Chapter 3 – Water Budgets

3.1 What is a Water Budget?

A *water budget* is very much like a financial budget, but instead of tracing how money flows in and out, it traces water. A *water budget* accounts for all water into and out of a *watershed* (or *subwatershed*). This includes *precipitation*, evaporation, transpiration, *runoff*, as well as the movement of water within the *watershed*, such as *infiltration*, *recharge* to groundwater, and reservoir storage (lakes, *wetlands*, *aquifers*).

For the purposes of *drinking water source protection*, four questions are to be answered (MOE, 2007):

- Where is the water? (*streams*, lakes, *wetlands*, *aquifers*)
- How does the water move? (pathways, surface/groundwater)
- What and where are the stresses on the water? (water withdrawals)
- What are the trends? (rising or falling water levels or water use).

The general equations to be satisfied for a *water budget* are:

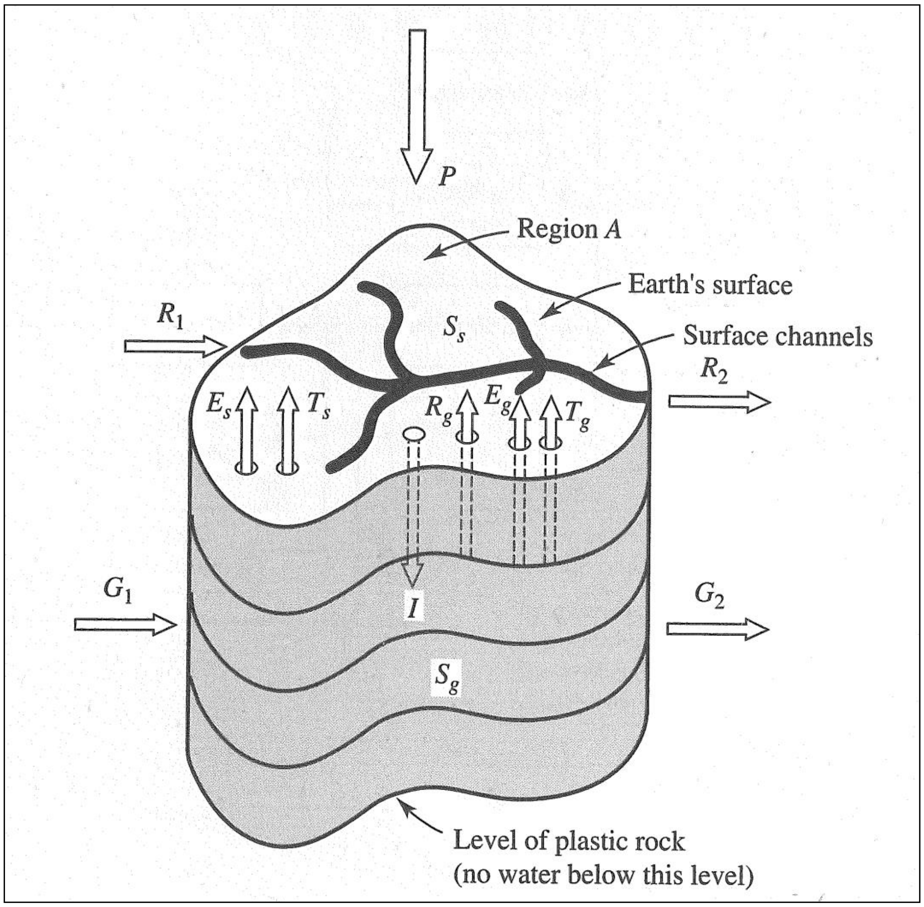
$$\text{Inputs} = \text{Outputs} + \text{Change in Storage}$$

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

Where:	P	=	precipitation
	SW_{in}	=	surface water flow in
	GW_{in}	=	groundwater flow in
	$ANTH_{in}$	=	anthropogenic or human inputs
	D_{in}	=	diversion into the watershed
	ET	=	evaporation and transpiration
	SW_{out}	=	surface water flow out
	GW_{out}	=	groundwater flow out
	$ANTH_{out}$	=	anthropogenic or human abstractions
	D_{out}	=	diversion out of the watershed
	ΔS	=	change in storage.

(Based on MOE, 2006)

Figure 3-1 below gives a general schematic representation of the presented *water budget* equation.



Source: Veissman and Lewis, 1996

Figure 3-1: Regional hydrologic cycle

P = precipitation, R_1 = surface runoff in, R_2 = surface runoff out,

S_s = surface storage, E_s = surface evaporation, T_s = surface transpiration,

I = infiltration, R_g = recharge to streams, S_g = groundwater storage.

E_g = evaporation from groundwater, T_g = transpiration from groundwater,

G_1 = groundwater into the regions, and G_2 = groundwater flowing out of the region.

There are four levels of *water budget* required for *drinking water source protection*:

- The *Conceptual Water Budget* (Section 3.2) looks at an entire *source protection area* as one entity, and calculates the *water budget* based on average annual values.
- The Tier 1 Water Budget (Section 3.3) looks at *subwatersheds* of the *source protection area*, and calculates the *water budget* based on average monthly values.
- The Tier 2 Water Budget (Section 3.4) looks at specific *subwatersheds*, again on an average monthly value basis, but considers some drought conditions.
- The Tier 3 Water Budget (Section 3.5) looks at specific areas (called *local areas*), and could consider daily or hourly conditions. Tier 3 looks at the *tolerance* and *risk* levels for the *local area* being examined.

In addition to the *water budget* portion of the work, a stress assessment is also required. The stress assessment compares the demand, supply and reserve within each *water budget* area, giving an estimate on whether there is enough water available to meet the demand.

The Ontario Ministry of Environment (MOE) has provided technical instructions to foster a consistent approach in every source protection area and region (see the Technical Rules: Assessment Report (MOE, 2009a) in **Appendix 'L-1'**).

All levels of the water budgeting work in the Cataraqui Source Protection Area (CSPA) were subject to peer review by a team of experts that was shared with the adjacent Mississippi-Rideau and Quinte Source Protection Regions. The peer review team had expertise in climatology, *geology*, *hydrogeology* and *surface water* resources. Consultants and staff from participating conservation authorities, municipalities and the Ontario Ministry of Natural Resources also participated in the peer review meetings. The names of the peer review team members, as well as other contributing staff, are noted in each of the original study reports.

3.2 Conceptual Water Budget

As mentioned in Section 3.1, the *Conceptual Water Budget* (CRCA, 2009) was prepared by treating the entire CSPA as one entity, and examining average annual conditions. A copy of the report is included in **Appendix 'L-3'**. This tier of the *water budget* identified the data available to be used for future work (and associated limitations). These findings should be used cautiously, as the report was prepared over a large area, with time scales that are too long to have an acceptable level of uncertainty for all applications.

The water use amount is very low compared to water available amount, on an average annual basis. However, it is important to note that over the summer there is much less water available during a time where water is in much greater demand. This particular fact is masked by the *scale* of the *Conceptual Water Budget*.

For the *Conceptual Water Budget*, the authors assumed that the net groundwater movement into the CSPA was zero. That is, groundwater flow in is equal to groundwater flow out. This is not necessarily the case, but is expected when looking at the CSPA as one very large unit, and looking at average annual conditions. The short period of record available for the seven

Provincial Groundwater Monitoring Network (PGMN) stations appears to confirm this assumption. Water levels in these wells appear to rise and fall in a similar fashion each year. In the Cataraqui area, there are limited data for use in the assessment of groundwater *aquifers* and their flow direction, and for mapping of the *water table* and potentiometric surface. This has been identified as a *data gap*, as discussed in Chapter 8.

The following sections provide a summary of the *water budget* data of the CSPA available in the *Conceptual Water Budget* report. For consistency and to facilitate comparison, amounts are presented in millimetres across the entire Cataraqui area of 3,571 square kilometres. More information on the physical geography of the CSPA (*bedrock*, soils, *topography*, etc.) is summarized in Chapter 2, and provided in more detail in the Drinking Water Source Protection Water Budget Conceptual Report (CRCA, 2009).

3.2.1 Climate Data

There are 53 Environment Canada *climate* stations within the CSPA (and within ten kilometres of the boundary, outside of the CSPA) with data from as early as the 1870's. Most are listed in Table 2.1 of the *Conceptual Water Budget*, from west to east, and their locations are shown in Figure A2.1 of the *Conceptual Water Budget*. Of these 53 stations, seven are still active. These stations have recorded a variety of climatic parameters, including *precipitation*, temperature, and snow depth.

Precipitation

Eighteen of the above noted 53 stations were used to estimate *precipitation* across the CSPA. The stations used for the estimate are those with recent, full year, or longer periods of record. The average annual *precipitation* across the CSPA is 954 millimetres. The estimated *precipitation* falls within the range of other estimates made, as noted in the report.

It should be noted that data from the late 1800's and early 1900's suggests that the average *precipitation* was lower in that period than in the period over the last 30 or 40 years, as has been confirmed via personal correspondence with a former Environment Canada climatologist (B. Hogg, 2007). Kruskall-Wallis testing of the data also confirms that the station data do not come from the same population.

Trends in *precipitation* data have been found by some researchers, and not found by others. There is also a discrepancy with the datasets used by different researchers. When using a corrected Environment Canada dataset, trends in *precipitation* over the 100 years of the 20th century are not statistically significant.

Further Kruskall-Wallis testing found that rain amounts have remained steady over the period of record, while snow amounts have not.

Temperature

Kruskall-Wallis testing of temperature data has also found that temperature data is not from the same population, but has been changing over time. A small increasing trend over the 20th century has been found by Environment Canada researchers.

Evapotranspiration

There is little *evapotranspiration* data available for the CSPA; therefore it needs to be synthesized from *precipitation*, temperature and *runoff* data. As such, any trends in the *evapotranspiration* values are likely due to the base data. The average annual *evapotranspiration* across the CSPA is 502 millimetres.

Runoff

There are eight hydrometric *monitoring* gauges in the CSPA (see Figure 1-21 of the Watershed Characterization Report: Cataraqui Source Protection Area (CRCA, 2008)). They have been recording streamflow between five and 45 years depending on the location. The average annual flows in the CSPA appear to be reasonably constant, with monthly variation, as is expected. The average annual *runoff* across the CSPA is 452 millimetres. Environment Canada researchers have seen a decrease in mean annual flows in Canada, however the change in eastern Ontario is not statistically significant. Two of the eight monitored *streams* in the CPSA show a significant trend using the Mann-Kendall test. Both *streams* have control structures, and one has undergone considerable land use change during the flow period of record, which could explain the trends.

3.2.2 Water Use

Water use information is very important in creating a *water budget*, as the amount of water being removed from a *watershed* must be accurately represented.

3.2.2.1 Permits to Take Water

There were close to 250 current and 150 historic Permits to Take Water (PTTW) across the CSPA (as of September 2005, the most recent list provided (MOE, 2005)). These vary from small one time takings to test natural gas pipelines for leaks, to long term municipal takings, and both groundwater and *surface water* takings.

The estimated total annual volume of water currently withdrawn across the CSPA is almost 32.7 x 10^7 cubic metres. However, 88 per cent of that is taken from Lake Ontario (82 per cent) and the St. Lawrence River (six per cent), and is not necessarily directly related to the *water budget* work of *drinking water source protection*. Of the remaining 12 per cent, 3.4 per cent (1.10 x 10^7 cubic metres) is taken from inland *surface water* sources, and 8.4 per cent (2.74 x 10^7 cubic metres) is taken from groundwater sources (not including domestic water wells) (see **Figure 3-2**).

The following sections detail the PTTW water uses, based on the PTTW listing, and the permitted volumes, as well as correction factors derived by the Grand River Conservation Authority (GRCA, 2004) which provide estimates of actual water use.

Withdrawals that would be subject to a PTTW, but do not have one, are expected. These withdrawals are not accounted for in the above estimations. An initial assumption that there are as many non-permitted uses as permitted uses was used for the *Conceptual Water Budget*, with more refinement of the permit assumptions in later *water budget* tiers.

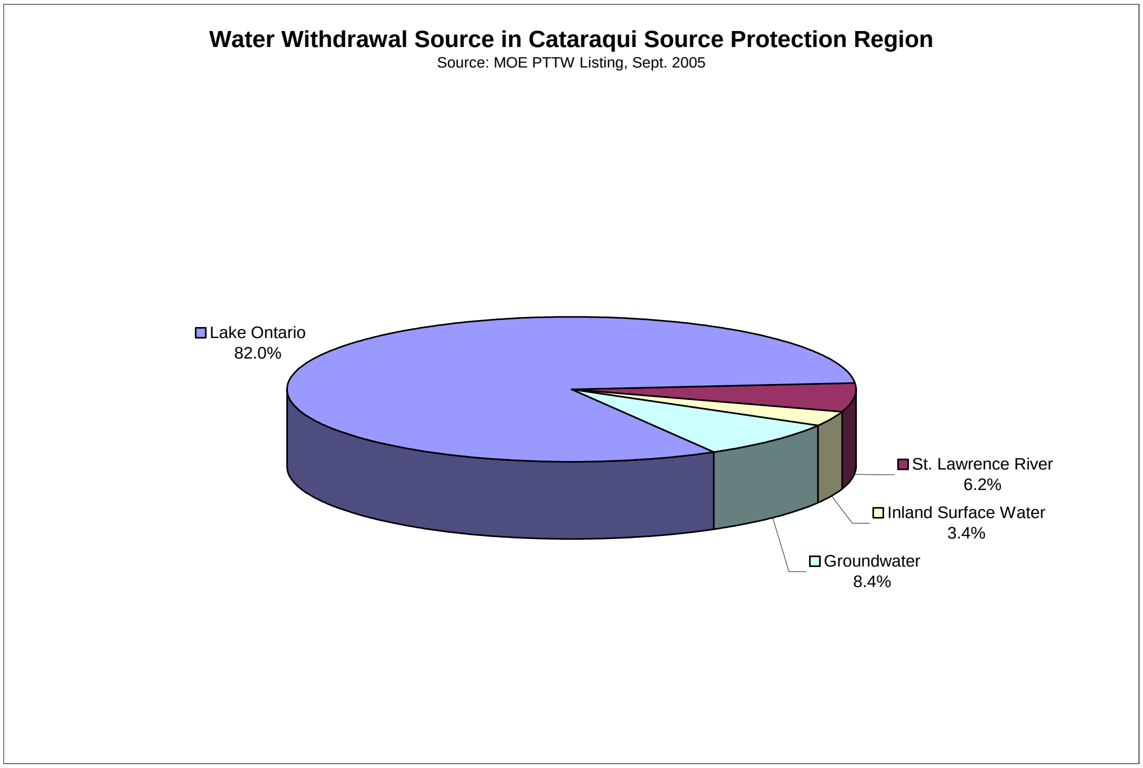


Figure 3-2: Water withdrawal source

Municipal and Federal Penitentiary Water Use

There are twelve municipal residential *drinking water systems* in the CSPA. Eight systems remove water from Lake Ontario (Napanee, Sandhurst, Bath, Amherstview, Kingston Township, City of Kingston) or the St. Lawrence River (Gananoque, Brockville), one system draws from an *inland lake* (Sydenham), with the remaining three drawing groundwater (Lansdowne, the Cana subdivision, and the Miller Manor Apartments.). In the year 2000, the municipal supply for Odessa was transferred from Millhaven Creek to Lake Ontario (Amherstview).

In addition to the municipal systems, the federal penitentiary at Joyceville (Joyceville and Pittsburgh Institutions) has its own *drinking water system* drawing from the River Styx on the Cataraqui River.

Actual water-taking information has been made available for the years 2005 to 2008 for some of the water treatment plants discussed above (MOE, 2010). **Table 3-1** shows this data, as well as the maximum daily withdrawals based on the *Permit to Take Water* listing. Where actual water-taking values were not available, the PTTW data was used to estimate water withdrawals of the municipal supplies for the *Conceptual Water Budget*. In those situations, the annual withdrawal is calculated assuming that the average daily withdrawal over the year is half of the maximum withdrawal.

Table 3-1: Municipal and Federal Water Treatment Plant Withdrawal Volumes

System	Source	Permitted withdrawals under Permit to Take Water		Actual Average Annual Withdrawal (m^3) under Permit to Take Water (MOE, 2010)
		Maximum Daily Withdrawal (m^3)	Annual Withdrawal (m^3)	
A.L. Dafoe (Napanee)	Lake Ontario	12,000	2,190,000	2,478,300 (2005-2008)
Sandhurst Shores	Lake Ontario	600	55,000	25,100 (2005-2008)
Bath	Lake Ontario	7,515	696,000	640,400 (2005-2008)
Fairfield (Amherstview)	Lake Ontario	9,000	1,640,000	1,654,000 (2005-2008)
Kingston Central	Lake Ontario	118,000	21,500,000	21,274,250 (2007-2008)
Point Pleasant (Kingston West)	Lake Ontario	39,500	7,220,000	7,892,500 (2005-2008)
James W. King (Gananoque)	St. Lawrence River	10,200	1,870,000	1,460,000* (EC, 2006)
Brockville	St. Lawrence River	36,400	6,640,000	5,342,700 (2005-2008)
Joyceville and Pittsburgh Institutions	Cataraqui River (River Styx)	1,200	219,000	*n/a*
Sydenham**	Sydenham Lake	1,300	235,000	58,200 (2006-2008)
Odessa*	Millhaven Creek	2,000	404,000	*n/a*
Cana Subdivison	Groundwater	300	50,000	*n/a*
Lansdowne	Groundwater	1,400	263,000	70,500 (2006-2008)
Miller Manor Apts.	Groundwater	70	8,000	*n/a*

Notes: * Removed, ** Not all residents are connected to system at this time.

The Lake Ontario water volume withdrawn for municipal purposes (using the best estimates from **Table 3-1**) is estimated to be 3.4 x 10^7 cubic metres per year. This supplies the Town of Greater Napanee, Loyalist Township and the City of Kingston intakes.

The St. Lawrence River water volume withdrawn for municipal purposes (using the best estimates from **Table 3-1**) is estimated to be 6.8 x 10^6 cubic metres per year. This supplies the Town of Gananoque and City of Brockville intakes.

The inland *surface water* volume withdrawn for municipal purposes (using the best estimates from **Table 3-1**) is estimated to be 5.8 x 10^4 cubic metres per year. This supplies the community of Sydenham. An additional 2.2 x 10^5 cubic metres is withdrawn by the federal penitentiaries.

The inland groundwater volume withdrawn for municipal purposes (using the best estimates from **Table 3-1**) is estimated to be 1.30 x 10^5 cubic metres per year. This supplies the Cana subdivision in the City of Kingston, Lansdowne, and the Miller Manor Apartments in the Township of Front of Yonge.

There are an additional 2.78 x 10^6 cubic metres per year withdrawn from inland *surface waters*, and 7.24 x 10^4 cubic metres per year from groundwater for public supplies.

Water withdrawal sources for public water supplies are shown in **Figure 3-3**.

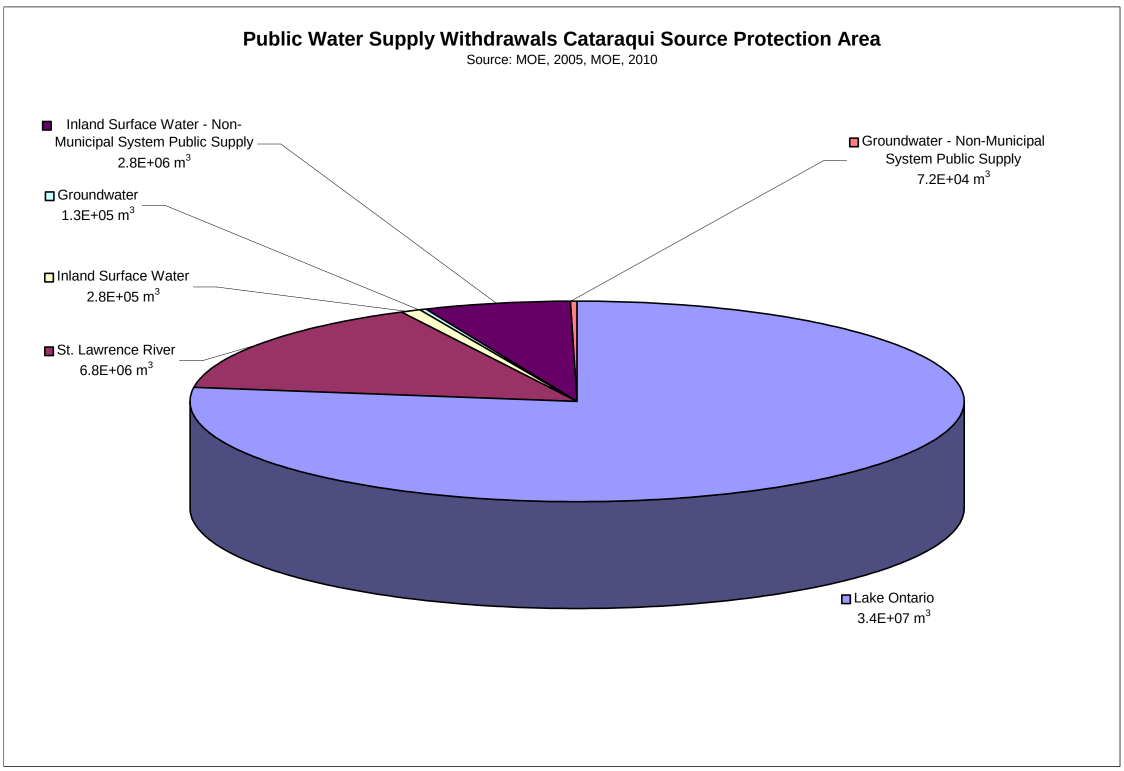


Figure 3-3: Public Water Supply Withdrawal Source

Water Wells

There are almost 25,000 wells across the CSPA (MOE, 2008b). These are a mixture of residential, agricultural, commercial/industrial, and institutional uses, as well as abandoned wells. Detailed information is given in **Table 3-2**.

Table 3-2: Water Well Use Breakdown

(MOE, 2008b)

Use Category	Number of Records	Percentage
Domestic	20,213	81.3%
Stock	1,327	5.3%
Irrigation	42	0.2%
Industrial	66	0.3%
Commercial	403	1.6%
Municipal	70	0.3%
Public Supply	378	1.5%
Cooling or A/C	38	0.2%
Not Used	805	3.2%
No Designation	1,513	6.1%
Total	24,855	100.0%

There are approximately 20,200 private residential wells in the CSPA (MOE, 2006b), and there are approximately 47,000 residents in the CSPA (Environment Canada, 2006) not on municipal services, which equals roughly 2.3 persons per well. The Statistics Canada Rural Analysis Bulletin estimates approximately 2.75 persons per household, the Mississippi-Rideau SWP group calculated 2.85 persons per well for their *watersheds*, and the Quinte SWP group calculated three persons per well for their *watersheds*. Estimating a withdrawal volume of 0.175 cubic metres per person per day (MOE, 2001), the total withdrawal would be 3.0×10^6 cubic metres. This volume is approximately 11 per cent of the PTTW groundwater withdrawals. There are no withdrawal estimates available for other categories of wells.

Most of the private domestic or commercial wells are likely twinned with a septic system, and most of the water withdrawn from the groundwater is directed back into the ground through the treatment process. In some cases, though not accounted for by these numbers, domestic water supplies are provided through shore wells, or *surface water* intakes. In these cases, *surface water* is diverted to groundwater via the septic system. It is expected that the volume of these diversions will be quite small. It is also expected that any rise in *water table* levels due to these effects will be very localized.

Industrial Water Use

Direct industrial water takings are generally located along the Lake Ontario and St. Lawrence River shoreline. Water withdrawal is taken directly from the surface source or from a municipal supply (dependent on location of the industry). As such, they will have little effect on most of the *water budget* process, since Lake Ontario and the St. Lawrence River are outside the *water budget* area, and municipal takings are being accounted for in a separate category.

The large industrial users with a PTTW are below. They include:

- Lafarge (Lake Ontario)
- Lennox & Addington Generating Station (Ontario Power Generation) (Lake Ontario)
- Celanese (Lake Ontario) (No longer operating)
- Invista/DuPont (Lake Ontario)
- Armstrong Cheese/Saputo Foods (Groundwater near Harrowsmith) (No longer operating)
- Ashwarren International (Lake Ontario)
- BICC Phillips Inc. (St. Lawrence River)
- Tackaberry (Groundwater near Athens)
- Kraft Foods (Groundwater on Wolfe Island) (No longer operating).

Commercial Water Use

Most commercial water takings are from municipal services but recreational commercial takings, such as golf courses, will likely come from a combination of surface and ground water sources. A sod farm exists near Odessa, which has a groundwater source, and historically there were once aquaculture companies in the region, one near Gananoque, and one near Mallorytown.

In addition, there are a number of de-watering *activities* in quarries around the region, which can be incorporated into the same commercial category.

There are also commercial water users who have a private surface or groundwater well. Withdrawals from these locations will be highly variable, and volume numbers are not available, however the amount of water withdrawn through these locations is expected to be small compared to the other withdrawal sectors.

Agricultural Water Use

There are four agricultural operations in the CSPA that are large enough to require a PTTW, but the majority are too small to require a permit for their water use. However, data is available from Ministry of Natural Resources (MNR) (de Loe, 2002) estimating the general agricultural water use on a quaternary *watershed* basis. There are also a number of water wells with an irrigation or stock designation; however withdrawal volumes are not available for these wells. There is also no information in the MNR database as to whether the water use originates from surface or groundwater.

To summarize the MNR data for the entire CSPA, the volume of use is 1.2 x 10^6 cubic metres, which is equal to an approximate depth of 0.3 millimetres spread over the CSPA.

3.2.2.2 Structures

As noted in the previous sections, the CSPA has a number of *water control structures* across its *watersheds* (see **Map 2-9**). There are 37 larger *water control structures* across the CSPA owned and operated by the CRCA (ten), City of Kingston (four), Loyalist Township (two), MNR-Kemptville (three), Rideau Canal (six), and Fortis Ontario (12). The structures, and their locations and operators, are listed and mapped in the *Conceptual Water Budget* report (**Appendix 'L-3'**). There are also a number of smaller *water control structures* throughout the CSPA that have not been catalogued.

3.3 Tier 1 Water Budget and Stress Assessment

The Tier 1 Water Budget was prepared for 21 *subwatersheds* (see **Map 3-2**) across the CSPA using average monthly conditions with consideration for natural subdivides such as *stream* gauges (see **Map 3-1)** and *water control structures*, as well as data availability. This work was completed by XCG Consultants Ltd. (2010a)(see **Appendix 'L-4'**).

Three categories of *subwatershed* are used: gauged, semi-gauged, and un-gauged. There are eight gauged *subwatersheds*. These are *subwatersheds* where there are reasonable data available and collected at streamflow gauging stations. There are eight semi-gauged *subwatersheds*. These are *subwatersheds* where there are some data available to synthesize records and have a reasonable idea on the range of values.

There are five un-gauged *subwatersheds*. These are *subwatersheds* where there are minimal data, and extrapolation from other locations is needed to estimate variables. Of the above *subwatersheds*, one of the semi-gauged *subwatersheds*, and two of the un-gauged *subwatersheds* are defined for areas related specifically to the municipal residential *drinking water systems* in the CSPA.

One municipal residential *drinking water system* is missing from the Tier 1 Water Budget. Localized *water budget* work was unable to be completed for the Miller Manor Apartments at Mallorytown (Township of Front of Yonge) as there are no data available for analysis (water supply, water demand, Permit to Take Water values, etc.).

Water budgets were prepared for each of the 21 above noted *subwatersheds*. *Precipitation*, streamflow, *evapotranspiration*, and *recharge* were all quantified for each of the *subwatersheds*. Once the *water budget* was completed, a stress assessment was conducted, comparing supply to demand. The prescribed equation to do this is:

$$\%\,Water\ Demand = 100 \times \left[\frac{Q_{DEMAND}}{Q_{SUPPLY} - Q_{RESERVE}} \right]$$

For *surface water subwatersheds,* Q_{SUPPLY} was derived from the *water budget* work, and defined in the Technical Rules: Assessment Report (MOE, 2009a) as the monthly median streamflow. $Q_{RESERVE}$ was also from the *water budget* work, and is the monthly lower tenth percentile flow, as defined in the Technical Rules: Assessment Report (MOE, 2009a). Q_{DEMAND} is the water demand calculated for the *subwatershed*. The demand is calculated based on estimations of the consumptive use of water with respect to the PTTW[1] withdrawals in the *subwatershed*, as well as estimates of residential and agricultural consumptive use. For gauged *subwatersheds*, Q_{SUPPLY} was also modified, at the request of Ministry of Natural Resources (MNR) staff, by adding Q_{DEMAND} to the Q_{SUPPLY} term, forming a new variable, where $Q_{SUPPLY} = Q_{RECORD} + Q_{DEMAND}$, and Q_{RECORD} is the monthly median streamflow noted above.

For the groundwater stress assessment, the same formula was used, except that Q_{SUPPLY} is derived as 1/12th of the long-term average annual *groundwater recharge*, and $Q_{RESERVE}$ is ten per cent of Q_{SUPPLY}, as defined by the Technical Rules: Assessment Report (MOE, 2009a). The stress was also calculated for two conditions, the current existing demand, and an estimated future demand, using the same supply values for both assessments. However, given the method used to calculate stress, the stress did not change between current and future demand scenarios.

Stress was then determined based on the per cent water demand equation. For *surface water subwatersheds*, the stress is defined as per **Table 3-3**. Groundwater stress is defined as per **Table 3-4**.

Table 3-3: Surface Water Stress Thresholds

Stress Level Assignment	Maximum Monthly Per cent Water Demand
Low	< 20 %
Moderate	20 % - 50 %
Significant	> 50 %

Table 3-4: Groundwater Stress Thresholds

Stress Level Assignment	Average Annual Per cent Water Demand	Maximum Monthly Per cent Water Demand
Low	0 - 10 %	0 - 25 %
Moderate	> 10 %, <= 25 %	> 25 %, <= 50 %
Significant	> 25 %	> 50 %

[1] With certain exceptions, persons who wish to withdraw water at a rate greater than 50,000 litres per day must obtain a Permit to Take Water (PTTW) from the Ministry of Environment, under the Ontario Water Resources Act, 1990. These permits contain maximum allowable withdrawal amounts, which can be very large, typically larger than the actual water withdrawals. In fact, the consumptive use can be a fraction of the allowable withdrawal. The Tier 1 water budget work used estimated consumptive use volumes, and not the maximum allowable volumes.

There were a number of *subwatershed*s deemed as stressed in terms of the MNR equation (see **Appendix 'D-1', Table 1** and **2**).

As stress assessments are undertaken for every *subwatershed* at the Tier 1 *water budget* level, a stress assessment was conducted for each of the four inland municipal residential *drinking water systems*. Sydenham, the only *surface water* system, is identified as having a significant stress. The other three systems are groundwater systems. The community of Lansdowne in the Township of Leeds and the Thousand Islands is identified as having moderate stress. The Cana well supply in the City of Kingston is identified as having low stress. Stress identification was not available for the Miller Manor Apartments well supply in the Township of Front of Yonge, as the required data were not available.

The following is a summary of the stress designations from the Tier 1 Water Budget:

Of the 21 *surface water subwatershed*s considered:

- eight gauged *subwatershed*s: one significant stress, five moderate stress, two low stress
- eight semi-gauged *subwatershed*s: eight low stress
- five un-gauged *subwatershed*s: three significant stress, one moderate stress, one low stress.

Of the 21 groundwater areas considered:

- eight gauged areas: one moderate stress, seven low stress
- eight semi-gauged areas: one moderate stress, seven low stress
- five un-gauged areas: one significant stress, two moderate stress, two low stress
- one not designated (Miller Manor): but located in a low stress area.

Map 3-2 shows the *subwatersheds* that were evaluated, and **Maps 3-3** and **3-4** shows their designated stress assessment values for the Tier 1 stress assessment. **Tables 1** and **2** in **Appendix 'D-1'** show the *subwatersheds,* and their stress assessment values. **Tables 3** to **63** in **Appendix 'D-1'** show the *water budget* values for each *subwatershed*, as well as each *subwatershed* stress assessment. For more information, please refer to the Tier 1 Water Budget and Water Quantity Stress Assessment report detailed in **Appendix L-4** (XCG Consultants Ltd., 2010a).

It should be noted, from a groundwater perspective, that much of the *hydrogeology* of the CSPA is not thought to be a regional system that can be considered on a large-scale basis, but rather a very intricate and localized system that should be considered on a site-specific *scale*. This topic is discussed in greater detail in Chapter 5.

Based on the significant and moderate stress assessment results of the Tier 1 work, the Sydenham and Lansdowne *drinking water system* areas moved to the Tier 2 stage of the *water budget*/stress assessment process. The Cana Well Supply area did not move to the next stage of the process given that it scored a low stress according to the prescribed assessment criteria and using the extensive area of *recharge* to the well that was prescribed by the MNR.

As noted above, the vicinity of the Miller Manor Apartments Well Supply has minimal information associated with it, and a stress assessment could not be completed, therefore it did not move to the next stage of the process. The result of the Tier 1 Water Budget and Stress Assessment for those areas that contain municipal *drinking water* systems within the CSPA is summarized in **Table 3-5** below.

Table 3-5: Tier 1 Water Budget Stress Assessment for the CSPA

Municipal Drinking Water System Areas	Type of System	Stress Assessment	Tier 2 Required
Cana	Groundwater	Low	No
Lansdowne	Groundwater	Moderate	Yes
Miller Manor	Groundwater	*n/a*	No
Sydenham	Surface Water	Significant	Yes

3.4 Tier 2 and 3 Water Budgets

The Tier 2 and 3 Water Budget work is intended to look in more detail at those areas deemed to have a moderate or significant stress at the Tier 1 stage, and also contain a municipal residential *drinking water system*.

The Sydenham Tier 2 Water Budget created a daily *model* of the Sydenham Lake *subwatershed* and included assessment of the following factors:

- water withdrawals
- water control structure log settings
- outflows
- *precipitation*
- *evapotranspiration*
- *groundwater recharge*, and
- *groundwater discharge*.

This work was conducted by XCG Consultants Ltd. (2010b) and is detailed within the Tier 2 Water Budget for Sydenham Lake Subwatershed (**Appendix 'L-5a'**).

The Sydenham Tier 3 Water Budget took that Tier 2 work further, looking at the water treatment plant intake in relation to simulated water levels, and assigning *tolerance* and *risk* levels to the *local area*. The work was also conducted by XCG Consultants Ltd. (2011) and is presented in the Tier 3 Water Budget Community of Sydenham (see **Appendix 'L-5b'**).

The Lansdowne Tier 2 Water Budget work was completed in conjunction with the updated Lansdowne *wellhead protection area* work (full discussion of this work is included in Chapter 5). A monthly *model* of the Lansdowne area was created, including *recharge*, groundwater in, groundwater out and withdrawals. The work was conducted by Geofirma Engineering Ltd. (2011)(see **Appendix 'L-6'**).

3.4.1 Sydenham Lake Tier 2 and 3 Water Budgets

3.4.1.1 Tier 2 Water Budget

As mentioned above, the Tier 2 work at Sydenham was conducted by XCG Consultants Ltd. (2011).

They separated the process into four parts:

- *model* selection
- *model* development
- *significant groundwater recharge area* (SGRA) delineations
- stress.

A technical memo was prepared by the consultant at each stage, for review and approval by the peer review team. This was thought to expedite the process and review, and ensure that the peer review team was satisfied with each piece prior to moving on to the next step. For instance, prior to building and *calibrating* a *model*, the peer reviewers would be in agreement that the *model* selected was acceptable.

XCG Consultants Ltd. selected the Hydrologic Simulation Program - Fortran (HSP-F) *model* for use on the Sydenham Lake *subwatershed*. This was for a number of reasons, including the fact that it includes all the relevant hydrologic and hydraulic components required for the *model*, is very comprehensive, and is freely available from the US Environmental Protection Agency (EPA).

For the *model* development, XCG Consultants Ltd. took the *water control structure* log settings, water levels, and c*limate* records and divided them into two sets of data; one for calibration of the *model*; and one for *validation* of the *model*. There were over 50 years of data available, and they were able to calibrate the *model* with very good accuracy.

XCG Consultants Ltd. used the previous *significant groundwater recharge areas* work completed for the Groundwater Vulnerability Analysis Report (GVAR) (Dillon Consulting Ltd., 2008) and Tier 1 Water Budget (XCG Consultants Ltd., 2010a), and refined it for the smaller Sydenham Lake *subwatershed*.

Sydenham Lake had only three PTTW (the most recent data available, September 2005) to consider for the supply versus demand calculations, two of which were Ducks Unlimited *wetland* projects, whose consumptive use is zero. The third PTTW is for the plant itself. At the time of analysis, the actual taking records for the plant (obtained from the operators) were used in the water demand analysis. It must be noted that the hook-up to the plant is only at 50 per cent of expected users, so the initial analysis is well below the planned water use. When considering future growth, the full withdrawal allowed by the PTTW is used, as that was the projection for 20 years after the plant construction used in the Environmental Study Report, and PTTW application. In addition to the PTTW, residential water withdrawals from the lake, and agricultural water uses were also considered.

The final result of the stress assessment for Sydenham Lake was that the community of Sydenham intake has an infinite (see **Map 3-5**) stress designation. This is because the Tier 2 rules assume that the lake is not there, and while the demand from the water treatment plant WTP remains constant, the supply falls to zero in the summer months. Over the summer, there is typically no outflow from Sydenham Lake, and any *precipitation* is negated by evaporation from the lake, resulting in constant falling lake levels in most summers.

Considering the per cent water demand equation as noted in Section 3.3, if $Q_{SUPPLY} = 0$, regardless of how small the Q_{DEMAND} term may be, the per cent water demand is infinite (as the denominator of a fraction approaches zero, the resulting number equivalent approaches infinity), resulting in a significant stress. It must be noted that this is only because the actual water in the lake cannot be considered at Tier 2, and there is definitely water available for the WTP withdrawals. However, since the Tier 2 rules identify a significant stress, the system must move on to Tier 3.

In light of the concern of residents in Sydenham and around Sydenham Lake, the following points need to be considered, as calculated outside of the Tier 2 Water Budget study:

- Sydenham Lake has a surface area of 7.4 square kilometres (GIS data layers)
- The area of the Sydenham Lake *subwatershed* is 57.6 square kilometres (*subwatershed* delineation for Tier 1 study (XCG Consultants Ltd., 2010b))
- the area of land that drains to Sydenham Lake is 50.2 square kilometres
- the average annual *precipitation* on Sydenham Lake is 931 millimetres (XCG Consultants Ltd., 2010b)
- the average annual evaporation from Sydenham Lake is 557 millimetres (XCG Consultants Ltd., 2010b)
- the estimated average annual flow out of Sydenham Lake is 372 millimetres (XCG Consultants Ltd., 2010b)
- the *Permit to Take Water* for the Sydenham WTP allows a maximum withdrawal of 1290 cubic metres per day. This represents a depth of 0.2 millimetres over the lake each day, or 63 millimetres in a year
- the average evaporation from the lake in one day during the summer months is estimated to be six millimetres (CRCA, 2009)
- the WTP intake pipe is approximately seven metres (7,000 millimetres) below the water surface.

It can be seen that the WTP withdrawal is in no danger of running dry on a regular basis, and the water level changes on the lake over the summer are largely due to evaporation.

The uncertainty analysis of the Sydenham Tier 2 work has been deemed to be low, in accordance with Technical Rule 36. The authors and peer reviewers support a low uncertainty analysis based on the following data results being satisfactory to good:

- the input *climate*, water level and log setting data
- the QA/QC procedures applied
- the level of *calibration* of the *model*.

The full details of the Sydenham Tier 2 Water Budget work are detailed in XCG Consultants Ltd. (2010b) in **Appendix 'L-5a'**.

3.4.1.2 Tier 3 Water Budget

Given that the Tier 2 stress designation for the Sydenham WTP was significant, it moved to a Tier 3 consideration. The Tier 3 work considered whether the withdrawal amount could or could not be met during regular conditions, as well as a number of drought scenarios.

For the Tier 3 exercise at Sydenham, the storage in Sydenham Lake was considered, and the *tolerance* and *risk* levels were determined. XCG Consultants Ltd. continued with the Sydenham work, and built on the work completed for Tier 2, with consideration for storage in the lake. An updated set of technical guidelines (Technical Bulletin: Part IX Local Area Risk Level (MOE/MNR, 2010)) was used to guide the preparation of the Tier 3 study report. The use of these guidelines (as an alternate method from the Technical Rules: Assessment Report (MOE, 2009a) was approved by the Ontario Ministry of the Environment in an approval letter dated February 17, 2011 (please refer to **Appendix 'D-2'**).

Using the *model* and scenarios prepared for the Tier 2 study, XCG Consultants Ltd. then considered the depth of the intake for the water plant, and compared that to the various water level scenarios prepared for Tier 2. In all scenarios, the minimum simulated level was above the critical level, and sufficient water supply was expected.

The *tolerance* was determined based on the difference between the minimum simulated water level for the various scenarios, and the safe shut-off level. In the three scenarios (A, B (ten year drought) and B (two year drought)), the minimum level was more than 0.6 metres above the safe shut-off level, and therefore the *tolerance* is deemed "high".

The *risk* level was determined based on the Technical Bulletin, and scenarios A, B, E and F. The conditions required for a "significant" or "moderate" *risk* level as per the Bulletin do not exist.

The uncertainty analysis of the Sydenham Tier 3 work, similar to Tier 2, has been deemed to be low. The authors and peer reviewers support a low uncertainty analysis based on the following data results being satisfactory to good:

- the input *climate*, water level and log setting data
- the QA/QC procedures applied

- the level of *calibration* of the *model*.

The full details of the Sydenham Tier 3 Water Budget work are detailed in XCG Consultants Ltd. (2011) in **Appendix 'L-5b'**.

Based on the "significant" and "moderate" *risk* level requirement details in the Technical Bulletin, and the assigned uncertainty, the assigned *risk* level for the Community of Sydenham *local area* is "low".

3.4.2 Lansdowne Wells Tier 2 Water Budget

The Lansdowne Tier 2 Water Budget work was carried out by Geofirma Engineering Ltd. (2011). They also completed the Phase 3 *wellhead protection area* work for the Lansdowne wells in conjunction with the *water budget* work.

Previous WHPA work conducted for the Lansdowne wells has identified *recharge areas*, *recharge* rates, as well as the estimated direction of groundwater flow to the wells (Malroz Engineering Inc., 2006, 2008). Work completed by Geofirma Engineering Ltd., updated and expanded the previous work conducted through Malroz Engineering Inc.

Using data from additional field work such as *monitoring* well pumping tests, water level measurements, and refinement of the *hydrogeology model* (MODFLOW) for the Lansdowne area, Geofirma Engineering Ltd. was able to better estimate the water use, and *recharge* to the well system.

Geofirma Engineering Ltd. found that the input variables for the Lansdowne system could have a reasonable amount of variability, based on field work and the *model calibrations*. The three input variables that make the greatest difference include:

- the consumptive use factor for the well withdrawals
- the *recharge* to the groundwater, and
- the lateral groundwater flow in.

For normal conditions, the consumptive use factor was set at 0.82 (to account for pipe losses back to groundwater, and spreading of lagoon septage back onto land), and the *recharge* was set at 60 millimetres per year. It is expected that the consumptive use factor could be as high as 1.0 (no pipe losses, and no septage spreading), and the *recharge* could vary from 40 to 80 millimetres per year.

Under normal conditions, the monthly and annual per cent water demand is less than ten per cent, resulting in a low stress designation. The average monthly withdrawal of the two Lansdowne wells is around 6,000 cubic metres, approximately 71,000 cubic metres annually.

Once normal conditions are considered, if the system is deemed at a low stress, two drought scenarios are also to be considered. These are the two-year drought (with no *recharge* for a period of two years), and the ten-year drought (which is defined as the ten year historic period with the lowest mean annual *precipitation*) scenarios.

In the case of Lansdowne, the two year drought would result in the water level in the well falling over seven metres, slightly more using future pumping rates. However, the pump would still be below the water surface in the well, and should still be able to adequately supply water into the system, though its efficiency would be reduced.

The ten-year drought condition would drop the water level approximately 1.5 metres below current levels, with minimal impact on the pump efficiency. Based on these findings, and the resulting determination of low stress (see **Map 3-6**), the system did not move on to Tier 3.

While the system will not move on to the third tier of the *water budget* process, additional *monitoring* of water levels (due to the potential falling water levels in the wells) is recommended. Ongoing water level records in the wells suggested potential groundwater mining. However, during the treatment system upgrade at the wells in the fall of 2010, OCWA found that the water level sensor may have been giving inaccurate readings, and it was replaced. It is unclear whether the water levels are in fact falling, as first thought, and continued monitoring should be done to confirm. It should also be noted that even if water levels are falling, the rate of falling water levels means they are not expected to impact the efficiency of the pump in the near future.

The uncertainty analysis of the Lansdowne Tier 2 work has been deemed to be high, in accordance with Technical Rule 36. The authors and peer reviewers support a high uncertainty analysis based on the following:

- the estimation of hydrologic parameters were very sensitive to change
- the true value of consumptive factors within the system are unknown
- the potential for falling groundwater levels in the supply wells.

The full details of the Lansdowne Tier 2 Water Budget work are detailed in Geofirma Engineering Ltd. (2011) in **Appendix 'L-6'**.

3.5 Conclusions

The tiered-approach to preparing *water budgets* under the Ontario Clean Water Act, 2006 has been implemented in the Cataraqui Source Protection Area over the past five years.

The work has been conducted in accordance with the prescribed Technical Rules: Assessment Report (MOE, 2009a) the new Technical Bulletin: Part IX (MOE/MNR, 2010), and it has been subject to both peer review and a comprehensive review by the Ontario Ministry of Natural Resources. The findings represent an initial step towards understanding the quantity of water that is available for drinking and other purposes in the CSPA.

It can be concluded that:

- The Tier 1 findings identify numerous *subwatersheds* with significant and moderate stress (from a *surface water* and groundwater perspective) that were not investigated further. The Tier 2 findings assign a significant stress to the *surface water subwatershed* that contains the Sydenham Water Treatment Plant. The Tier 3 findings assign a low *risk* level to the Sydenham *local area*.

- The *surface water subwatershed* containing the Lansdowne Well Supply received a low stress rating in the prescribed Tier 2 process. Tier 3 work will therefore not be undertaken at Lansdowne.
- Climate change has the potential to affect the available quantity of water in the CSPA, as discussed in Chapter 7.
- Additional data (particularly for *precipitation*, *evapotranspiration*, and groundwater levels) would strengthen our ability to understand this aspect of source protection, as discussed in Chapter 8.