Chapter 3
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3 Water Budget

Introduction

This chapter provides information on how water quantity and distribution in the Mississippi-Rideau Source Protection Region (MRSPR) is determined.

The Water Budget estimates *how much* water exists in the MRSPR through measuring or estimating values of components of the Water (hydrologic) cycle.

A Conceptual Water Budget was first developed. The purpose of this water budget is to determine the major hydrological pathways through the watersheds. The Tier 1 Water Budget is completed after the Conceptual Water Budget. The Tier 1 refined the scale of the Conceptual by developing water budgets for each of the 22 subwatersheds in the region using monthly and annual data.

Stress levels for surface water and groundwater were calculated for each of the subwatersheds in the MRSPR. Three subwatersheds showed a surface water stress of moderate under the current and future demand scenarios:

- Carp River Near Kinburn;
- Ottawa MVC; and
- Fall River At Bennett Lake.

One subwatershed, Rideau River at Ottawa, showed a groundwater stress of moderate under current and future demand scenarios.

The Technical Rules require further study (Tier 2) if subwatersheds supplying municipal drinking water systems are determined to have moderate or high stress. Of the four subwatersheds identified as showing moderate stress under current and future demand scenarios, none supply municipal drinking water systems.

When surveyed during the Tier 1 study, no municipality with a surface water or groundwater system reported conditions within the defined timeframe so no additional stress studies were required.

Therefore, the Tier 1 Water Budget for the MRSPR concludes that Tier 2 and 3 studies are not required.

Technical Studies

The Conceptual Water Budget study was completed in 2007 by Mississippi-Rideau Source Protection Region staff and Intera Engineering Ltd. The Tier 1 Water Budget and Stress Assessment study was completed in 2009 by Mississippi-Rideau Source Protection Region staff and Intera Engineering Ltd.

Peer Review

In 2006, the Cataraqui Source Protection Area, the Quinte Source Protection Region and the Mississippi-Rideau Source Protection Region formed a joint team for peer review of the conceptual water budget studies and subsequent Tier 1 water budget studies. A Terms of Reference was developed for the peer review process in accordance with the provincial water budget peer review guidance document.

The peer review consisted of the following external reviewers:

- Bill Hogg M. Sc., Private Consultant, Former Climatologist with Environment Canada
- Dr. Ed Watt, XCG Consulting Ltd., Former Professor (Hydrology) at Queen's University
- Darin Burr, Dillon Consulting Ltd., Hydrogeologist
- Dr. Kent Novakowski, Queen's University, Hydrogeolgist
- Dr. Michel Robin, University of Ottawa, Hydrogeolgist
- Michel Kearney, City of Ottawa, Infrastructure Planner

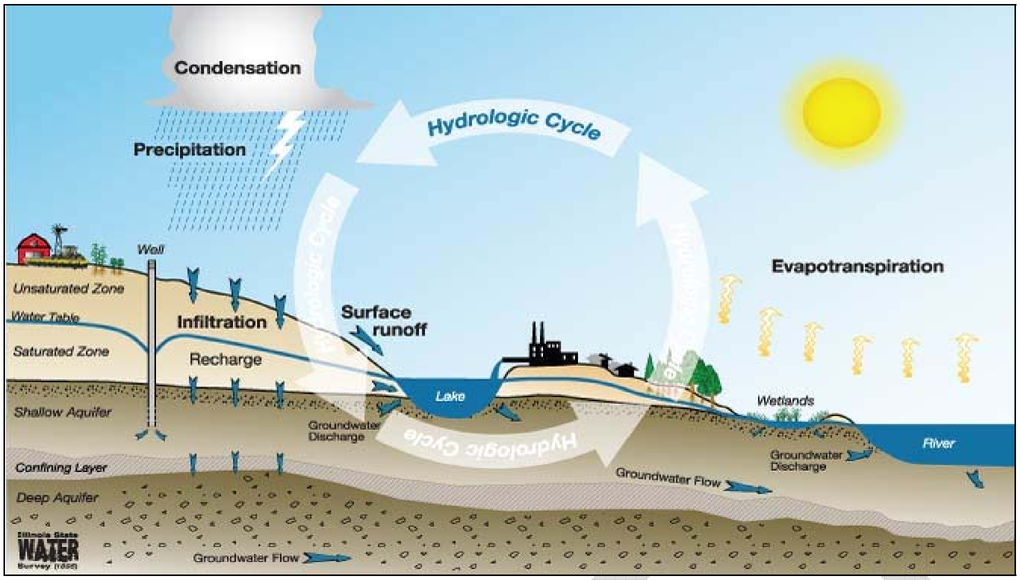
Regular meetings were held with the peer review team between early 2006 and 2009. Complete Peer Review records are available for the Mississippi-Rideau Conceptual Water Budget, and Tier 1 Water Budget and Water Quantity Stress Assessment Reports (see Appendix A-1).

Information on water quality work completed in the MRSPR may be found in Chapter 5 for groundwater and Chapter 6 for surface water. Data gaps for this and other chapters may be found in Chapter 8. Information on how climate change may influence the water budget can be found in Chapter 7. Appendix A-1 provides a full list of technical studies completed in the MRSPR.

3.1 What is a Water Budget?

A water budget estimates how much water exists in a watershed or subwatershed over a period of time, usually monthly or yearly. Water budgets account for water that is being added to a watershed, such as precipitation and removed (e.g. rivers flowing out) from a watershed. They also account for changes in storage (e.g. lake level changes).

The watershed boundaries are determined by the highest land elevations in the area, which then direct the surface water flow into respective basins. Each watershed can be broken down into smaller areas called subwatersheds, each which has water running off into the smaller areas which contribute to the larger watershed.



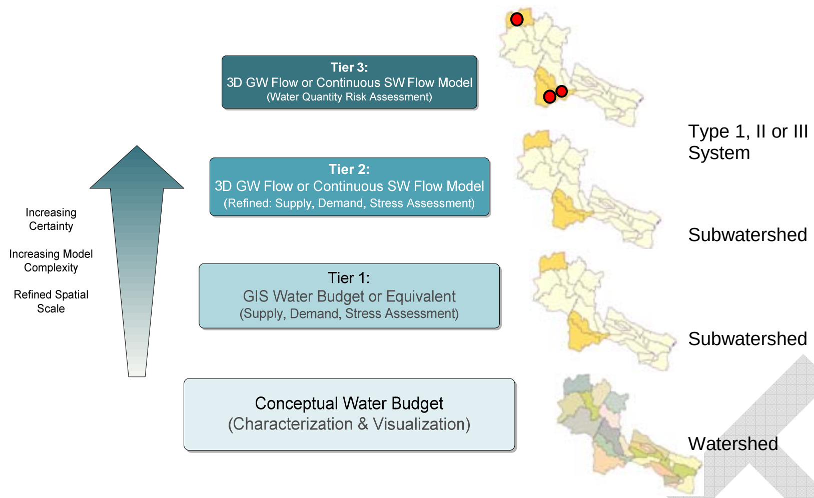
The Water Cycle. Source: Illinois State Water Survey website
http://www.isws.illinois.edu/docs/watercycle/

As illustrated, the water budget examines the various parts of the water (hydrologic) cycle. The water cycle components include precipitation, evaporation, transpiration (water uptake and release of water vapour by plants), surface water and groundwater flows, water takings and storage. Water enters a watershed as precipitation. Precipitation not lost to evapotranspiration (ET), the combination of evaporation and transpiration, may run off the land or seep into the ground as groundwater recharge. This in turn may eventually discharge back to the surface. When water levels rise and fall in lakes and aquifers, water storage increases and decreases respectively.

When calculating water budgets the only source of water is considered to be precipitation, since the high surface elevations around the perimeter prevent surface water from flowing into the watersheds from outside sources. Background documents (MRSPR, 2007, 2009) show that there is some horizontal groundwater flow into the MRSPR however this amount is considered negligible compared to the amount of water added to the region by precipitation.

3.1.1 Water Budgets and Source Protection

The Technical Rules prescribe a tiered approach for the completion of water budget studies. With each subsequent tier a smaller area is studied, model complexity increases, and confidence in the results improves.



Tiered Water Budget Approach. Source: MNR "Technical Information Session", January 9, 2009, Brockville

Water budgets help to build an understanding of how water moves through the watershed. They require information on climate, surface water and groundwater, and also on land cover, soils, topography, and geology. Calculations may be simple or complex depending on the study scope and the quality and quantity of the data.

The Conceptual Water Budget is the first level of water budget which is developed. It builds on the data and information gathered for the Watershed Characterization and it identifies important hydrologic processes using the best available data. The Conceptual Water Budget provides estimates of the annual water budgets on a watershed scale.

The Tier 1 Water Budget and Water Quantity Stress Assessment build on the Conceptual Water Budget. Tier 1 water budgets are required to study smaller areas (subwatersheds) and monthly time scales instead of the annual time scales used in the Conceptual Water Budget. Technical Rules require Tier 1 water quantity stress assessments for surface water and groundwater in all subwatersheds. Subwatersheds that may be limited in surface water or groundwater supply relative to demand are then identified. This is called a water quantity stress.

A Tier 2 assessment is required if the Tier 1 assessment results in a moderate or significant stress, or if there have been historical water quantity issues identified, *and* the subwatershed contains a municipal drinking water system.

A Tier 3 or Local Area water budget is required if the Tier 2 assessment still results in moderate or significant stress. Water quantity threats can be identified at the Local Area water budget stage.

3.1.2 Completed Water Budget Studies

Water Budgets and the Mississippi-Rideau Source Protection Region

The MRSPR includes the boundaries of Mississippi Valley Conservation (MVC) and Rideau Valley Conservation Authority (RVCA). Figure 3-1 shows the boundaries of the MRSPR and includes the MVC, RVCA, their watersheds and subwatersheds. MVC boundaries include the Mississippi River and Carp River watersheds and Ottawa River subwatersheds within MVC. RVCA boundaries include the Rideau River watershed and Ottawa River subwatersheds within RVCA.

Note: The Technical Rules stipulate that the Ottawa River is not considered in the water budget studies, so water budget studies completed in the MRSPR do not account for water supply in or water demand from the Ottawa River.

Conceptual and Tier 1 Studies

As discussed above, the MRSPR has completed two water budget studies, the 2007 "Conceptual Understanding of the Water Budget", referred to as the Conceptual and the "Tier 1 Water Budget and Stress Assessment", referred to as Tier 1. The Conceptual Water Budget study is summarized in Section 3.2. The Tier 1 Water Budget and Stress Assessment study is summarized below in Section 3.3 and 3.4.

Climate change was not accounted for in the Conceptual and Tier 1 studies as the Technical Rules require the use of historical data to estimate the water supply. Climate change may impact future water supply but the impact that climate change will have on water supply in the MRSPR is currently unknown. For more information on climate change please see Chapter 7.

The Conceptual and Tier 1 studies were completed by MRSPR staff and Intera Engineering, Ltd. using best available data and Geographic Information System (GIS) tools. Both studies were peer-reviewed and conform to the Technical Rules issued under the *Clean Water Act (2006)*. Methods were further refined by MOE in "Guidance Module 7: Water Budget and Water Quantity Risk Assessment" (MOE 2007). The Ontario Ministry of Natural Resources (MNR) provided key direction and provided draft acceptance of the two studies.

Climate Change Review

In addition to the two water budget studies, a climate change review is required. Technical Rules require a summary of climate change knowledge and climate data, and an interpretation of how climate change can impact the conclusions in the Assessment Report. Please refer to the climate change technical report, referred to in Appendix 1, and Chapter 7 for this information.

3.2 Conceptual Water Budget

3.2.1 What is the Conceptual Water Budget?

The Conceptual Water Budget is a study that uses best available data, spreadsheet models and GIS tools to examine how surface water and groundwater move through a watershed. Its purpose is to determine the major hydrologic pathways controlling water flow through the watersheds. The Conceptual Water Budget also provides a framework for data collection. The first step of the Conceptual Water Budget was to describe how water enters and leaves the MRSPR.

3.2.2 Surface Water Flow Systems

This section describes the factors that affect surface water flow and identifies the major surface water bodies in the MRSPR.

Climate

The amount of precipitation that falls in a watershed is the key factor affecting surface water and groundwater flows. Precipitation is considered to be the only source of water to the watersheds in the MRSPSR.

Annually, approximately 77% of precipitation in the MRSPR falls as rain and 23% as snowfall. The driest month of the year is February. The wettest month is September. The greatest amount of snowfall occurs in December.

Average precipitation and (air) temperature models were developed using North America-wide climate models of the Canadian Forest Service (McKenney et al. 2006) for 1971-2000 with data from Meteorological Service of Canada climate stations. Figure 3-2 shows average annual precipitation across the MRSPR and the climate stations used to develop these models. Precipitation is lowest in the central part of the MVC (less than 850mm per year) and greatest near the eastern edge of the RVCA (greater than 950mm per year). Overall, 850 to 950 mm per year is a relatively large amount of annual precipitation in a watershed compared to many other areas in Canada.

Average temperature was calculated from the Canadian Forest Service data as the average of minimum and maximum temperature. Average annual temperature varies across the MRSPR from 4ºC in the west to 7ºC in the south-east. Figure 3-3 shows the distribution of average annual temperature across the MRSPR. The data sources used for the water budgets are listed in Table 3-1.

Land Cover

Once precipitation arrives at the ground surface the land cover, topography and geology play important roles in determining how much water is removed from the watershed by ET and how much water becomes overland flow or groundwater flow.

Agriculture, forest and plantations will return a significant amount of water to the atmosphere by ET. The MNR 1998 provincial land cover data shows that more than 50 percent of the MRSPR is categorized as forest and plantations and agricultural land represents almost 25% of the MRSPR.

Lakes and wetlands store surface water and may release water slowly. These features are critical for controlling peak river flows associated with floods. Open water and wetlands cover 16% of the MRSPR.

Water mainly runs off land with low permeability such as pavement. More permeable surfaces such as cultivated land and woodland will allow infiltration more readily. Approximately 2.4% of the MRSPR is developed.

Category	Land Cover Percentage		
	MVC	RVCA	MRSPR
Forest and Plantations	66	39	50
Agriculture	19	34	25
Open Water and Wetlands	14	19	16
Settlement	0.4	4.5	2.4
Other	0.6	3.5	6.6
Total Percentage	100	100	100

Land Cover in the MRSPR. Source: 1998 MNR Land Cover Data

Groundwater recharge is discussed further in Section 3.2.3.

The land cover categories described here are based on groupings shown on Figure 3-4.

Physical Geography

The MRSPR is divided into two distinct geographical and geological zones. The western half of the MRSPR, where the Canadian Shield is exposed at the surface, is relatively higher in elevation compared to the eastern zone and is hilly with little to no overburden sediments overlying the Precambrian bedrock (see Figure 3-5 for surficial geology). The eastern half of the MRSPR is part of the larger Central St. Lawrence Lowland basin. The Precambrian bedrock is overlain by sedimentary bedrock units and overburden deposits in the eastern zone.

Ground surface topography within the MRSPR, shown in Figure 3-6, generally slopes from the western zone towards the east. The ground surface in the western zone is generally greater than 175 metres above sea level (masl) and the ground surface in the eastern zone is generally less than 175 masl. The lowest elevation is along the shores of the Ottawa River where ground surface is approximately 40 masl.

Steep slopes promote overland flow of water and inhibit groundwater recharge. This is more characteristic in the western zone of the MRSPR, although there are some isolated areas in the eastern zone that have steep slopes. The western zone is characterized as hilly with wetlands, which can store overland flow. Chapter 2 provides further information on MRSPR watershed characteristics.

Precipitation that lands on flat-lying areas is more likely to contribute to groundwater recharge because it has a greater chance of infiltrating the soil or rock. However, surficial geology is a key contributing factor affecting how much water can recharge the groundwater flow system. Groundwater recharge is discussed further in Section 3.2.3.

Mississippi River and Rideau River Flow Systems

The largest rivers (excluding the Ottawa River) in the MRSPR are the Mississippi River and the Rideau River. The Mississippi River flows over 212 km from Mazinaw Lake before discharging to the Ottawa River near Galetta. The main tributaries of the Mississippi River include the Clyde River, Fall River, and Indian River. The Carp River discharges into the Ottawa River just downstream of Galetta. The Rideau River flows 160 km from Burridge Lake to downtown Ottawa where it discharges into the Ottawa River. The main tributaries on the Rideau River include the Tay River, Jock River, and Kemptville Creek. There are also many smaller tributaries in the MRSPR that discharge directly to the Ottawa River, as shown in Figure 3-1.

The upper portion of the MRSPR contains many small lakes that, when considered together, represent a significant capacity for surface water storage. Dams on lakes and rivers operated or owned by Parks Canada (for the Rideau Canal), MNR, the Conservation Authorities, and power generation companies control flow. There are approximately 30 water control structures in the Mississippi River watershed including 25 dams and 5 power generating stations. There are approximately 46 control structures in the Rideau River watershed including 24 dams, 19 locks (on the Rideau Canal) and three power generating stations. These structures can have a significant effect on surface water flows. The surface water control structure locations in the MRSPR are shown in Figure 3-7.

Surface water flow is measured at flow gauges, called streamflow hydrometric stations. Long-term streamflow data was obtained from flow gauges by Water Survey of Canada (HYDAT database), Parks Canada, MVC and Ontario Power Generation. Table 3-2 shows the average annual and monthly flows in the Mississippi and Rideau Rivers measured at their most downstream flow gauges (see Figure 3-7 for surface water flow gauge locations). It should be noted that flows in Table 3-2 are given in cubic metres per second (m^3/s).

Flows in the MRSPR rivers historically peak in April due to snowmelt. Low flows occur in August due to high ET and a decline in surface water storage. Storage includes natural storage (e.g. wetlands and uncontrolled lakes) and man-made storage (e.g. dammed reservoirs). Flows increase in the fall and winter due lower ET rates. This serves to minimize the amount of water that leaves the watersheds through the atmosphere during this time and maximizes the amount of water available for groundwater recharge and overland flow.

Flows in rivers with dams on them, called regulated rivers, generally vary less throughout the year as they are managed to keep water levels within certain ranges. Summer flows are typically higher and spring flows are lower in regulated rivers compared to unregulated rivers.

Aquatic Habitat

There are a number of types of aquatic habitats found in the MRSPR, from warm shallow water wetlands to deep cold water systems. Each habitat type is dependant upon specific characteristics of depth, flow and temperature of surface water.

Cold water creeks in the Mississippi system are:

- Poole's Creek;
- Pauls Creek;
- Eastons Creek;
- Long Sault Creek; and
- Bolton Creek.

Wetland locations in the MRSPR are shown in Figure 2-9.

3.2.3 Groundwater Flow Systems

Precipitation that is not lost by ET and not moved by overland flow to surface water bodies is available for groundwater recharge. Groundwater recharge is the process where water seeps into the ground and travels to the water table. Not all infiltrated water contributes to groundwater recharge; ET reclaims some water from the soil before the water reaches the water table.

Groundwater discharge is a process where groundwater leaves the groundwater flow system and discharges at the surface, typically into municipal drainage systems, rivers, lakes, and wetlands.

This section describes the major factors that affect groundwater recharge and identifies the regional groundwater flow systems.

Climate

Precipitation is considered to be the only source of water to the watersheds in MRSPR. Precipitation, or surface water that began as precipitation, are the only sources of water available to recharge the groundwater in the MRSPR.

It is difficult to quantify groundwater recharge on a regional scale but the climatic factors that affect groundwater recharge are generally well known. High ET in the summer months and frozen soils in winter inhibit groundwater recharge.

Spring and fall are the times of the year when the climate is conducive to groundwater recharge. Spring melt releases large amounts of water from the snow pack that may recharge the groundwater, although the majority of spring melt travels by overland flow to rivers. Annually, the largest amount of precipitation falls in September in the MRSPR, some of which will recharge the groundwater system.

Land Cover

During the growing season, typically late spring through early fall, potential groundwater recharge is lost to the transpiration component of ET. As discussed in Section 3.2.2, more than 50% of the MRSPR is classified as forest and plantations and almost 25% is classified as agricultural land, and these types of land cover have vegetation which consumes a significant amount of the water that infiltrates into the ground. Tiled agricultural fields may also inhibit groundwater recharge since infiltrated water is forced to run off into surface water bodies, including municipal drains.

Surface water may promote recharge or cause groundwater to discharge to surface water depending on their location relative to the local groundwater flow system, and in some cases, depending on the time of year. Surface water bodies cover 16 percent of MRSPR.

Natural landscapes typically promote groundwater recharge compared to developed landscapes. Only 2 percent of the MRSPR is classified as developed. Developed land typically inhibits groundwater recharge due to impervious land cover such as asphalt.

Further information on land cover in the MRSPR may be found in Chapter 2.

Geology

The overburden thickness in the MRSPR, shown in Figure 3-8, is generally thin to non-existent (< 1 m) in the west with the exception of areas in the north where bedrock valleys near the Ottawa River and Rideau River allow the accumulation of 10-30 m of clays and sands. Immediately below the overburden sediments in the west is the Precambrian basement, also called the Canadian Shield, as shown in Figure 3-5.

The overburden deposits thicken in the east as the underlying bedrock drops in elevation. Below the overburden in the east are Paleozoic bedrock formations including the Potsdam, Beekmantown and Ottawa Groups, as shown in Figure 3-9. The Paleozoic bedrock overlies the Precambrian basement.

Further information on the geology of the area may be found in Chapter 2.

Major Aquifers

Aquifers are geologic formations that have high groundwater yields. Aquifers can be either overburden or bedrock. Regionally significant overburden aquifers include sand and gravel units and eskers. Regionally significant bedrock aquifers in the MRSPR are typically sandstone or fractured bedrock. Within the western zone, domestic groundwater supply is obtained from the upper parts of the Precambrian, which tends to be significantly fractured. Central MRSPR uses the Nepean Formation (sandstone) and the Oxford and March Formations (fractured dolostone). Finally, the north and extreme east portions of the MRSPR use a mixture of unconfined and confined overburden (sand and gravel) and bedrock (Oxford-March and Nepean Formations) aquifers.

The Nepean Sandstone aquifer 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 locations of the drinking water supply aquifers in the MRSPR are shown in Figure 3-10. The remaining aquifers are not typically used for water supply due to slow flow into wells or poor-quality water.

Groundwater Recharge and Discharge Areas

Areas of significant groundwater recharge typically exist on high elevations or where a porous surficial sand or gravel cover exists in a flat lying area, allowing precipitation to infiltrate the deeper groundwater aquifers. Heavily fractured bedrock outcrops can also be areas of groundwater recharge. There is significant uncertainty about mapping groundwater recharge at a regional scale due to the number of factors that affect groundwater recharge.

It is equally difficult to map groundwater discharge features at a regional scale because discharge sites are commonly below water, where it is difficult to obtain accurate measurements.

Groundwater recharge and discharge areas in the MRSPR, delineated based on regional data, are shown in Figure 3-11. Local information should be considered more accurate than this regional scale map.

Groundwater Flow Systems

The water layer and water level measurements from wells that are in connected overburden or bedrock units can be used to interpret groundwater flow systems. Water level measurements from water wells in the MRSPR were compiled from MOE water well records (Golder et al. 2003). Two groundwater flow systems were identified in that study – a shallow system, shown in Figure 3-12, and a deep groundwater flow system, shown in Figure 3-13.

The shallow and deep groundwater flow systems generally follow the same pattern as ground topography, shown in Figure 3-6. The regional groundwater flow direction in the MRSPR is from the south-west to north-east. Shallow groundwater flow is influenced by topography and generally flows from higher elevations towards lower lying surface water bodies.

Local variation in geology also influences groundwater flow where the groundwater connection is typically through the higher permeability rock or soil. Deep groundwater flow is less influenced by surface features and more influenced by connectivity of aquifer material (i.e. fractured bedrock or sand and gravel). It therefore may flow underneath smaller surface water features that act as minor discharge features for shallow groundwater flow.

Based on water level measurements in the deep flow system, groundwater flow in the Nepean Formation (sandstone) was calculated to be approximately 0.2 m^3/s. This is significantly lower than average flows in the Mississippi (31.5 m^3/s) and Rideau (40.6 m^3/s) Rivers, shown in Table 3-2.

One of the complicating factors affecting regional groundwater flow that is not well understood is the presence of bedrock faults. Faults can act as conduits or barriers to groundwater flow depending on how and where the fault was created. There are likely significant differences between the groundwater flow rates in the faults compared to groundwater flow rates elsewhere in the MRSPR, but there is not currently a good understanding of groundwater flow in faults.

3.2.4 Anthropogenic Water Use

Anthropogenic (human) water use in the MRSPR includes drinking water, agriculture, and industrial/commercial uses. Water is also required for ecological needs.

Drinking water takings data was obtained for municipal systems and private wells. Data for private surface water intakes was not available. There are currently twelve municipal drinking water systems in the MRSPR including five municipal surface water intakes, three on regional rivers and two on the Ottawa River, and seven municipal wells. Operators of municipal systems maintain records of municipal water takings.

The total municipal surface water and groundwater takings in the MRSPR are approximately 9.5 million m^3/yr.

Please Note: This excludes Britannia and Lemieux surface water intakes in the Ottawa River, which take approximately 22 million m^3/yr.

Private well consumption in the MRSPR is estimated as 9.2 million m^3/yr.; 3.1 million m^3/yr in MVC, and 6.1 million m^3/yr in RVCA. Private well 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 L per capita per day.

The Ontario Permit to Take Water (PTTW) database compiles permitted water takings in Ontario for water takings greater than 50,000 L/day and typically represents industrial and commercial takings. The total volume of permitted water takings in the MRSPR is more than 31 million m^3/day including 8 million m^3/day in the Mississippi watershed and 23 million m^3/day in the Rideau watershed.

The database only lists the maximum permitted takings, not what is actually taken. Also included in these totals are the permits for power generation or to fill constructed wetlands. In both of these cases the large majority of the water is returned to the environment. Therefore, the volumes listed in the PTTW database overestimate the amount of water consumed for anthropogenic uses.

Subsequent examination of PTTWs in the Tier 1 assessment found considerably lower consumptive water takings. The Tier 1 water takings results are more accurate than the values presented in the Conceptual Water Budget. Maximum permitted takings for each permit is discussed in Section 3.3.5.

Annual agriculture water use data was obtained from MNR (de Loe 2002). Water use data was given for livestock and crops based on the estimated number of farms. According to the MNR data, approximately 55% of agricultural water use is used for livestock and 45% is used for crops. Estimates show approximately 1 million m^3/yr of water are used for agriculture in the Mississippi watershed and 2 million m^3/yr of water are used for agriculture in the Rideau watershed.

Tables 3-5 and 3-6 list consumptive demands for groundwater and surface water. Takings from private wells and agriculture are discussed above and other non-permitted takings are not accounted for in this study. The cumulative effects of other non-permitted takings are assumed to be negligible compared to the amount of water available at the watershed scale.

3.2.5 Long-Term Annual Water Budget for MRSPR and its Watersheds

Water Budget Equation

Water budget equations were carried out on three areas: the entire MRSPR, the Mississippi River watershed, and the Rideau River watershed all on a long-term (1971-2000) annual scale. The hydrologic processes moving water through a watershed may be expressed as:

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

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 (removed) from the watershed and not returned

The above terms have the same units of depth – mm (millimetres). An example of how to interpret these depths is the amount of precipitation that falls per unit area of the watershed. Surface water flow out (SW_{OUT}) has been converted into a depth of runoff (in mm) by multiplying the surface water flow rate (in m^3/s) with the time step to get volume and dividing by the drainage area.

The number of variables in the equation above can be reduced through the following assumptions. Over the long-term (i.e. 30 years), changes in surface and groundwater storage are negligible so the ΔS term is assumed to be zero.

Human water uses within each watershed currently add and remove the same amount of water (e.g. water supply systems and waste water treatment systems). Therefore, additions and removals ($ANTH_{IN,\ OUT}$) related to human activity negate each other and were not considered at the watershed scale. Also, diversions of water between watersheds are negligible, therefore; this term is assumed to be zero. This assumption should be reviewed regularly for the removals of water from the watershed.

Groundwater flow in and out of the watersheds is assumed to be equal, so these terms ($GW_{IN,\ OUT}$) cancel each other out. This does not mean that groundwater flow in the MRSPR is negligible, only that the amount of flow into the system equals the amount of flow out over the year. All subwatersheds considered in the water budget are treated as headwater subwatersheds, meaning the drainage area is cumulative above the gauges and extends to the headwaters. This results in no surface water flow coming in at the upstream boundary and therefore SW_{IN} is zero.

This leaves precipitation (P), surface water flow out (SW_{OUT}), and evapotranspiration (ET). Therefore, the water budget equation is reduced to:

Precipitation – SW_{OUT} – ET = 0

Long-term averages (1971-2000) of precipitation and surface water data were obtained (see Table 3.2-1 for data sources); therefore ET was derived as the difference between precipitation and surface water flowing out of the watershed, or:

Derived ET = P – SW_{OUT}

Long-term (1971-2000) annual water budgets given in Table 3-3 show the majority of water leaves each watershed and the MRSPR by ET, and the remainder leaves by surface water flowing out of the rivers. In the MRSPR as a whole, it is estimated that of the annual precipitation amount of 912mm, 366mm leaves the region as surface water flow and 546mm is lost to ET.

Data Limitations and Uncertainty

The climate data and surface water flow data used for the Conceptual Water Budget were averaged over long time periods. The conceptual water budget results are considered to be accurate in each watershed over the long term. A high amount of uncertainty will be introduced to the water budget if it is used to examine hydrological processes at smaller time or spacial scales.

Climate change has not been included in these calculations but may affect the water budget over time. A discussion of potential impacts of climate change can be found in Chapter 7.

3.3 Tier 1 Water Budget and Water Quantity Stress Assessment

3.3.1 What is the Tier 1 Water Budget?

The Tier 1 water budget follows the same basic steps as the Conceptual Water Budget but examines hydrologic processes in more detail. Whereas water budgets for the Conceptual Water Budget study were completed on a watershed level on an annual basis, Tier 1 Water Budgets were completed at the subwatershed level on a monthly and annual basis. The Tier 1 Water Budget uses spreadsheet models and GIS maps to estimate the amount of water in each subwatershed for each month of the year.

What is the Tier 1 Water Quantity Stress Assessment?

The Tier 1 Water Quantity Stress Assessment looks at whether or not a water source can meet water demands in a subwatershed and not be under stress. The term stress is used to identify potential problems with water quantity and means further study is required to better understand the water source, its water uses and the environmental needs of the area.

The Tier 1 Water Quantity Stress Assessment looks at the amount of water currently being taken, as well as future takings, and compares it to the water supply. If a subwatershed results in a Tier 1 stress, a Tier 2 Water Budget and Stress Assessment is required.

The level of stress is determined by comparing the amount of water that is available in a subwatershed (supply) to the amount of water being used by humans (demand) and needed for the environment (reserve). The higher the stress level the more likely the water supply is insufficient to meet demands.

Water quantity stressors include water that is taken by municipalities for drinking water; by industry and businesses, agriculture and private wells. Water quantity stressors include activities that reduce or divert water supplies. Climate change may also lead to water quantity stress if water supplies become variable or reduced or if a drought occurs. This, however, is not evaluated in Tier 1.

3.3.2 Refining the Scale

The Tier 1 Water Budget and Stress Assessments were carried out on smaller spatial and time scales than Conceptual Water Budget.

Tier 1 Subwatersheds

The spatial scale was refined by examining the subwatersheds that make up the watershed, rather than just the watershed as a whole.

The MRSPR was divided into 22 new subwatersheds for Tier 1 based on the location of surface water flow gauges. Figure 3-14 shows the location of the Tier 1 subwatersheds as either gauged (for surface water flows) or un-gauged. As per the Technical Rules, groundwater stress assessments were carried out on the same subwatersheds as the surface water assessments.

Tier 1 subwatersheds used for Tier 1 water budgets and stress assessments are different than the natural subwatersheds introduced above in Chapter 2. The Tier 1 subwatersheds are defined based on flow gauges. The natural subwatersheds in Chapter 2 are defined based on natural flow outlets.

The Tier 1 Water Budget was refined to a monthly scale in order to improve the understanding of how changing seasons affect water flows in the MRSPR.

3.3.3 Tier 1 Water Budgets

As with the Conceptual, analysis of the Tier 1 Water Budget showed the most important hydrologic processes in the MRSPR are determined to be precipitation, ET and surface water flow.

ET, however, was calculated independently in the Tier 1 (see below) and data errors were accounted for by a 'residual' term. The residual is calculated as precipitation minus ET minus surface water flow.

Precipitation and Surface Water Flow Data

For the Tier 1 Water Budgets, the same data sources, seen in Table 3-1, were used for precipitation and surface water flows as for the Conceptual Water Budget. Flows for ungauged subwatersheds were estimated by pro-rating to gauges in subwatersheds with similar environments and water regulatory regimes. Detailed data inventory and methodology for data infilling approaches for surface water gauges can be found in the Tier 1 study (MRSPR, 2009) in Appendix 3-1.

Calculation of Evapotranspiration

ET is usually calculated, not measured. Many methods for calculating ET exist, depending on the data and the scale upon which the calculations are being performed.

For the Conceptual Water Budget, average annual ET was derived (Derived ET = P – SW_{OUT}) from precipitation and streamflow data (Table 3.2-3). This approach was applicable on an annual scale. However, for the Tier 1 water budgets, monthly values were needed so a different approach was taken. These values are used in the groundwater recharge (supply) calculations in the Tier 1 stress assessment (see Section 3.3.6).

For the Tier 1 Water Budgets, average monthly ET was calculated using Thornthwaite and Mather (1957). First, potential ET was calculated in GIS on a 25 m x 25 m scale based on precipitation and temperature data. Then, actual ET was estimated based on land cover data (Ministry of Natural Resources (1991-1998)) and soils data (Agriculture Canada). Annual ET was taken as the sum of the monthly values.

Long-Term Annual Water Budgets for Subwatersheds

The long-term (1971-2000) annual water budgets for the Tier 1 subwatersheds are given in Table 3-4. As with the watershed scale, precipitation is the only source of water. Water is removed from each subwatershed primarily by ET, and then by surface water flowing out of the subwatershed.

The "residual" amount accounts for less than 5% of precipitation for each subwatershed, with the exception of Ottawa RVCA West (11%). This higher percentage is due to uncertainty in the flow data. Because there is no flow gauge in the Ottawa RVCA West subwatershed (ungauged), flows had to be estimated.

Long-Term Monthly Water Budgets for Subwatersheds

The long-term (1971-2000) monthly water budgets for the Tier 1 subwatersheds are given in Appendix 3-1 for the Mississippi watershed and Appendix 3-2 for the Rideau watershed.

3.3.4 Tier 1 Stress Assessment

Once the water budgets were completed, a water quantity stress assessment was completed for surface water and groundwater in each Tier 1 subwatershed. The stress assessment required the calculation of 'percent water demand' for each subwatershed plus a review of the historical performance of the municipal drinking water systems in that subwatershed.

Only subwatersheds with a municipal system and which are assigned a moderate or significant stress level, or where there have been historical water quality issues identified, move on to Tier 2. Subwatersheds assigned a low stress do not move on to Tier 2.

Percent Water Demand Equation

The percent water demand calculation is the primary tool used in Tier 1 to evaluate the subwatershed water quantity stress levels. As per the Technical Rules, percent water demand (% water demand) is calculated as follows:

$$\% Water\ Demand = \frac{Q_{Demand}}{Q_{Supply} - Q_{\mathrm{Re}\,serve}} \times 100$$

Q_{Demand} is the water takings (anthropogenic) that are consumptive,

Q_{Supply} is the water supply to the surface water system (surface water flow data) or groundwater system (groundwater recharge calculations),

Q_{Reserve} is the water reserve set aside for other uses.

Time Scales

Stress assessments were completed for the following time scales:

Surface water stress assessments were completed on a monthly scale.

Groundwater stress assessments were completed on monthly and annual scales.

Demand Scenarios

Percent water demand was calculated using current water demand and supply. The Technical Rules also require the calculation to be completed for a future scenario. The difference between current and future demand was estimated solely based on population growth at the municipal systems and, due to complexity, does not account for future changes in water supply.

The future groundwater scenario accounts for Lanark as a future municipal system.

3.3.5 Water Demand (Q_{Demand})

Human water demand was calculated based on four data sources:

- **Permits to Take Water** –The MOE maintains a database of permits to take water for large water takings (>50,000 L/day). Temporary permits (e.g. short term construction) and permits expired for more than 5 years were not included in the calculations.
- **Municipal Systems** – Actual water takings data from municipal drinking water systems was obtained from the system operators and used in the calculations.
- **Agriculture Takings** – Agricultural water takings data was obtained from the Agricultural Census Database (de Loe, 2002) and divided into two categories - livestock and irrigation. Takings were assumed to be distributed equally between surface water and groundwater for the Tier 1 analyses.
- **Private Wells** – The number of private wells in each subwatershed was determined using the MOE Water Well Information System. As per the Conceptual Water Budget, each private well was estimated to use 570 L per day based on input from the City of Ottawa and an analysis of a local system.

Consumptive Water Demand

Consumptive demand assumes that a portion of the surface water or groundwater used by permits to take water, municipal systems, agriculture, and private wells is returned to the aquifer or surface water body. The ratio of 'water taken to water returned' for each type of taking is prescribed in the Guidance (MOE, 2007). This ratio is defined by a 'Consumption Factor (C.F.)'. Water not returned to the natural environment is consumed; this amount is the consumptive demand.

For example, 20% of water used by households (either from municipal systems or private wells) is consumed, which allows 80% to be returned to surface water or groundwater systems.

The consumptive demand was calculated for each water taking and was used to calculate the total water demand for each Tier 1 subwatershed.

Surface Water Demand

Anthropogenic consumptive surface water demand was identified from the following sources:

- permits to take water
- municipal surface water systems
- agriculture

The demands from these sources are added together for each subwatershed and are given in Table 3-5. Consumptive demands for each permit to take water for surface water are shown in Appendix 3-3.

Groundwater Demand

Anthropogenic consumptive groundwater demand was identified from the following sources:

- permits to take water
- municipal groundwater systems
- agriculture
- private wells

The demands from these sources are added together for each subwatershed and are given in Table 3-6. Consumptive demands for each permit to take water for groundwater are given in Appendix 3-4.

3.3.6 Water Supply and Reserve (Q_{Supply} and $Q_{Reserve}$)

Surface Water Supply and Reserve

Surface water supply was calculated for each subwatershed as the median monthly stream flow at the gauge. The surface water reserve was calculated as the tenth percentile of stream flow (the rate of flow that is exceeded 90% of the time). Surface water supply and reserve values are given in Table 3-7.

Groundwater Supply and Reserve

Groundwater supply was assumed to be due to groundwater recharge. Annual groundwater recharge was calculated using the MOEE method (1995). The MOEE 1995 method uses the water surplus (precipitation minus ET). Infiltration coefficients (the ease of water seeping into the ground) were assigned based on soils, slope and land cover. Groundwater recharge was calculated in a GIS program by taking the sum of the infiltration coefficients multiplied by the water surplus.

Annual groundwater supply was divided evenly across the months to produce a constant monthly groundwater supply. The groundwater reserve was calculated as 10% of the groundwater supply for annual and monthly time scales. Groundwater supply and reserve values are given in Table 3-8.

3.4 Tier 1 Assignment of Stress Levels

Percent water demand was calculated for each subwatershed for surface water and groundwater for the current and future demand scenarios. Percent water demand for surface water was calculated on a monthly basis. Percent water demand for groundwater was calculated on a monthly and annual basis. Stress levels were assigned based on MOE criteria given in Table 3-9. Percent water demands and assigned stress levels for surface water are given in Table 3-10 and for groundwater are given in Tables 3-11 and 3-12.

Table 3-13 identifies the current maximum stress levels, the municipal systems, and decisions to advance to Tier 2. Three subwatersheds resulted in moderate surface water stresses. One subwatershed resulted in a moderate groundwater stress. None of these subwatersheds contain municipal systems therefore Tier 2 is not required for any subwatersheds in the MRSPR. Figure 3-15 shows the maximum stress levels for all of the Tier 1 subwatersheds.

3.4.1 Surface Water Stresses

Three subwatersheds showed a surface water stress of moderate under the current and future demand scenarios. The stressed surface water subwatersheds include "Carp River Near Kinburn" (32.5%), "Ottawa MVC" (24.5%) and "Fall River At Bennett Lake" (22.5%). None of these subwatersheds contain a municipal surface water system therefore they do not require Tier 2 analyses.

The surface water stress in the "Carp River near Kinburn" subwatershed is due to low surface water flows in August combined with demands from permits to take water for golf course irrigation and dewatering at pits and quarries.

The surface water stress in the Ottawa MVC subwatershed is due to low flows in July and a permit to take water for golf course irrigation.

The surface water stress in the Fall River at Bennett Lake is due to low flows in September and a permit to take water for aquaculture. These subwatersheds had small agricultural water takings and no municipal takings.

The surface water percent water demand for the "Mississippi River at Galetta" subwatershed originally resulted in a significant stress however this was reduced to a low stress level after receiving new direction from the Province regarding the amount of water actually consumed by power generating stations – a major factor in that subwatershed.

3.4.2 Groundwater Stresses

One subwatershed, "Rideau River at Ottawa" showed a groundwater stress (11.7%) of moderate under current and future demand scenarios. This subwatershed does not contain a municipal well therefore it does not require Tier 2 analyses.

The groundwater stress in the "Rideau River at Ottawa" subwatershed was primarily due to commercial permits to take water since the supply and reserve are the same for every month of the year.

3.4.3 Historical Performance of Municipal Systems

According to the Technical Rules, a municipal intake or municipal well that has reported either of the following criteria since January 1, 1990, must be assigned a moderate stress level.

Municipal Surface Water Intakes:

- any part of a surface water intake was not below the water's surface during normal operation of the intake; or
- the operation of a surface water intake pump was terminated because of an insufficient quantity of water being supplied to the intake.
- Municipal Groundwater Wells:
- he groundwater level in the vicinity of the well was not at a level sufficient for the normal operation of the well; or
- the operation of a well pump was terminated because of an insufficient quantity of water being supplied to the well.

The review of historical performances of municipal systems is done in addition to the percent demand calculations. It is intended as an independent verification that the percent demand calculations at the subwatershed scale are consistent with observations at municipal systems. When surveyed during the Tier 1 study, no municipality with a surface water or groundwater system reported either of the criteria listed above. Therefore, no additional stress study was required.

3.4.4 Data Limitations and Uncertainty

The long-term averages used to generate the climate and flow data in the Tier 1 Water Budget and Stress Assessment are representative of an average year. These data are not representative of individual years. A high level of uncertainty will be introduced if these results are used to examine hydrological processes and water quantity stresses at smaller time or space scales.

Stresses may exist on smaller spatial scales near large water takings; however, these local stresses may be masked on a subwatershed scale. Stresses may also exist on smaller time scales due to continuous changes in flows and demands for water.

Regulation of rivers and lakes by hydraulic control structures helps to maintain surface water supply and thus control drinking water stresses. Current stress levels assume that regulation regimes will remain unchanged.

The Tier 1 subwatersheds were delineated based on ground surface topography. This is appropriate for characterizing the surface water system, but it may not be appropriate for groundwater systems because surface water divides may not coincide with groundwater divides. The uncertainty with this approach is likely acceptable given that this is a screening level exercise.

Eight of the 22 subwatersheds were ungauged, meaning they had no surface water flow data. Flows for ungauged subwatersheds were estimated from gauged subwatersheds with similar physical environments and regulation regimes. These flow estimates will be more uncertain than flow gauge data.

Groundwater recharge was calculated using a simplified approach (MOEE 1995) that was considered applicable at the regional scale and given the limited data. Low groundwater recharge estimates mean low groundwater supply estimates. Despite the low estimates of groundwater supply only one subwatershed resulted in a water quantity stress.

Actual demand data was obtained from the municipal water supply operators. The maximum permitted takings were used to estimate consumptive demand, which is likely a conservative overestimation of the consumptive demand as most permit holders do not take their maximum permitted volumes. There is also some uncertainty in the distribution of the agricultural water takings however this error is small due to the relatively small water demands from agriculture compared to municipal demands and permits to take water. The uncertainty in private well demand is small assuming variation in household use is normally distributed across each subwatershed. Other non-permitted takings were not included though these are assumed to be negligible.

There is more uncertainty in the future demand scenario calculations compared to the current scenario. Due to the complexity in predicting future changes, the future scenario was calculated solely by increasing municipal demand by projected population growth and does not account for hydrologic changes.

The conservatively high demand estimates by permits to take water and the low supply estimates increases the confidence in the low stress assignments.

A discussion of potential impacts of climate change is in Chapter 7.

3.4.5 Mississippi-Rideau Source Protection Region Water Budget Conclusions

Based on the methodologies and results presented above, a Tier 2 study is not required for the MRSPR.

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