-4	-3	4	12	20	24	27	26	20	13	5	-2	12
Mean	-10	-9	-2	6	13	18	20	19	14	8	1	-6	6
Potential ET[1]	0	1	6	33	82	116	135	112	71	34	10	1	602
Kemptville													
Precipitation (mm)	61	60	63	72	78	79	84	81	85	77	80	77	898
Snow water equivalent (mm)	42	37	36	11	0	0	0	0	0	3	18	45	192
Rainfall (mm)	25	20	34	64	75	80	85	84	83	74	65	34	722
Temperature (°C)													
Min.	-14	-14	-10	-3	4	10	13	13	10	5	0	-8	1
Max.	-5	-4	0	8	16	22	26	26	22	17	9	0	11
Mean	-9	-9	-5	3	10	16	19	19	16	11	5	-4	6
Potential ET[1]	0	1	6	32	82	115	132	108	70	34	10	1	591
1. All values are measured except for potential ET. Potential ET is calculated (Thornthwaite and Mather).													

Table 3.2-3 Maximum and minimum precipitation occurrences in MRSPR

Parameter	Mississippi	Rideau
Maximum Annual Precipitation	1250 mm (1971)	1213 mm (1972)
Maximum Snow water equivalent	297 mm (1972)	313 mm (1993)
Maximum Rainfall	953 mm (1974)	948 mm (1973)
Minimum Annual Precipitation	506 mm (1964)	619 mm (2001)
Minimum Snow water equivalent	65 mm (1981)	92 mm (1961)
Minimum Rainfall	428 mm (1960)	460 mm (1971)

Table 3.3-1 Land cover percentages in the MRSPR

Land Cover[1]	Land Area (km^2)	% of Total Area
Water	642.3	7.5
Wetlands (marsh, swamp, fen, bog)	744.0	8.7
Forest and Plantation	4,532	52.8
Agriculture (cropland, pasture and abandoned fields)	2,298	26.8
Settlement and Developed Land	206.1	2.4
Aggregate (mine tailings, quarries, and bedrock outcrop)	23.5	0.3
Other Natural Areas (alvar)	141.5	1.6
Unclassified (Cloud & Shadow)	2.8	0.0
Total Area in M-R Region	8,591	100
[1]Land cover data is from the Ontario Ministry of Natural Resources Land Cover 28, 1998		

Table 3.4-1 Summary of overburden deposits in MRSPR

Sediment Type (Feature)	Location	Typical Thickness
Alluvium (fine-grained sand, silt, clay)	near surface water (Ottawa River, Rideau River, Mer Bleu, Constance Bay)	<2 m
Organic Deposits (muck, organic soils)	sporadic low lying areas in Leeds and Grenville County, Lanark County and southern portion of City of Ottawa	< 2 m
Sand and Gravel Eskers	[1] Arnprior-Richmond-Osgoode (east-west) [2] Ottawa-Kemptville (north-south) [3] Kemptville-Maitland (north-south)	2 to 30 m
Continuous sand plain	[1] east of City of Ottawa near Clarence/Rockland and Greely (Russell and Prescott Sand Plain Physiographic Region) [2] Kemptville area extending eastward (Edwardsburg Sand Plain Physiographic Region)	5 to 20 m
Localized pockets of sand	throughout central, southern and western portions of study area	< 5 m
Clay	[1] Ottawa River Valley [2] eastern portion of study area between Kemptville and City of Ottawa	2 to 40 m
Till (moraines and drumlins)	Township of North Gower (North Gower Drumlin Field Physiographic Region)	2 to 10 m

Table 3.4-2 Summary of bedrock formations in MRSPR

Formation	Age	Thickness	Lithology
OTTAWA GROUP			
Carlsbad	Upper Ordovician	0 to 120 m	shale and siltstone
Billings	Upper Ordovician	0 to 60 m	shale
Eastview	Upper Ordovician	0 to 10 m	limestone and shale
Lindsay	Upper Ordovician	0 to 20 m	limestone
Verulam	Middle Ordovician	0 to 50 m	limestone with shale interbeds
Bobcaygeon	Middle Ordovician		limestone with shale partings
Gull River	Middle Ordovician	0 to 80 m	limestone and dolostone
Shadow Lake	Middle Ordovician	0 to <5 m	dolostone with interbeds of sandstone and shaly partings
BEEKMANTOWN GOUP			
Rockcliffe	Middle Ordovician	0 to 50 m	interbedded sandstone, shale and limestone
Oxford	Lower Ordovician	0 to >100 m	dolostone
March	Lower Ordovician	0 to >70 m	dolomitic sandstone and dolostone
POTSDAM GROUP			
Nepean	Cambro-Ordovician	0 to >150 m	sandstone
Covey Hill	Cambrian	0 to >13 m	conglomerate and quartz sandstone
PRECAMBRIAN			
	Precambrian	basement rock	igneous and metamorphic rocks

Table 3.5-1 Summary of regional hydrostratigraphic units in the MRSPR

Stratigraphic Unit	Formation	Thickness/ Depth	Comments	Hydraulic Conductivity[1]	Percent Used[2]
Regional Bedrock Aquifers					
1 Igneous/Metamorphic	Precambrian	< 50 mbgs	Domestic supply	$1x10^{-7}$ m/s	21%
2 Sandstone	Nepean / Covey Hill	~ 40 m	Municipal supply	$1x10^{-4}$ m/s	14%
3 Dolostone / Sandstone	Oxford / March	20 to 35 m	Domestic supply	$1x10^{-6}$ m/s	43%
4 Limestone / Shale / Sandstone	Rockcliffe, Gull River, Bobcaygeon, Verulam, Lindsay, Eastview, Billings, Carlsbad	≤ 40 m	Poor domestic supply	$1x10^{-7}$ m/s	2%
5 Upper Weathered Bedrock Units	Upper 10 m of bedrock	Upper 10 m	Domestic supply	$1x10^{-6}$ m/s	13%
			Subtotal		93%
Regional Overburden Aquifers					
6 Surficial Sand Units		≤ 20 m	Domestic supply	$1x10^{-4}$ m/s	2%
7 Basal Sand and Gravel Units		≤ 15 m	Domestic and municipal supply	$2x10^{-4}$ m/s	3%
8 Sand and Gravel Eskers		≤ 15 m	Domestic and municipal supply	$1x10^{-3}$ m/s	2%
			Subtotal		7%
Regional Bedrock Aquitards					
9 Igneous/Metamorphic	Precambrian	> 50 m bgs		$1x10^{-8}$ m/s	NA
10 Dolostone	Oxford / March	~ 20 m	Local conditions	$1x10^{-8}$ m/s	NA
11 Limestone / Shale	Rockcliffe, Gull River, Bobcaygeon, Verulam, Lindsay, Eastview, Billings, Carlsbad	≤ 40 m		$1x10^{-7}$ m/s	NA
Regional Overburden Aquitards					
12 Silt, Clay and Clay Till Units		≤ 20 m	Not used as supply	$1x10^{-8}$ m/s	NA

Notes:

1 Hydraulic conductivity estimates are from numerous calibrated 3D numerical modelling progject and hydraulic testing completed within the hydrostratigraphic units within the MR SWP region and surrounding area and are presented in more detail as part of the Watershed Characterization report.

2 Statistics are approximate only and were calculated based on the deepest hydrostratigraphic aquifer accessed by each well using the upated MOE WWIS database (2006) with 73,861 entries.

Table 3.6-1 Details of selected hydrometric stations within the region and their long-term mean annual flow and depth of runoff over 30 years (1974-2003)

Jurisdiction	Station ID (WSC)	Station Name (WSC)	Drainage Area [1] (km^2)	Mean Annual Streamflow [2] (m^3/s)	Mean annual runoff [2] (mm/yr)
Mississippi	02KF001	Mississippi River at Fergusons Falls	2,620	30.9	371
	02KF006	Mississippi River at Appleton	2,900	32.9	357
	02KF010	Clyde River near Lanark	614	7.0	360
	02LF011	Carp River near Kinburn	269	2.8	330
	02KF012	Indian River near Blakeney	203	2.1	328
	02KF016	Mississippi River below Marble Lake	357	4.8	420
	02KF014	Fall River near Fallbrook	277	3.3	379
Rideau	02LA004	Rideau River at Ottawa	3,830	42.8	352
	02LA007	Jock River near Richmond	559	6.2	347
	02LA006	Kemptville Creek near Kemptville	409	4.8	372
	02LA012	Rideau River below Manotick	3,120	35.0	353
	02LA011	Rideau River below Merrickville	1,920	22.6	371
	02LA005	Rideau River above Smiths Falls	1,290	15.3	374
	02LA024	Tay River in Perth	661	9.3	446
Mississippi	Area-weighted average of Mississippi stations				365
Rideau	Area-weighted average of Rideau stations				364
MRSPR	Area-weighted average of all stations in the Mississippi-Rideau Region				364

1. Drainage area from HYDAT
2. Streamflow at all stations was calculated using 30 years of data (1974-2003) with data gaps filled using correlated data, except for the Tay River at Perth, where only 7 years of data was available.

Table 3.6-2 Comparison of mean annual streamflow and mean annual depth of runoff for different record lengths at two hydrometric stations

Station Name	Period of Record	Record Length (years)	Mean Annual Flows (m^3/s)	Mean Annual Runoff (mm)	% Difference
Mississippi River at Appleton	1918-2003	84	31.3	340	5%
	1974-2003	30	32.9	357	
Rideau River at Ottawa	1949-2003	55	39.7	327	7%
	1974-2003	30	44.1	352	

Table 3.6-3 USGS baseflow indexes for six groundwater models for the Mississippi and Rideau River watersheds (and MRSPR) (after Table 4.4 USGS 2005, p. 21)

	Baseflow indexes for six models						
Watershed	UKIH-G	PART-G	BFLOW-G	HYSEP1-G	HYSEP2-G	HYSEP3-G	Average
Mississippi	0.51	0.69	0.42	0.70	0.69	0.57	0.60
Rideau	0.46	0.63	0.40	0.65	0.65	0.53	0.55
MRSPR[1]	0.48	0.66	0.41	0.67	0.67	0.55	0.58

1. The baseflow indexes for the MRSPR were calculated by taking an area-weighted average of the indexes for the Mississippi and the Rideau watersheds.

Table 3.6-4 Long-term baseflow estimates in the MRSPR (1974-2003)

Watershed	Station Name (Water Survey of Canada)	Annual Runoff 1974-2003 (mm/year)	Average USGS Baseflow Index[1]	Average Baseflow 1974-2003 (mm/yr)
Mississippi	Mississippi River at Fergusons Falls	371	0.60	222
	Mississippi River at Appleton	357	0.60	213
	Clyde River near Lanark	360	0.60	215
	Carp River near Kinbun	330	0.60	197
	Indian River near Blakeney	328	0.60	196
	Mississippi River below Marble Lake	420	0.60	251
	Fall River near Fallbrook	379	0.60	226
Rideau	Rideau River at Ottawa	352	0.55	195
	Jock River near Richmond	347	0.55	192
	Kemptville Creek	372	0.55	206
	Rideau River below Manotick	353	0.55	196
	Rideau River below Merrickville	371	0.55	206
	Rideau River above Smiths Falls	374	0.55	207
	Tay River in Perth	446	0.55	247
Mississippi	Area-weighted average of Mississippi stations			217
Rideau	Area-weighted average of Rideau stations			201
MRSPR	Area-weighted average of all stations			207
1. BFI values are the average of the six models in the USGS 2005 study (Neff et al., 2005)				

Table 3.6-5 Wetland coverage in the MRSPR

Wetland Type	Area (km^2)	Area (%)
Deciduous Swamp	402.5	4.7
Conifer Swamp	138.2	1.6
Open Fen	82.2	1.0
Inland Marsh	52.6	0.6
Open Bog	0.9	0.0
Treed Bog	67.6	0.8
Total Wetland Coverage	744	8.7
Total Area in M-R Region	8,590.8	100%

Table 3.7-1 Inventory of data collected to date from the municipal drinking water facilities

Surface Water Systems[1]		Groundwater Systems	
Municipal Plants	Data collected to date	Municipal Wells	Data collected to date
Inland Rivers:		Carp	2000-2005
Carleton Place	1985-2005	Almonte	1999-2005
Smith Falls	1961-2005	Kings Park – Richmond	2000-2005
Perth	1996-2005	Munster Hamlet	2000-2005
		Kemptville	1998-2005
		Merrickville	1990-2005
		Westport	2003-2006
1. Ottawa River plants: Britannia and Lemieux (2000-2005)			

Table 3.7-2 Average water takings from municipal drinking water facilities (2000-2005)

Surface Water Systems[1]		Ground Water Systems	
Municipal D.W. Plants	**Average Taking (1000 m^3/yr)**	**Municipal Wells**	**Average Taking (1000 m^3/yr)**
Carleton Place	2,306	Almonte	668
Smiths Falls	3,465	Carp	114
Perth	1,764	Kings Park-Richmond	67.9
TOTAL	7,535	Munster Hamlet	158
		Kemptville	545
		Merrickville	188
		Westport	133
		TOTAL	1,874
TOTAL MUNICIPAL REGIONAL TAKINGS: 9,409,000 m^3/yr			
1. Ottawa River plants: Britannia takes 62,768 (1000 m^3) and Lemieux takes 59,269 (1000 m^3) of water each year from the Ottawa River			

Table 3.7-3 Average annual sewage discharge rates at municipal sewage treatment discharge locations in the MRSPR (2000-2005)

Watershed	Location of Municipal Sewage Discharge Facility	Data collected to date	Average annual discharge (2000-2005) (1,000 m^3/yr)
Mississippi	Almonte	1999-2005	859.3
	Carleton Place	1991-2005	2,015
Rideau	Kemptville	1994-2003	503.4
	Merrickville	1986-2005	173.6
	Smiths Falls	2000-2005	4,257
	Perth	1988-2005	2,334
* ROPEC (Robert O. Pickard Environmental Centre) discharges to the Ottawa River. Sewage discharge data has not been collected for this plant.			

Table 3.7-4 Municipal drinking water systems and sewage discharge facilities and significance to water budget

Municipal Drinking Water System	**Type of Sewage System**	**Point of Discharge**	**Significance to Water Budget**
Municipal Drinking Water Plants (Surface Water Takings – Inland Rivers)[1]:			
Carleton Place	Treatment Plant[2]	Mississippi River	Net consumption insignificant to regional annual water budget calculations
Smiths Falls	Treatment Plant	Rideau River	Net consumption insignificant to regional annual water budget calculations
Perth	Lagoon	Tay River	Net consumption insignificant to regional annual water budget calculations
Municipal Wells (Groundwater Takings):			
Almonte	Lagoon	Mississippi River	Significant - groundwater taking, surface water discharge
Carp	Forcemain to R.O.P.E.C. (Ottawa)	Ottawa River	Drinking water is from groundwater – taking without replacing may be significant to groundwater
Kings Park-Richmond	Forcemain to R.O.P.E.C. (Ottawa)	Ottawa River	Drinking water is from groundwater – taking without replacing may be significant to groundwater
Munster Hamlet	Forcemain to R.O.P.E.C. (Ottawa)	Ottawa River	Drinking water is from groundwater – taking without replacing may be significant to groundwater
Kemptville	Treatment Plant	Rideau River	Significant (at subwatershed scale)
Merrickville	Treatment Plant	Rideau River	Significant (at subwatershed scale)
Westport	Snow-fluent	Not applicable	Not significant
1. Ottawa River drinking water plants (Britannia and Lemeiux) discharge sewage at R.O.P.E.C. 2. “Treatment plant” means the same thing as “water pollution control plant” shown on Fig. 3.7-3.			

Table 3.7-5 Comparison of municipal water takings and sewage discharges (2000-2005)

Location	**Average monthly water taking (1000 m^3)**	**Average monthly sewage discharge (1000 m^3)**	**% Difference**
Carleton Place	195	170	-13%
Smiths Falls	285	317	11%
Perth	150	199*	32%
Merrickville	15.3	14.1	-7%
Almonte	56.9	72.6	28%
Kemptville	44.9	60.6	35%
Carleton Place	195	170	-13%
*All data is averaged from 2000-2005 except Perth. Perth is averaged from 2001-2003.			

Table 3.7-6 Estimates of private well consumption

Watershed Region	Number of Private Wells[1]	Number of Persons[2]	Estimated annual consumption[3] (1,000 m^3/yr)
Mississippi	14,686	41,855	3,055
Rideau	29,535	84,175	6,145
Total MRSPR	44,221	126,030	9,200

1. Number of wells was obtained from MOE Wells database (excludes monitoring wells).
2. Number of persons was estimated based on 2.85 persons per well.
3. Annual consumption calculated as the number of persons multiplied by 200 Lpcd.

Table 3.7-7 Agriculture Water Use (de Loe, 2002) in the MRSPR

Watershed	Number of Farms	Livestock (m^3/yr)	Crops (m^3/yr)	Total (m^3/yr)
Mississippi	752	539,387	475,688	1,015,075
Rideau	1,468	1,205,482	948,370	2,153,852
Total MRSPR	2,219	1,744,869	1,424,059	3,168,928

Table 3.7-8 OMYA water consumption (2004-2005)

	Upstream Flow Volume (1,000 m^3)	Volume Consumed (1,000 m^3)	Percent Taking
January	30,853	12.3	0.04%
February	18,827	15.4	0.08%
March	9,067	13.0	0.15%
April	24,903	10.4	0.04%
May	20,994	7.7	0.04%
June	13,079	10.3	0.10%
July	7,980	12.4	0.16%
August	7,462	14.0	0.20%
September	10,156	12.0	0.15%
October	11,674	16.4	0.14%
November	6,905	13.9	0.24%
December	21,247	14.2	0.07%
Annual	183,147	152	0.08%

OMYA data is reported from 2004-2005.
Upstream flows are measured on the Tay River at the gauge owned/operated by OMYA.
Percent taking is calculated as percentage of Volume Consumed/Upstream Flow Volume.

Table 4.1-1 Summary of data sources for water budgeting in the MRSPR

Component	**Data Sources**	**Annual Water Budget (Conceptual)**	**Monthly Water Budget (Tier 1)**
Precipitation and Temperature	Data from Environment Canada Great Lakes Forestry Study (McKenney et al., 2006)	Required	Required
Evapotranspiration	Calculations from Thornthwaite and Mather using climate data from Great Lakes Forestry Study data (McKenney et al., 2006) and soils water holding capacities.	Required	Required
Streamflow	Water Survey of Canada/Parks Canada hydrometric stations	Required	Required
Net Consumption	Municipal drinking water data and sewage discharge data. OMYA data.	Not required	Required
Snow pack storage	Data from the Conservation Authorities and Parks Canada snow sites	Not required	Required
Reservoir storage	Data from Conservation Authorities and Rideau Canal. Storage can be estimated using Reservoir Rule Curves.	Not required	Required
Groundwater recharge	No data. Computed using Modified MOE 1995 methodology (Appendix F).	Not required	Required
Baseflow	No data. Computed using annual runoff and USGS Baseflow Method (Neff et al., 2005).		
Diversions	No data.	Not required	Required

Table 5.1-1 Long-term, annual, regional water budget estimates (1971-2000)

Watershed Region	**Precipitation[1] (mm/year)**	**Runoff[2] (mm/year)**	**Derived ET[3] (mm/year)**
Mississippi	898	367	531
Rideau	926	365	561
MRSPR	912	366	546

1. Precipitation (McKenney et al., 2006) (1971-2000)
2. Runoff from the Mississippi River at Appleton and Rideau River at Ottawa (1971-2000)
3. Derived ET = Precipitation - Runoff

Table 5.1-2 Comparison of calculated and derived evapotranspiration estimates

Watershed Region	**ET Derived [1] (mm/year)**	**ET Calculated [2] (mm/year)**	**Difference**
Mississippi	531	570	7% (39 mm)
Rideau	561	581	3% (20 mm)
MRSPR	546	575	5% (29 mm)

1. ET derived = Precipitation – Runoff (from Table 5-1)
2. ET was calculated using Thornthwaite and Mather (1955, 1957) with 30 years (1971-2000) of climate data from the Great Lakes Forestry study (McKenney et al., 2006) (Section 3.2.4).

Table 5.2-1 Baseflow and groundwater recharge estimates using the USGS 2005 BFI Method (Neff et al., 2005) and the Modified MOE 1995 Method

	Annual Runoff[1] (mm/yr)	**USGS 2005 Baseflow index[2] BFLOW-G**	**USGS 2005 Baseflow[3] (mm/yr)**	**Modified MOE 1995 GW recharge (mm/yr)**	**Percent Difference**
Mississippi	367	0.42	154	122	-21% (32 mm)
Rideau	365	0.40	146	142	-3% (4 mm)
MRSPR	366	0.41	150	132	-12% (18 mm)

1. Long-term data (1971-2000) from Mississippi River at Appleton and Rideau River at Ottawa
2. USGS baseflow index from the BFLOW-G (groundwater) model (Neff et al., 2005)
3. USGS baseflow estimated as annual runoff (1971-2000) multiplied by the baseflow index: Baseflow = Runoff x Baseflow Index (Neff et al. 2005)

Table 5.3-1 Quantification of uncertainties in regional annual water budget estimates

Watershed Region	**Mean Annual Precipitation[1]**		**Mean Annual Runoff[2]**		**Derived ET[3]**	
	Value (mm)	Uncertainty 10% (mm)	Value (mm)	Uncertainty 5% (mm)	Value (mm)	Uncertainty (mm)
Mississippi	898	89.8	367	18	531	92
Rideau	926	92.6	365	18	561	94
MRSPR	912	91.2	366	18	546	93

1. Precipitation uncertainty – 10% (McKenney et al., 2006). See Section 4.2 for discussion.
2. Runoff uncertainty – 5% (Water Survey of Canada)
3. Derived ET uncertainty = Square root [(precipitation uncertainty)^2 + (runoff uncertainty)^2]

Table 5.3-2 Quantification of uncertainty in USGS BFLOW estimates[1]

Watershed Region	**USGS 2005 Baseflow[3] (mm)**	**10% Uncertainty (mm)**	**USGS Range (mm)**
Mississippi	154	15.4	139 - 169
Rideau	146	14.6	131 - 161
MRSPR	150	15.0	135 - 165

1. An average of 10% standard error was found in USGS 2005 study (Neff et al., 2005)

Table 6.1-1 Average, annual, regional water demand estimates calculated based on available water use data (does not include all PTTW's in the MRSPR)

Description		**Mississippi (million m^3/yr)**	**Rideau (million m^3/yr)**	**MRSPR (million m^3/yr)**
DEMAND				
Surface Water Takings	Municipal Plants[1]	2.31	5.23	7.54
	OMYA[2]	0	0.15	0.15
Ground Water Takings	Municipal Wells[3]	0.78	1.09	1.87
	Private Wells[4]	3.06	6.14	9.20
	Agriculture[5]	2.15	1.02	3.17
Total Surface Water Takings		2.31	5.38	7.69
Total Ground Water Takings		5.99	8.25	14.24
Total Water Takings		8.30	13.63	21.93
SUPPLY				
Precipitation[6]		3,893	3,941	7,835
Evapotranspiration[7]		2,469	2,474	4,941
Water Supply = Precipitation - Evapotranspiration		1,424	1,467	2,894

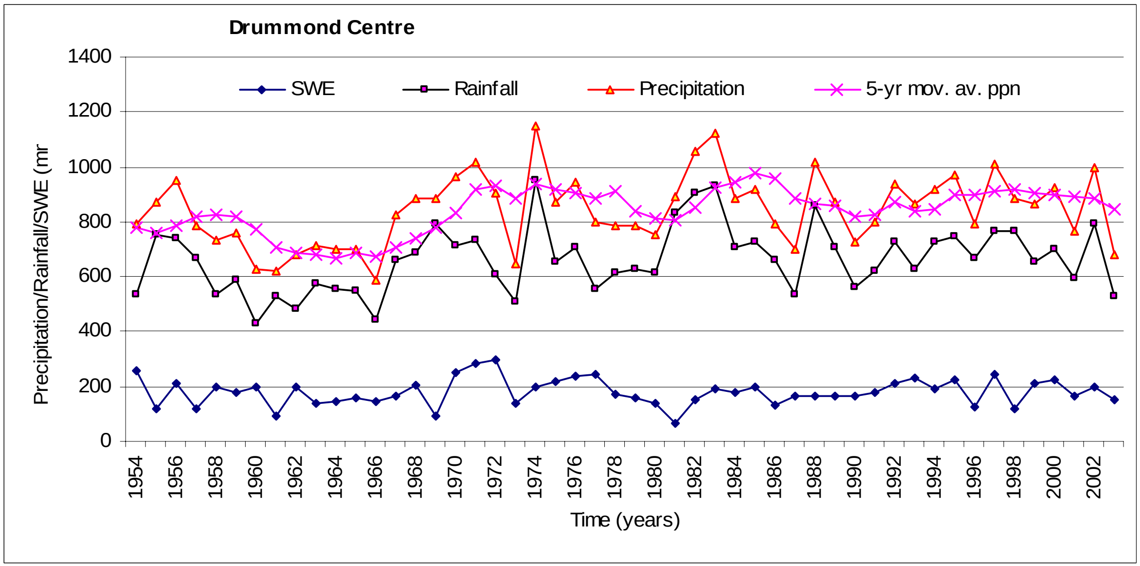
1. Carleton Place, Smiths Falls and Perth (excludes the Ottawa River plants (Britannia & Lemieux)
2. Average OMYA takings from the Tay River for available data (2004-2005)
3. Almonte, Carp, Kings Park Richmond, Kemptville, Merrickville, Munster Hamlet, Westport
4. Private wells from MOE wells database (2.85 persons/well at 200 Lpcd)
5. Agriculture water takings (de Loe, 2002) are assumed to come from groundwater.
6. Long-term, annual precipitation & evapotranspiration data (1971-2000) (McKenney et al., 2006)

Table 6.2-1 Comparison of maximum water takings and minimum stream flows at municipal drinking water plants in MRSPR

D.W. Plant	**Water Supply**	**Maximum Monthly Taking at D.W. Plant[1]**		**Nearest Hydro-metric Station**	**Lowest Monthly Flow at Station**		**Percent Water Demand**
		Month	**1,000 m^3 per month**		**Month**	**1,000 m^3 per month**	
Carleton Place	Mississippi River	Aug-87	355	Mississippi R. at Appleton	Aug-99	8,994	4%
Perth	Tay River	Aug-02	197	Tay R. at Perth	Jan-03	2,244	9%
Smiths Falls	Rideau River	Mar-94	573	Rideau R. above Smiths Falls	Feb-03	5,950	10%

1. Maximum monthly takings were obtained from municipal plant pumping records.
2. Lowest monthly flow at station was obtained from review of all available data (see Appendix C for periods of record at hydrometric stations).
3. Percent Water Demand = Maximum Monthly Taking at D.W. Plant / Lowest Monthly Flow at Station × 100%

Graph 3.2-1 Annual precipitation at Drummond Centre - Mississippi (1954-2003)



Graph 3.2-2 Annual precipitation at Kemptville - Rideau (1954-2003)

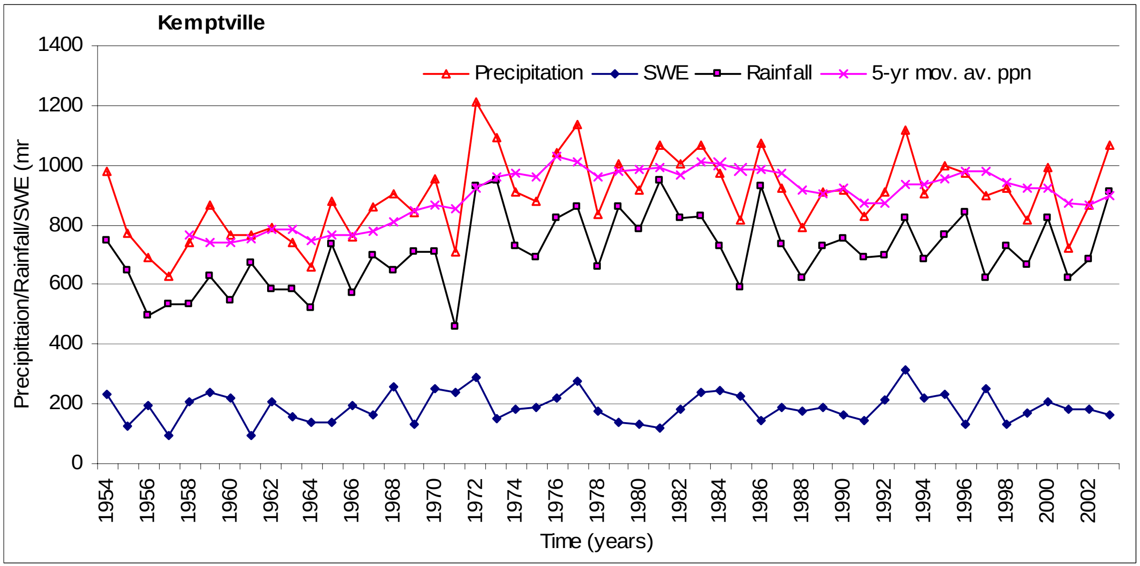
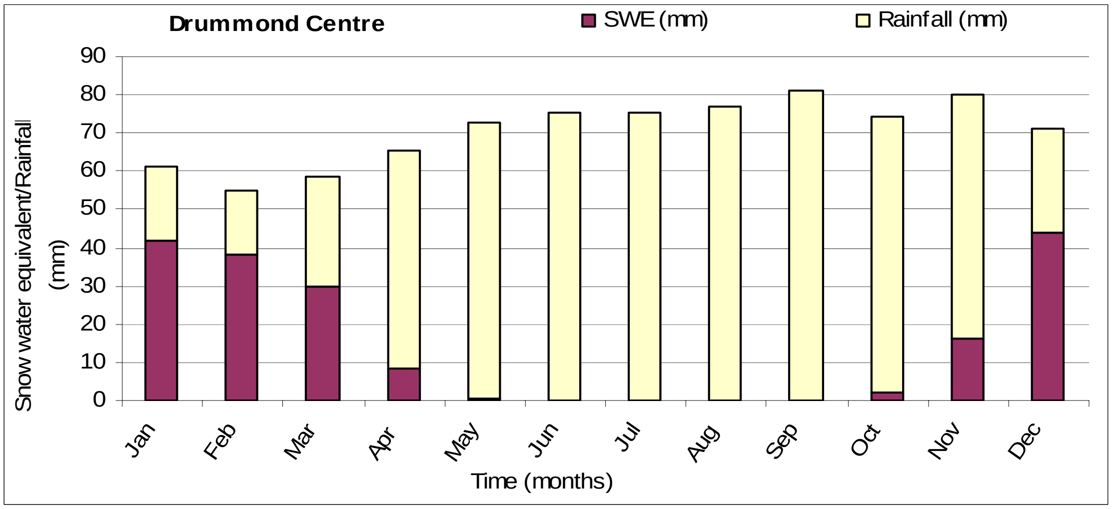
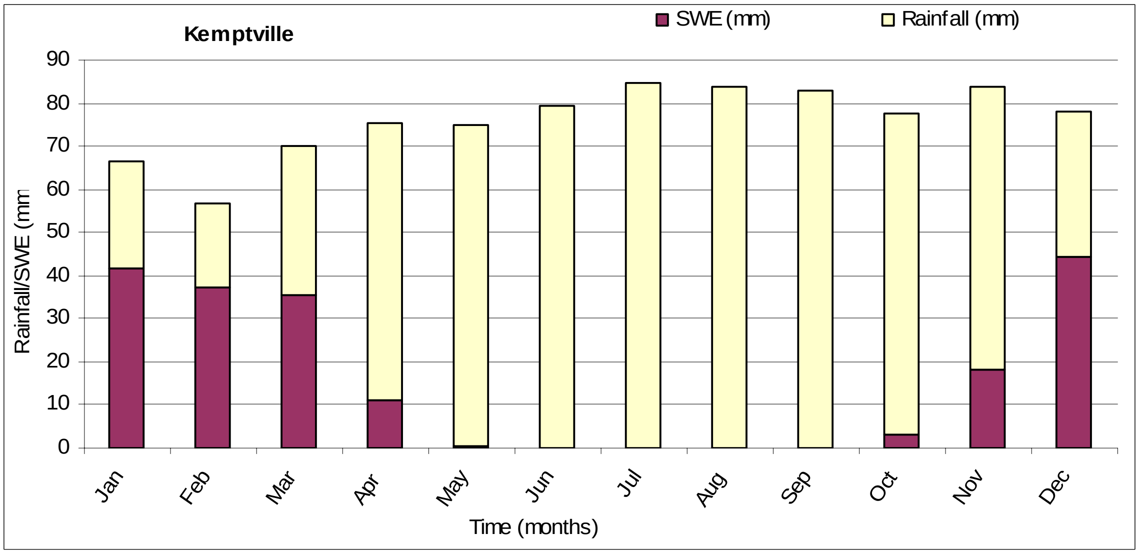


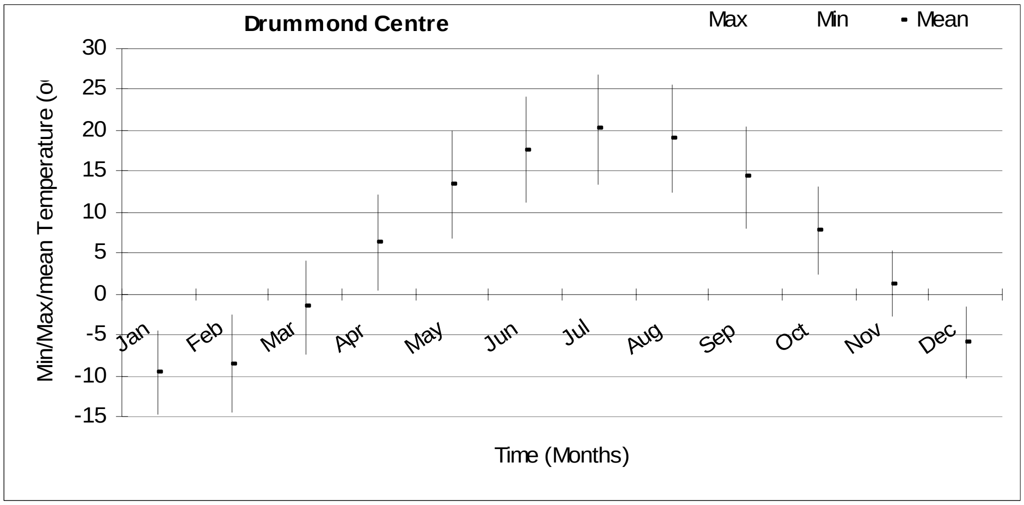
Figure 3.2-3 Average monthly precipitation at Drummond Centre - Mississippi (1954-2003)



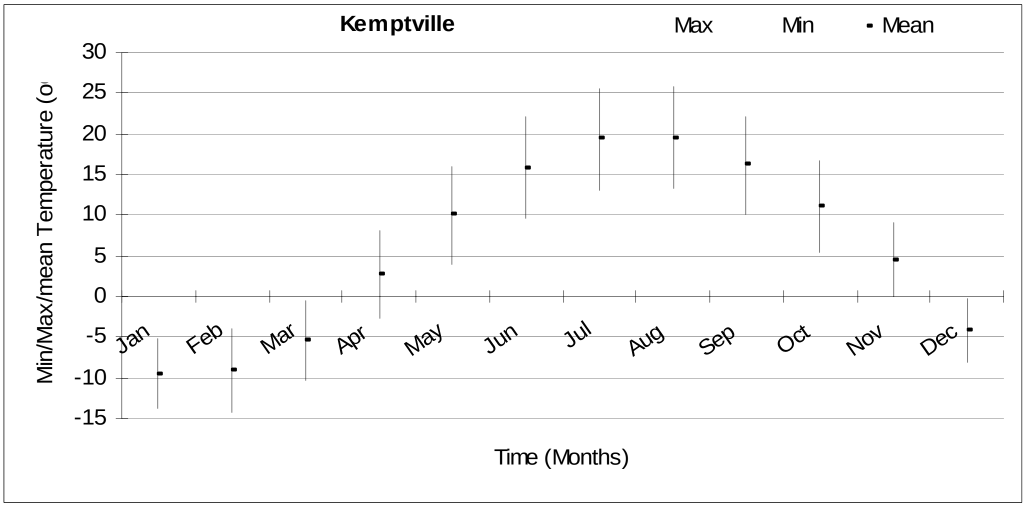
Graph 3.2-4 Average monthly precipitation at Kemptville - Rideau (1954-2003)



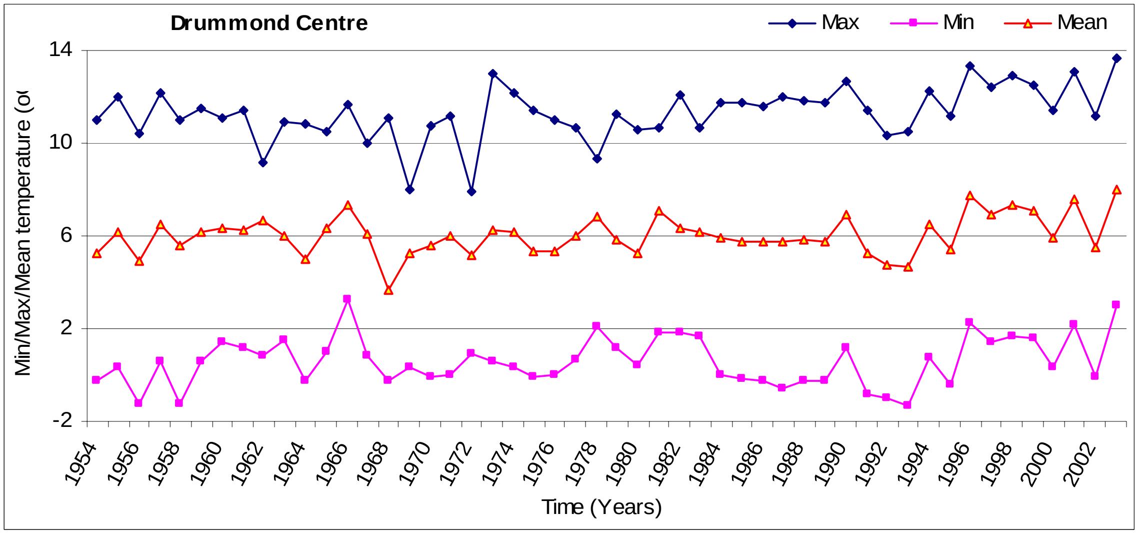
Graph 3.2-5 Monthly temperature at Drummond Centre-Mississippi (1954-2003)



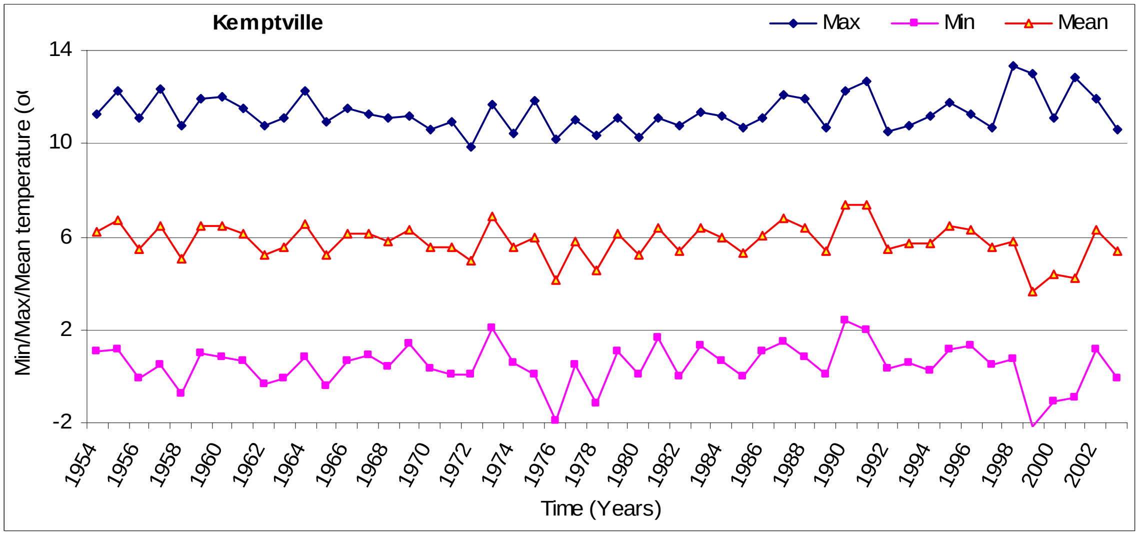
Graph 3.2-6 Monthly temperature at Kemptville-Rideau (1954-2003)



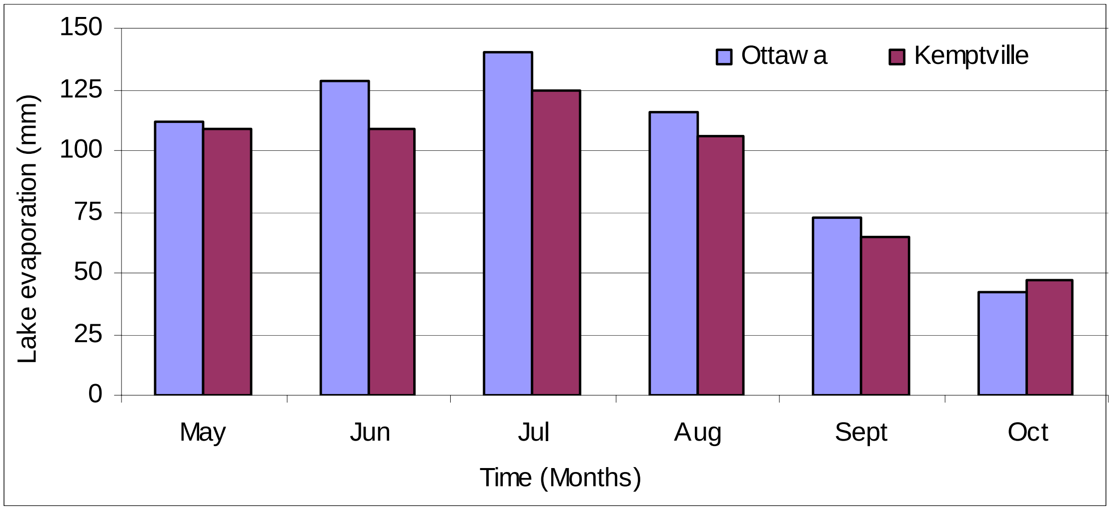
Graph 3.2-7 Annual temperature at Drummond Centre-Mississippi (1954-2003)



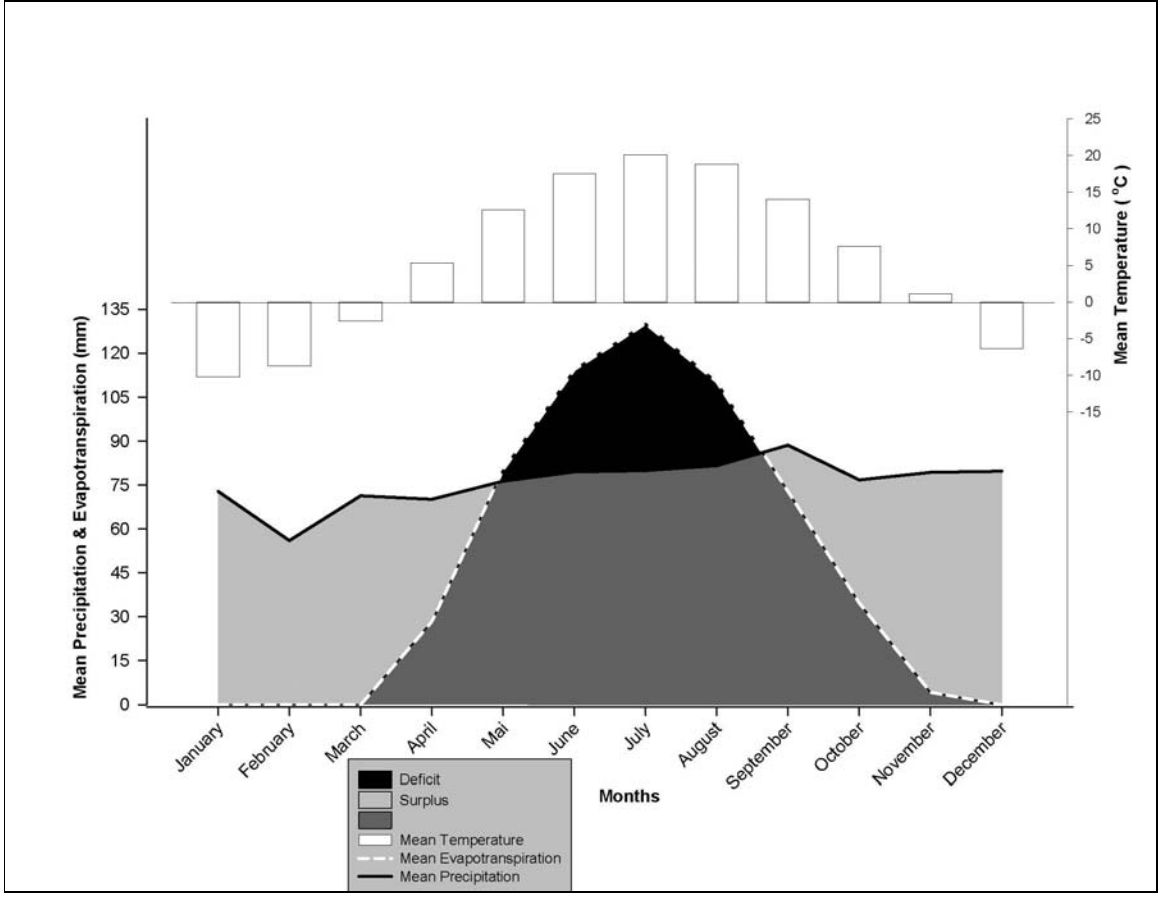
Graph 3.2-8 Annual temperature at Kemptville-Rideau (1954-2003)



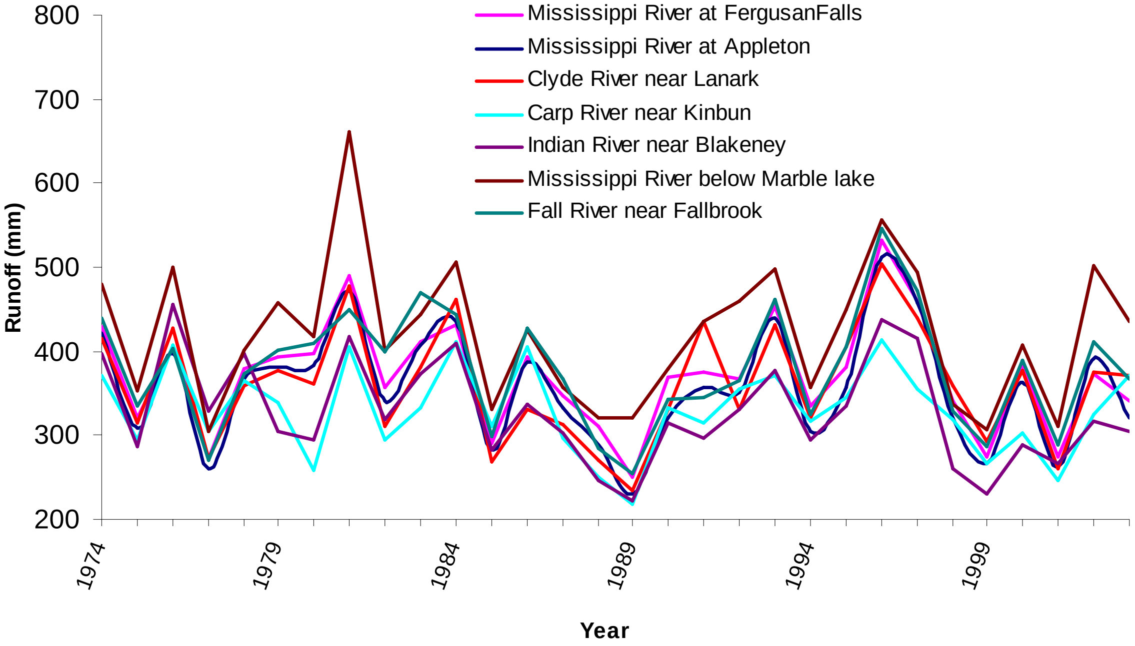
Graph 3.2-9 Monthly average lake evaporation at Ottawa and Kemptville



Graph 3.2-10 Average monthly precipitation, temperature and evapotranspiration for the MRSPR (1971-2000)

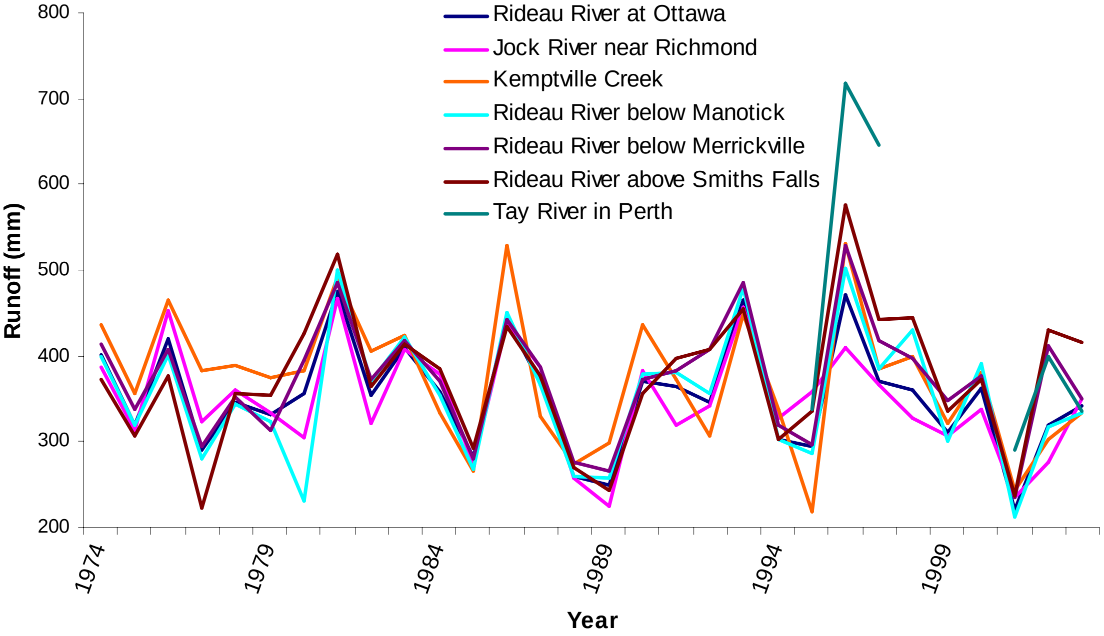


Graph 3.6-1 Mean annual runoff (mm) – Mississippi Stations (1974-2003)

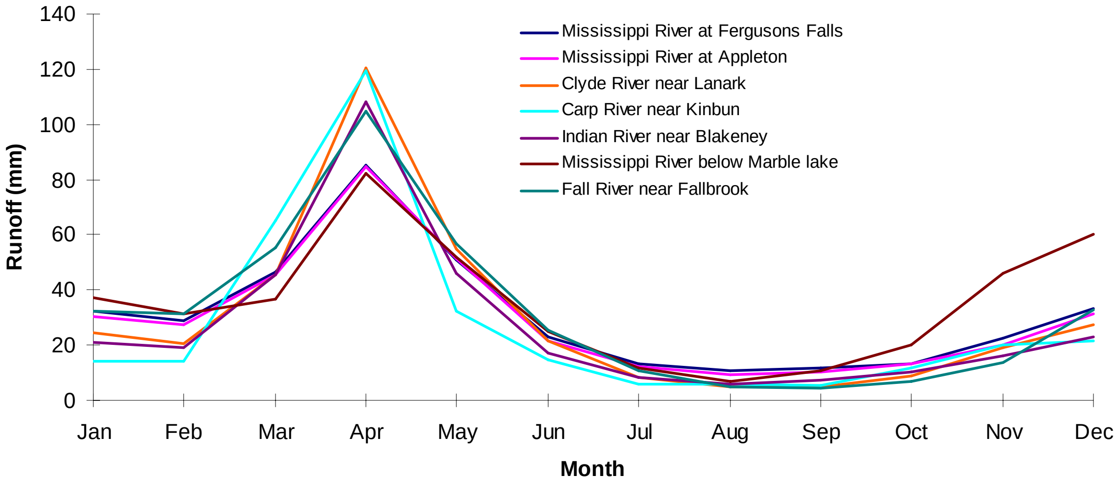


Graph 3.6-2 Mean annual runoff (mm) – Rideau Stations (1974-2003)

* The Tay River at Perth station only has 7 complete years of data; all other stations have 30 years (already complete or filled with correlated data).



Graph 3.6-3 Mean monthly runoff (mm) - Mississippi Stations (1974-2003)



Graph 3.6-4 Mean monthly runoff (mm) - Rideau Stations (1974-2003)