



CATARAQUI REGION  
CONSERVATION AUTHORITY



# Drinking Water Source Protection Water Budget Conceptual Report

prepared to meet the  
“Technical Rules (MOE, 2008)”

Date: October 27, 2009

Disclaimer

This Conceptual Water Budget report has been prepared to specifically meet the requirements of the Ontario *Clean Water Act* (proclaimed July 2007), as expressed in the document titled “Water Budget and Water Quantity Risk Assessment“ that was prepared by the Ontario Ministry of Natural Resources in March, 2007 and the “Technical Rules: Assessment Report” prepared by the Ministry of the Environment in December, 2008. It is not to be used for any other purposes.

For complete information, please contact the CRCA.

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On the cover: Village of Odessa from the Air, May 3, 2004.  
 Showing Wastewater and Water Treatment Plants,  
 3 road crossings, and 3 water control structures.

## Table of Contents

Disclaimer	i
Acknowledgements	ii
List of Tables	v
List of Figures	viii
1.0 Introduction	1
1.1 Objectives	3
1.2 Questions	5
1.3 Simplification of the Water Budget Equation	5
2.0 Data	7
2.1 Climate	7
2.1.1 Precipitation	9
2.1.1.1 Combined Precipitation	9
2.1.1.2 Rain	17
2.1.1.3 Snow	17
2.1.2 Temperature	17
2.1.3 Evapotranspiration	18
2.1.3.1 Pan/Lake Evaporation	25
2.1.4 Infiltration/Recharge	27
2.2 Stream Gauges	33
2.2.1 Base Flow	41
2.3 Structure Water Levels	44
2.4 Hydrogeology	46
2.4.1 Fractured Bedrock	46
2.4.2 PGMN Wells	47
2.4.3 Groundwater Levels	49
2.4.4 Groundwater Recharge	55
2.4.5 Groundwater-Surface Water Interaction	57
2.5 Physical Land Characteristics	60
2.5.1 Bedrock Geology	60
2.6.1.1 Precambrian Geology	60
2.6.1.2 Palaeozoic Geology	62
2.5.2 Surficial Geology	65
2.5.3 Physiography	68
2.5.4 Soil Characteristics	69
2.5.5 Topography	70
2.5.6 Land Cover/Use	71
2.6 Water Use	72
2.6.1 Permits To Take Water	72
2.6.2 Municipal	75
2.6.2.1 Water Wells	77
2.6.3 Industrial	78
2.6.4 Commercial	78

2.6.5	Agricultural	79
3.0	Data Uncertainty	80
3.1	Precipitation	80
3.2	Streamflow	81
3.3	Evaporation/Evapotranspiration	81
3.4	Water Use	81
3.5	Groundwater	82
3.6	CSPA Uncertainties	82
4.0	Water Budget Values	84
5.0	Areas of “Stress”	87
6.0	Areas for Further Work	88
7.0	Field Program	90
8.0	Information Gaps	91
9.0	Discussion and Next Steps	92
10.0	References	94
10.1	Map Data References	102
Appendices		
	Appendix A – Maps	A-2
	Appendix B – Precipitation	A-35
	Appendix B-1 – Combined Precipitation	A-37
	Appendix B-2 – Rain	A-65
	Appendix B-3 – Snow	A-70
	Appendix C – Temperature	A-75
	Appendix D – Evapotranspiration	A-82
	Appendix D-1 – Pan/Lake Evaporation	A-97
	Appendix E – Stream Flow Data	A-103
	Appendix F – Water Use	A-144
	Appendix F-1 – PTTW	A-145
	Appendix F-2 – Water Wells	A-158
	Appendix G – PGMN Wells	A-161
	Appendix H – MOEE 1995 Method Slope Grouping Data	A-166
	Appendix I – Photographs	A-169
	Appendix J – Peer Review Record	A-186

## List of Tables

Table 2.1	Local Environment Canada Climate Stations	8
Table 2.2	Environment Canada Stations with Current Climate Normals meeting WMO Standards	9
Table 2.3	Precipitation Stations	10
Table 2.4	Full Set of Annual Precipitation Stations Record	12
Table 2.5	Mean Annual Precipitation with Uncertainties	16
Table 2.6	Turc Method ET Estimates	19
Table 2.7	Soil Water Holding Capacity	19
Table 2.8	Climate Stations Available for ET Estimation	20
Table 2.9	Evapotranspiration Values from EC Climate Stations Thornthwaite Method	21
Table 2.10	Pan Evaporation Data	25
Table 2.11	Lake Evaporation Data	26
Table 2.12	Infiltration Factors, Table 2 from MOEE (1995)	28
Table 2.13	Slope Infiltration Factors	29
Table 2.14	Soil Infiltration Factors	29
Table 2.15	Recharge and Runoff Estimates	30
Table 2.16	Typical Groundwater Recharge Rates, Table 3 from MOEE (1995)	31
Table 2.17	CSPA Stream Gauge Periods of Record	33
Table 2.18	Stream Gauge Mean Annual Flow	35
Table 2.19	Stream Gauge Drainage Areas	36
Table 2.20	Streamflow Low Months	39
Table 2.21	USGS/NWRI BFI for CSPA Streams	41
Table 2.22a	Well GA 278 Lithology and Depth	47
Table 2.22b	Well GA 383 Lithology and Depth	48
Table 2.22c	Well GA 334 Lithology and Depth	48
Table 2.22d	Well GA 365 Lithology and Depth	48
Table 2.22e	Well GA 200 Lithology and Depth	49
Table 2.22f	Well GA 279 Lithology and Depth	49
Table 2.23a	Percentage of Recharge - November 17 to December 1, 2004	56
Table 2.23b	Percentage of Recharge - May 16 to 27, 2004	56
Table 2.24	Streams with Possible Groundwater Discharge Sites	59
Table 2.25	Surficial Geology Grouping	66
Table 2.26	Soil Characteristic Percentage of Total Area	70
Table 2.27	Land Cover 28 Combination for Soil/Land Cover Comparison	71
Table 2.28	Actual Water Use Monthly Correction Factors	74
Table 2.29	Municipal Treatment Plant Withdrawal Volumes	75
Table 2.30	Water Well Use Breakdown	77
Table 4.1	Water Budget Parameter and Values - IN	84
Table 4.2	Water Budget Parameter and Values - OUT	84

## Appendices

Table B-1.1	Precipitation Kruskal-Wallis Test	A-41
Table B-1.2a	Mann-Kendall Test – Picton	A-45
Table B-1.2b	Mann-Kendall Test – Napanee	A-46
Table B-1.2c	Mann-Kendall Test – Centreville	A-47
Table B-1.2d	Mann-Kendall Test – Sandhurst	A-48
Table B-1.2e	Mann-Kendall Test – Cressy	A-49
Table B-1.2f	Mann-Kendall Test – Hartington	A-50
Table B-1.2g	Mann-Kendall Test – Godfrey	A-51
Table B-1.2h	Mann-Kendall Test – Cataraqui	A-52
Table B-1.2i	Mann-Kendall Test – Crow Lake	A-53
Table B-1.2j	Mann-Kendall Test – Kingston Airport	A-54
Table B-1.2k	Mann-Kendall Test – Wolfe Island	A-55
Table B-1.2l	Mann-Kendall Test – Glenburnie	A-56
Table B-1.2m	Mann-Kendall Test – Kingston Pumping Station	A-57
Table B-1.2n	Mann-Kendall Test – Delta	A-58
Table B-1.2o	Mann-Kendall Test – Lyndhurst	A-59
Table B-1.2p	Mann-Kendall Test – Mallorytown Graham Lake	A-60
Table B-1.2q	Mann-Kendall Test – Mallorytown Landing	A-61
Table B-1.2r	Mann-Kendall Test – Brockville	A-62
Table B-1.2s	Mann-Kendall Test – Kingston Queen’s	A-63
Table B-1.2t	Mann-Kendall Test – Brockville Older	A-64
Table B-2.1	Rain Kruskal-Wallis Test	A-66
Table B-3.1	Snow Kruskal-Wallis Test	A-71
Table C.1	Temperature Kruskal-Wallis Test	A-79
Table D.1a	Evapotranspiration Data – Picton	A-83
Table D.1b	Evapotranspiration Data – Napanee	A-84
Table D.1c	Evapotranspiration Data – Cressy	A-85
Table D.1d	Evapotranspiration Data – Hartington	A-86
Table D.1e	Evapotranspiration Data – Godfrey	A-87
Table D.1f	Evapotranspiration Data – Cataraqui	A-88
Table D.1g	Evapotranspiration Data – Kingston Airport	A-89
Table D.1h	Evapotranspiration Data – Wolfe Island	A-90
Table D.1i	Evapotranspiration Data – Glenburnie	A-91
Table D.1j	Evapotranspiration Data – Kingston Pumping Station	A-92
Table D.1k	Evapotranspiration Data – Lyndhurst	A-93
Table D.1l	Evapotranspiration Data – Mallorytown Landing	A-94
Table D.1m	Evapotranspiration Data – Brockville	A-95
Table D.2	ET Methods	A-96
Table D-1.1	Pan Evaporation Data	A-98
Table D-1.2	Lake Evaporation Data	A-101
Table E-1a	Buells Creek – Mann-Kendall Test	A-120

Table E-1b	Collins Creek – Mann-Kendall Test	A-121
Table E-1c	Little Cataraqui Creek – Mann-Kendall Test	A-122
Table E-1d	Lyn Creek – Mann-Kendall Test	A-123
Table E-1e	Millhaven Creek – Mann-Kendall Test	A-124
Table E-1f	Wilton Creek – Mann-Kendall Test	A-125
Table E.2	Buells Creek Annual Low Flow	A-126
Table E.3	Collins Creek Annual Low Flow	A-127
Table E.4	Little Cataraqui Creek Annual Low Flow	A-128
Table E.5	Lyn Creek Annual Low Flow	A-129
Table E.6	Lyndhurst Creek Annual Low Flow	A-130
Table E.7	Millhaven Creek Annual Low Flow	A-131
Table E.8	Wilton Creek Annual Low Flow	A-132
Table E.9	Moira River Annual Low Flow	A-134
Table E.10	Mississippi River Annual Low Flow	A-136
Table E.11	South Nation River Annual Low Flow	A-138
Table E.12	Field Monitoring Sites Mid-Summer Conditions, with Geology and Substrate Type	A-140
Table F.1	PTTW Listing	A-148
Table H.1	MOEE 1995 Method Slope Groupings	A-168

## List of Figures

Figure 1.1	Regional Hydrologic Cycle	2
Figure 2.1a	Annual Precipitation Map from Fisheries and Environment Canada (1978)	13
Figure 2.1b	Annual Precipitation Map from MNR (1984)	13
Figure 2.1c	Annual Precipitation Map from Moin & Shaw (1985)	14
Figure 2.2	Annual Precipitation Comparison w/ Confidence Interval	15
Figure 2.3	Soil Water Holding Capacity vs. Evapotranspiration	22
Figure 2.4a	Annual Evapotranspiration and Precipitation Map from Fisheries and Environment Canada (1978)	23
Figure 2.4b	Annual Evapotranspiration Map from MNR (1984)	24
Figure 2.5	Annual Lake Evaporation Map from Fisheries and Environment Canada (1978)	26
Figure 2.6	Slope vs. Infiltration Factor	28
Figure 2.7a	Mean Annual Flow from Fisheries and Environment Canada (1978)	34
Figure 2.7b	Mean Annual Flow from Moin & Shaw (1985)	34
Figure 2.8	Mean Annual Runoff and Precipitation	38
Figure 2.9	Monthly Percentage of Mean Annual Flow	40
Figure 2.10	BFI Map from Moin & Shaw (1985)	43
Figure 2.11a	Well 200 Water Level and Brockville Precipitation Record	51
Figure 2.11b	Well 222 Water Level and Hartington Precipitation Record	51
Figure 2.11c	Well 278 Water Level and Lyndhurst Precipitation Record	52
Figure 2.11d	Well 279 Water Level and Brockville Precipitation Record	52
Figure 2.11e	Well 334 Water Level and Lyndhurst Precipitation Record	53
Figure 2.11f	Well 365 Water Level and Kingston Precipitation Record	53
Figure 2.11g	Well 383 Water Level and Kingston Precipitation Record	54
Figure 2.11h	Well 383 Water Level and Belleville Precipitation Record	54
Figure 2.12	PGMN Water Levels - October 2002 to April 2006	56
Figure 2.13a	Bedrock Streambed Site, Little Creek, August 2006	58
Figure 2.13b	Stream Site, Little Creek	58
Figure 2.14	Bedrock Geology Timeline	61
Figure 2.15	Schematic Geological Cross-Section of CSPA	64
Figure 2.16	Water Withdrawal Source	72
Figure 2.17	Public Water Supply Withdrawal Source	76
Figure 4.1	Average Annual Water Budget Block Diagram	86
Appendices		
Figure A1.1	CSPA Watersheds and Study Areas	A-3
Figure A2.1	Historic Environment Canada Climate Stations	A-4
Figure A2.2	Environment Canada Stations with calculated Climate Normals	A-5
Figure A2.3a	Canadian Forestry Service Precipitation Map -	A-6

	Eastern Ontario	
Figure A2.3b	Canadian Forestry Service Precipitation Map - Cataraqui Source Protection Area	A-7
Figure A2.4a	Canadian Forestry Service Temperature Map - Eastern Ontario	A-8
Figure A2.4b	Canadian Forestry Service Temperature Map - Cataraqui Source Protection Area	A-9
Figure A2.5	Soil Water Holding Capacity Map	A-10
Figure A2.6	Evapotranspiration Map	A-11
Figure A2.7	CSPA Slope	A-12
Figure A2.8	CSPA Soils	A-13
Figure A2.9	CSPA Land Use	A-14
Figure A2.10	MOEE Infiltration/Recharge Coefficient Map	A-15
Figure A2.11	Stream Gauge Locations	A-16
Figure A2.12	Structure Locations	A-17
Figure A2.13	Provincial Groundwater Monitoring Network Well Locations	A-18
Figure A2.14	Bedrock Geology	A-19
Figure A2.15	Surficial Geology	A-20
Figure A2.16	Physiography	A-21
Figure A2.17	Overburden Thickness	A-22
Figure A2.18a	Soils Overview	A-23
Figure A2.18b	Soils Detailed	A-24
Figure A2.19	Topography	A-25
Figure A2.20	Land Use	A-26
Figure A2.21	Water Use – Permit To Take Water Locations Surface Water vs. Groundwater Takings	A-27
Figure A2.22	Municipal Water Supplies	A-28
Figure A2.23	Water Wells	A-29
Figure A2.24	Industrial/Commercial Water Supplies	A-30
Figure A2.25	Agricultural Water Supplies	A-31
Figure A6.1	Well Density	A-32
Figure A7.1	Field Sites	A-33
Figure A9.1	Tier 1 Spatial Scale Consideration	A-34
Figure B-1.1a	1860-1910 Annual Precipitation at Climate Stations	A-38
Figure B-1.1b	1910-1960 Annual Precipitation at Climate Stations	A-39
Figure B-1.1c	1960-2010 Annual Precipitation at Climate Stations	A-40
Figure C.1a	1860-1910 Annual Temperature at Climate Stations	A-76
Figure C.1b	1910-1960 Annual Temperature at Climate Stations	A-77
Figure C.1c	1960-2010 Annual Temperature at Climate Stations	A-78

Figure E.1a	Buells Creek Mean Annual Flow	A-104
Figure E.1b	Buells Creek Average Monthly Flow	A-105
Figure E.2a	Chaffey's Creek Mean Annual Flow	A-106
Figure E.2b	Chaffey's Creek Average Monthly Flow	A-107
Figure E.3a	Collins Creek Mean Annual Flow	A-108
Figure E.3b	Collins Creek Average Monthly Flow	A-109
Figure E.4a	Little Cataraqui Creek Mean Annual Flow	A-110
Figure E.4b	Little Cataraqui Creek Average Monthly Flow	A-111
Figure E.5a	Lyn Creek Mean Annual Flow	A-112
Figure E.5b	Lyn Creek Average Monthly Flow	A-113
Figure E.6a	Lyndhurst Creek Mean Annual Flow	A-114
Figure E.6b	Lyndhurst Creek Average Monthly Flow	A-115
Figure E.7a	Millhaven Creek Mean Annual Flow	A-116
Figure E.7b	Millhaven Creek Average Monthly Flow	A-117
Figure E.8a	Wilton Creek Mean Annual Flow	A-118
Figure E.8b	Wilton Creek Average Monthly Flow	A-119
Figure E.9	Field Monitoring Sites with Bedrock Geology	A-139
Figure F.1a	Water Use – Permit to Take Water by Sector	A-146
Figure F.1b	Water Use – Permit to Take Water by Taking Amount	A-147
Figure F.2a	Domestic Wells	A-159
Figure F.2b	Other Wells	A-160
Figure G.1	Well 200 Annual Water Level Comparison	A-162
Figure G.2	Well 222 Annual Water Level Comparison	A-162
Figure G.3	Well 278 Annual Water Level Comparison	A-163
Figure G.4	Well 279 Annual Water Level Comparison	A-163
Figure G.5	Well 334 Annual Water Level Comparison	A-164
Figure G.6	Well 365 Annual Water Level Comparison	A-164
Figure G.7	Well 383 Annual Water Level Comparison	A-165
Figure H.1a	MOEE 1995 Method Slope Values (Full Data)	A-167
Figure H.1b	MOEE 1995 Method Slope Values (Smaller Data Set)	A-167
Figure I-1a	Babcock Mill Dam on Millhaven Creek. June 24 2003	A-170
Figure I-1b	Babcock Mill Dam on Millhaven Creek. Sep 16 2003	A-170
Figure I-1c	Babcock Mill Dam on Millhaven Creek. Sep 19 2003	A-171
Figure I-1d	Babcock Mill Dam on Millhaven Creek. Oct 17 2003	A-171
Figure I-1e	Babcock Mill Dam on Millhaven Creek. Nov 16 2003	A-172
Figure I-1f	Babcock Mill Dam on Millhaven Creek. Dec 1 2003	A-172
Figure I-2a	Sydenham Lake Dam on Millhaven Creek. Apr 24 2002	A-173
Figure I-2b	Sydenham Lake Dam on Millhaven Creek. Jul 22 2002	A-173
Figure I-2c	Sydenham Lake Dam on Millhaven Creek. Oct 17 2003	A-174
Figure I-2d	Sydenham Lake Dam on Millhaven Creek. Dec 1 2003	A-174
Figure I-3a	Little Creek looking upstream from L&A Cty Rd 9. Aug 8 2006	A-175

Figure I-3b	Little Creek looking upstream from L&A Cty Rd 9. Aug 23 2006	A-175
Figure I-3c	Little Creek looking upstream from Little Creek Rd. Aug 8 2006	A-176
Figure I-3d	Little Creek looking upstream from L&A Cty Rd 2. Aug 8 2006	A-176
Figure I-4a	Wilton Creek, near L & A Cty Rd 2 crossing, looking south. Oct 20 2005	A-177
Figure I-4b	Wilton Creek looking downstream from Chambers Rd. Aug 8 2006	A-177
Figure I-5	Millhaven Creek downstream of Sydenham, wetland flooded. May 3 2004	A-178
Figure I-6	Unnamed Amherst Island creek looking downstream from Stella 40 ft Rd. Aug 14 2006	A-178
Figure I-7	Village of Delta, looking west. Oct 20 2005	A-179
Figure I-8a	Unnamed Creek East of Brockville looking upstream from Cty Rd 2. Aug 10 2006	A-179
Figure I-8b	Unnamed Creek East of Brockville looking upstream from Cty Rd 2. Aug 10 2006	A-180
Figure I-9a	Migmatic Gneiss Core from Drilling in Lansdowne. Sep 19 2006	A-181
Figure I-9b	Migmatic Gneiss Outcrop on L-G Cty Rd 3 near Lansdowne. Sep 19 2006	A-181
Figure I-10a	March Formation Core from Drilling near Lansdowne with Water Bearing Fracture (staining) Sep 19 2006	A-182
Figure I-10b	Contact between March Formation (grey) and Precambrian (pink) Core from Drilling near Lansdowne. Nov 22 2006	A-182
Figure I-10c	March Formation Outcrop near Lansdowne. Sep 19 2006	A-183
Figure I-11	Gull River Outcrop near Little Cataraqui Creek Conservation Area entrance. Sep 22 2006	A-183
Figure I-12	Gull River Outcrop along northwest shoreline of Wolfe Island. Nov 6 2006	A-184
Figure I-13	Gull River Outcrop along South Shore Road on Howe Island. Nov 21 2006	A-184
Figure I-14	Typical Small Water Withdrawal along Millhaven Creek, downstream of Odessa. Aug 12 2004	A-185

## 1.0 Introduction

The objective of this report is to provide a Conceptual Understanding Water Budget for the Cataraqui Source Protection Area (CSPA), as required for the Source Water Protection Program. This will include a summary of the available data and the methodology for estimating the water budget parameter values. It will also identify the gaps in data that must be filled in order to refine future phases of water budget modeling and any more detailed numerical modeling.

The objectives of the Water Budget Modeling exercise are to (MOE, 2006a):

- Quantify the parameters of the water budget equation,
- Detail how the various components of the water budget interact,
- Investigate the potential water budget impacts from proposed land use, water use, or change in climate,
- Set the temporal and spatial scales for the calculations,
- Divide the Cataraqui Source Protection Region into logical study areas to be further evaluated, and
- Determine the most appropriate model or models to be used for the Water Budget.

This Conceptual Water Budget Model is just the first step in achieving these objectives.

The four questions that need to be answered to meet these objectives are (MOE, 2006a):

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

A water budget accounts for all water into and out of a watershed. This includes precipitation, evaporation, transpiration, runoff, etc., as well as movement of water within the watershed, such as infiltration, recharge to groundwater, and reservoir storage.

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 <sub>in</sub>	=	surface water flow in;
	GW <sub>in</sub>	=	groundwater flow in;
	ANTH <sub>in</sub>	=	anthropogenic or human inputs;
	D <sub>in</sub>	=	diversion into the watershed;
	ET	=	evaporation and transpiration;
	SW <sub>out</sub>	=	surface water flow out;
	GW <sub>out</sub>	=	groundwater flow out;
	ANTH <sub>out</sub>	=	anthropogenic or human abstractions; and

$D_{out}$  = diversion out of the watershed;  
 $\Delta S$  = change in storage. (Based on MOE, 2006a)

Figure 1.1 gives a general schematic representation of the presented water budget equation.

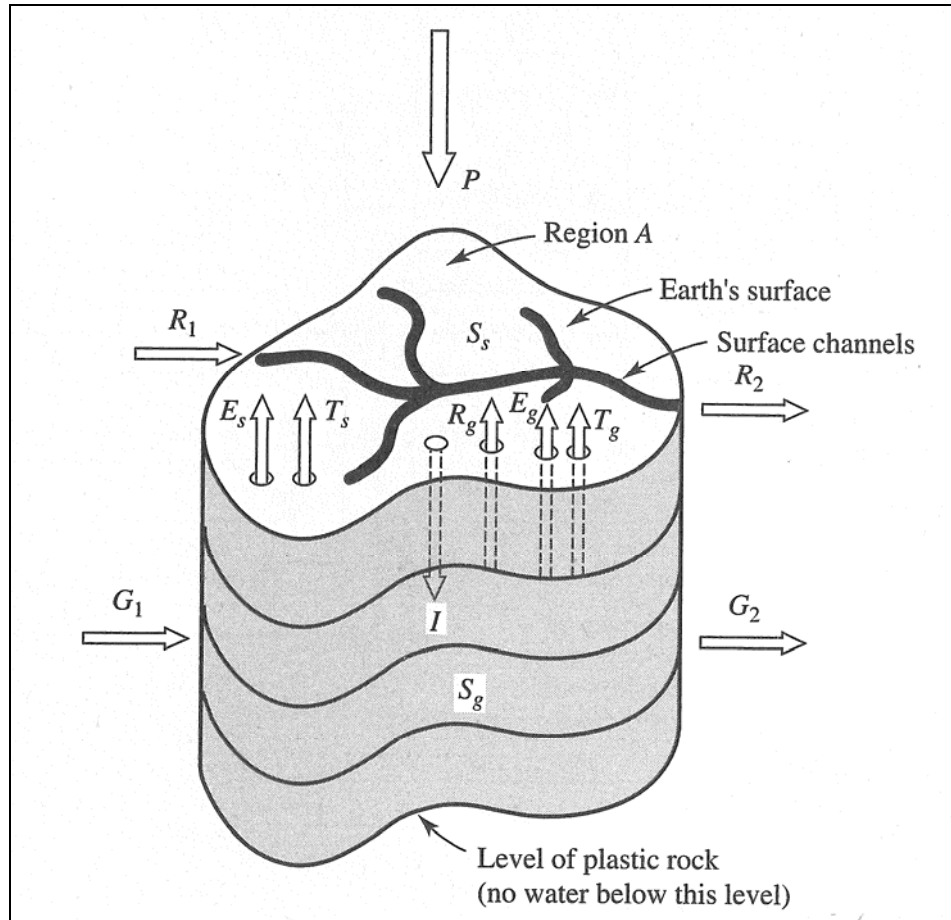


Figure 1.1 : Regional Hydrologic Cycle

Source: Veissman and Lewis, 1996

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.	

This report will outline and quantify each of the above parameters where possible. Otherwise, gaps will be identified and sources addressed to quantify the parameter.

## 1.1 Objectives

As stated above, the project has five general objectives:

- Quantify the parameters of the water budget equation noted below,
- Investigate the potential water budget impacts from proposed land use, water use, or changes in climate,
- Set the temporal and spatial scales for the calculations,
- Divide the Cataraqui Source Protection Region into logical study areas to be further evaluated, and
- Determine the most appropriate model or models to be used.

The equation parameters will be quantified and analyzed in Section 2.0 of this report. This Conceptual report will be a first step to the overall Water Budget Model. As such, this report will look at general numbers, with more detailed analysis to be done for subsequent phases of the Water Budget work.

Changes to the land use, such as increasing development, or changing development, can be used to estimate future water budget parameter values. Future water use can also be estimated based on predicted population growth, or through estimates of development via planning documents. And, some estimation of the variability of climatic conditions (such as comparison to a low water year or years) is needed to evaluate current conditions, and future change in water supply or demand.

Temporally, the Conceptual Water Budget is done on an annual basis and is not intended to identify stressed watersheds, as the average annual conditions are expected to result in perceived “surplus to need” water across the watershed, where water-in equals water-out and there is no change in storage. However, even in an average year, the monthly water budget, or smaller time step budget, may result in water supply not meeting water demand. The Conceptual Water Budget data is configured based on the “water year” concept. That is, annual refers to the period from October 1 to September 30. This allows snowfall to be considered in the same year as the runoff that is generated from its melting. From a notation perspective, data representing the year 2006 would span from October 1, 2005 to September 30, 2006.

Spatially, the Conceptual Water Budget covers the entire CSPA as one entity. This scale is also not appropriate to identify stressors. The Tier 1 Water Budget work will evaluate the CSPA on a watershed by watershed basis. Future Water Budget Tiers will evaluate specific areas within watershed or subwatersheds.

The CSPA’s 3568 km<sup>2</sup> can be divided into 12 separate watersheds as shown in Figure A1.1. Those watersheds have then been grouped into five “Study Areas” for the purposes of Source Protection work (divisions below). Study areas were grouped based on similarities in land use, geology, water course parameters (lakes and wetlands), regulation structures, as well as for “political” reasons. More detailed information about the CSPA can be found in the Watershed Characterization document (CRCA, 2006a).

## Lake Ontario Study Area Watersheds

- Wilton, Spring and Little Creeks
- Millhaven Creek
- Collins Creek
- Little Cataraqui Creek
- Smaller Creeks draining to Lake Ontario

## Cataraqui River Study Area Watershed

- Cataraqui River

## Tri-Islands Study Area Watersheds

- Amherst Island
- Wolfe & Howe Islands

## Gananoque River Study Area Watershed

- Gananoque River

## St. Lawrence River Study Area Watersheds

- Jones, Lyn and Golden Creeks
- Buells and Butlers Creeks
- Smaller Creeks draining to St. Lawrence River

While five areas were chosen to maintain similarity in those areas, in some cases the entire CSPA can be treated as one unit. However, considering the entire CSPA as one unit for the purposes of the Conceptual Water Budget may not be scientifically acceptable for all parameters, given the variability in monthly climate values, water use, and mean annual flow from watershed to watershed. Despite these possible sources of uncertainty, the Conceptual Water Budget was completed as a single regional water budget. The next stage water budget (Tier 1), will include a more detailed breakdown of watersheds and/or subwatersheds.

A simple spreadsheet model was used for the Conceptual Water Budget. However, there may be usefulness in creating a GIS based model in the future (which is being used by the Quinte SWP Region), where the watershed is divided into uniform blocks, and each block is analyzed for its own water budget. The resulting values could then be tied to a range of colours to visually show areas of stress. The specific model selection will be more critical if and when detailed numerical modeling is required. The results of the Conceptual Water Budget (and future phases) should help guide that model selection.

## 1.2 Questions

As referenced in the introduction, the project is to answer four general questions:

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

The question of where will be answered based on physical structures such as lakes, streams, flow gauges, precipitation gauges, and land use/soil estimates related to infiltration and runoff.

The movement can be identified via structures, stream gauges, and groundwater records (and groundwater studies).

The trends will be identified using long term data records, or through correlation with long term records.

## 1.3 Simplification of the Water Budget Equation

The Conceptual Water Budget will examine specifically the average annual condition, with more detailed temporal and spatial work to be completed with later phases (Tier 1 and beyond) as required. As such, assumptions can be made to simplify the water budget equation as presented in Section 1.0.

“The regional water balance is the application of the water-balance equation to a watershed. ... Consider the watershed ... over a reasonably long time period (many decades, say) in which there are no significant climatic trends or geologic changes and no anthropogenic inputs, outputs, or storage modifications. For such an idealized period we can assume that net changes in storage will be effectively zero ... and write the water balance as

$$P + G_{in} - (Q + ET + G_{out}) = 0,$$

Where P is precipitation (liquid and solid),  $G_{in}$  is ground-water inflow (liquid), Q is stream outflow (liquid), ET is evapotranspiration (vapor),  $G_{out}$  is ground-water outflow (liquid), and all values are the true totals or long-term averages. “

Dingman, 1994.

For our case, we assume:

- Surface water in ( $SW_{in}$ ), when dealing with a complete watershed, will be zero. Surface water out ( $SW_{out}$ ) is runoff ( $Q$ ).
- Deep groundwater in and out of the watershed ( $GW_{in}$  and  $GW_{out}$ ) balance, or that the surface watershed boundaries match the deep groundwater boundaries; and that recharge into the aquifers balances with discharge from the aquifers, for long-term average conditions.
- Change in storage ( $\Delta S$ ) should also equal zero for a long-term average water balance.
- Human inputs and withdrawals are in many cases very small compared to the other terms, and can be neglected, or balance each other out. In the conceptual case, the first balance of the equation is done without human inputs or withdrawals.

The simplified equation can then be written as:

$$P - Q - ET = 0$$

Precipitation and streamflow records are reasonably plentiful, and can therefore be used to calculate or estimate the value of the ET parameter. The ET parameter can also be calculated from climate data, and the results can be compared to give an indication of reasonableness.

## 2.0 Data

This section outlines the data required for the Water Budget Conceptual Model, as well as the methodology for estimation of the values of the parameters, and the estimated values used for the water budget exercise.

### 2.1 Climate

There are 51 historic Environment Canada climate stations within the CSPA (and within 10 km of the boundary, outside of the CSPA) with data from as early as the 1870's. They are listed in Table 2.1, from west to east, and their locations are shown in Figure A2.1. Of these 51 stations, six are still active (as of July 2006). However, it should be mentioned that the Grenadier Island station is only a seasonal station, the Kingston Airport station is maintained by the Kingston Airport Authority and data is not necessarily readily available, and the Kingston Pumping Station station is maintained by the City of Kingston, and has long periods of downtime due to lack of maintenance and repair. That leaves three active stations, 2 outside of the CRCA jurisdiction (Centreville, Hartington), and one in the very eastern end (Brockville PCC).

Station	Number	Period	Data Recorded
Picton Airport	6156535	1956-1961	P, R, S, T, MaT, MiT, SD
Picton	6156533	1915-1995	P, R, S, T, MaT, MiT, SD
Deseronto	6152007	1882-1905	P, R, S, T, MaT, MiT
Glenora RS	6152837	1958-1969	P, R, S, T, MaT, MiT
Napanee	615NNPL	1987-2001	P, R, S, T, MaT, MiT, SD
Parma	6156251	1895-1907	P, R, S
Centreville*	6151309	1985-2003	P, R, S, T, MaT, MiT, SD
Sandhurst	6107434	1993-2002	P, R, S, T, MaT, MiT, SD
Cressy	61519JM	1966-2002	P, R, S, T, MaT, MiT, SD
Morven IHD	6155496	1967-1976	P, R, S, T, MaT, MiT
Bellrock	6100720	1957-1978	P, R, S, T, MaT, MiT
Harrowsmith Bracken	6103366	1978-1983	P, R, S, SD
Hartington IHD*	6103367	1967-2003	P, R, S, T, MaT, MiT, SD
Hinchinbrooke	6103470	1961-1973	P, R, S
Stella-Amherst	6158012	1978-1982	P, R, S, T, MaT, MiT
Godfrey	6102857	1981-2003	P, R, S, T, MaT, MiT, SD
Cataraqui TS	6101265	1960-1995	P, R, S, T, MaT, MiT, SD
Crow Lake	6101920	1972-1991	P, R, S, SD
Kingston Airport*	6104146 YGK	1930-1996	P, R, S, T, MaT, MiT, SD
Sydenham	6108195	1903-1917	P, R, S
Kingston N & C Gas	6104160	1965-1977	P, R, S, T, MaT, MiT
Wolfe Island	6109558	1986-1996	P, R, S, T, MaT, MiT, SD
Kingston Beverley St.	6104147	1960-1966	P, R, S
Kingston	6104145	1947-1949	P, R, S, T, MaT, MiT
Kingston Queen's U	6104185	1872-1957	P, R, S, T, MaT, MiT
Kingston Ont Hydro	6104165	1945-1971	P, R, S, T, MaT, MiT

Glenburnie	6102808	1972-1999	P, R, S, T, MaT, MiT, SD
Kingston Pumping Station*	6104175	1960-2004	P, R, S, T, MaT, MiT, SD
Kingston Marine	6104153	1939-1967	P, R, S, T, MaT, MiT
Westport	6109458	1895-1920	P, R, S
Rideau Canal Wolfe Lake	6107119	1954-1961	P, R, S
Rideau Canal Upper Brewers	6107105	1954-1967	P, R, S
Rideau Canal Narrows	6107087	1954-1969	P, R, S
Rideau Canal Jones Falls	6107045	1954-1969	P, R, S
Gananoque	6102662	1969	P, R, S
Portland	6106677	1953-1958	P, R, S, T, MaT, MiT
Delta	6101986	1969-1994	P, R, S, SD
Lyndhurst Shawmere	6104725	1976-2003	P, R, S, T, MaT, MiT, SD
Outlet	6106123	1969-1970	P, R, S
Lansdowne (North)	6104347	1895-1910	P, R, S
Lansdowne (South)	6104348	1965-1967	P, R, S, T, MaT, MiT
Athens	6100375	1969-1978	P, R, S
Mallorytown Graham Lake	6104880	1961-1989	P, R, S, SD
Mallorytown Landing	6104882	1977-1991	P, R, S, T, MaT, MiT, SD
Grenadier Island*	6103024 WGH	1997-2003	P, R, S, T, MaT, MiT, SD
Lyn	6104723	1960-1969	P, R, S
North Augusta	6105678	1971-1972	P, R, S
North Augusta Mahoney	6105679	1973-1980	P, R, S, T, MaT, MiT
Brockville	6100969	1871-1980	P, R, S, T, MaT, MiT, SD
Brockville PCC*	6100971	1965-2003	P, R, S, T, MaT, MiT, SD
Maitland	6104840	1953-1954	P, R, S, T, MaT, MiT

Table 2.1: Local Environment Canada Climate Stations

\* Active Station

P – Precipitation, R-Rain, S-Snowfall, T – Mean Temperature, MaT - , Maximum Temperature, MiT – Minimum Temperature, SD – Snow Depth

Data for the climate stations is available from the Environment Canada Eastern Canada CD (April 2003), as well as through the Environment Canada climate website ([http://www.climate.weatheroffice.ec.gc.ca/climateData/canada\\_e.html](http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html)).

In addition to the stations located across the CRCA jurisdiction, there are 27 Environment Canada stations in Eastern Ontario that have calculated 1971 – 2000 climate normals for precipitation and temperature (See Figure A2.2 and Table 2.2).

Station	WMO Standard	Station	WMO Standard
Arnprior Grandon	Yes	Ottawa CDA*	Yes
Belleville	Yes	Peterborough Airport	Yes
Brockville PCC*	Yes	Peterborough Trent*	Yes
Cobourg STP	Yes	Renfrew	Yes
Combermere	Yes	South Mountain	Yes
Cornwall*	Yes	Trenton Airport*	Yes
Cressy	Yes	Cataraqui TS	No
Dalhousie Mills	Yes	Godfrey	No
Glenburnie	Yes	Kingston Airport*	No
Hartington*	Yes	Kingston Pumping Station*	No
Kemptville*	Yes	Lyndhurst Shawmere	No
Minden	Yes	Picton	No
Morrisburg	Yes	Smithfield CDA	No
Ottawa Airport*	Yes		

Table 2.2: Environment Canada Stations with Current Climate Normals meeting WMO Standards

\* 10 Active Stations as of Dec. 2006

Climate normal values can be found online at the Environment Canada website ([http://www.climate.weatheroffice.ec.gc.ca/climate\\_normals/index\\_e.html](http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html)).

In addition to the station records, some analysis has been completed by Natural Resources Canada, Canadian Forestry Service (McKenney et al., 2006a, 2006b) which created isoline mapping of precipitation and temperature across Canada. These maps are provided as Figures A2.3 and A2.4.

## 2.1.1 Precipitation

### 2.1.1.1 Combined Precipitation

Eighteen of the Environment Canada Stations mentioned in section 2.1 were used to estimate annual precipitation across the CSPA. The stations chosen (Table 2.3) were those with recent, full year, or longer periods of record.

Station	Period of Record Used	Years with Missing Data	Complete Years of Data	Mean Annual Precipitation (mm)
Picton	1917-1994	1920-1966, 1968, 1972, 1974, 1975, 1978-1980, 1986, 1991-1993	20	946
Napanee	1989-1999	1997	12	889*
Centreville	1987-2003	None	17	949
Sandhurst	1994-2001	1999, 2000	6	947*
Cressy	1967-2001	1977, 1978, 1985	32	947

Hartington	1969-2003	1970, 1985	33	958
Godfrey	1982-2000	1985	18	952
Catarqui TS	1961-1994	1963, 1965, 1986, 1992, 1993	29	953
Crow Lake	1973-1990	1976	17	958
Kingston Airport	1944-1994	1945-1967	28	955
Wolfe Island	1987-1996	1988, 1992	8	911*
Glenburnie	1973-1998	1987, 1996	24	1021
Kingston Pumping Station	1966-2003	1972, 1985, 1992, 1995	34	949
Delta	1970-1989	1972, 1975, 1977, 1982, 1984-1986, 1988	12	902*
Lyndhurst Shawmere	1977-2003	1996, 1999, 2001, 2002	23	977
Mallorytown Graham Lake	1968-1988	1979, 1981, 1984-1986	16	884
Mallorytown Landing	1979-1990	1986	11	980*
Brockville PCC	1968-2003	1971, 1979, 1984, 1993	32	973

Table 2.3: Precipitation Stations

(\*Less than 15 years of Data)

The annual precipitation values for these stations were compared using the Kruskal-Wallis non parametric test for same population set. The Kruskal-Wallis test is explained in Appendix B. The null hypothesis of the test is that all sample groups have identical distributions. The alternative hypothesis is that at least one of the groups has a different distribution. Based on the test result, the null hypothesis is not rejected, and the stations are assumed to have the same distribution for the purposes of this work. The full results of the test are shown in Appendix B-1. Based on the results of the test, the average annual precipitation (the average of *all* the annual data for the 18 stations, or weighted average) for the CSPA is calculated as 953 mm.

The Canadian Forestry Service has also created precipitation maps based on the data from Environment Canada's climate stations, as well as some US stations. This work is shown in Figure A2.3a (Eastern Ontario) and A2.3b (CSPA). The average precipitation across the CSPA based on this mapping is 954 mm.

The calculated average annual precipitation value appears to be slightly higher than previous analyses, such as the Hydrologic Atlas of Canada (1978), MNR (1984) and Moin & Shaw (1985) (See Figures 2.1a-c), though it does appear to relate well to the McKenney et al. (2006b) data.

However, if the highest (Glenburnie) and/or lowest (Mallorytown Graham Lake) station's data are removed, very little difference is seen in the average precipitation (948 mm when Glenburnie is removed, 956 mm when Mallorytown Graham Lake is removed, 952 mm when both are removed). Similarly, looking at only data from 1980 and before

(coincident with data probably used for these maps) the mean is still very similar (957 mm).

Using the entire 43 station annual precipitation data set (8 stations have no full years of data), a weighted average annual precipitation value of 914 mm is calculated. However, the older stations appear to have lower average precipitation values, which brings the overall average down when those values are included (See Table 2.4). The Kruskal-Wallis test for the full data set rejects the null hypothesis and therefore the full set of station data do not have the same distribution. This result indicates that there could be a trend over time with the precipitation in the area. This is confirmed by McKenney et al. (2006b), Zhang et al. (2000) and Mekis & Hogg (1999).

<b>Station</b>	<b>Period of Record</b>	<b>Complete Years of Data</b>	<b>Mean Annual Precipitation (mm)</b>
Picton Airport	1956-1961	0	
Picton	1915-1995	20	946
Deseronto	1882-1905	15	862
Glenora RS	1958-1969	1	769*
Napanee	1987-2001	12	889*
Parma	1895-1907	10	921*
Centreville	1985-2003	17	949
Sandhurst	1993-2002	6	947*
Cressy	1966-2002	32	947
Morven IHD	1967-1976	5	988*
Bellrock	1957-1978	14	867*
Harrowsmith Bracken	1978-1983	2	1015*
Hartington	1967-2003	33	958
Hinchinbrooke	1961-1973	4	874*
Stella-Amherst	1978-1982	1	1022*
Godfrey	1981-2003	18	952
Cataraqui TS	1960-1995	29	953
Crow Lake	1972-1991	17	958
Kingston Airport	1930-1996	28	955
Sydenham	1903-1917	8	902*
Kingston N & C Gas	1965-1977	4	896*
Wolfe Island	1986-1996	8	911*
Kingston Beverley St.	1960-1966	4	754*
Kingston	1947-1949	1	859*
Kingston Queen's	1872-1957	66	848
Kingston Ont Hydro	1945-1971	22	896
Glenburnie	1972-1999	24	1021
Kingston Pumping Station	1960-2004	34	949
Kingston Marine	1939-1967	4	873*
Westport	1895-1920	21	785
Rideau Canal Wolfe Lake	1954-1961	1	797*

Rideau Canal Upper Brewers	1954-1967	5	824*
Rideau Canal Narrows	1954-1969	3	629*
Rideau Canal Jones Falls	1954-1969	1	690*
Gananoque	1969	0	
Portland	1953-1958	3	770*
Delta	1969-1994	12	902*
Lyndhurst Shawmere	1976-2003	23	977
Outlet	1969-1970	0	
Lansdowne (North)	1895-1910	10	621*
Lansdowne (South)	1965-1967	0	
Athens	1969-1978	6	950*
Mallorytown Graham Lake	1961-1989	16	884
Mallorytown Landing	1977-1991	11	980*
Grenadier Island	1997-2003	0	
Lyn	1960-1969	0	
North Augusta	1971-1972	0	
North Augusta Mahoney	1973-1980	5	1096*
Brockville	1871-1980	65	898
Brockville PCC	1965-2003	32	973
Maitland	1953-1954	0	

Table 2.4: Full Set of Annual Precipitation Stations Record

(\*Less than 15 years of Data)

Zhang et al. (2000) noted that there has been a statistically significant rise in precipitation (12 %) in southern Canada (south of 60°N) over the 20<sup>th</sup> century (that equals 114 mm for the CSPA), as did Mekis & Hogg (1999) for the southern Ontario area close to the Great Lakes/St. Lawrence River (11 %). Both studies adjusted the precipitation data to account for known inconsistencies in measurements over time. This should result in a more accurate assessment of the actual trends. McKenney et al. (2006b) found a statistically insignificant increase of only 18 mm (that equals 2 % for the CSPA) across almost the same area (south of 55°N). These studies did not look specifically at the CSPA, so the trend here could be more or less than these amounts, however this would account for some of the range of the data (though not necessarily all of it). A Mann-Kendall test was also carried out for each of the 18 stations (Full tests shown in Appendix B-1), which showed a statistically significant trend in only 3 of the 18 stations, Catarauqui, Glenburnie and Mallorytown Graham Lake. The two stations with the longest period of record (dating back to the 1870's) were also tested and the Brockville station showed trend, while the Kingston (Queen's) station did not. The Mann-Kendall test (a non-parametric test for trend) is explained in Appendix B.



Figure 2.1a: Annual Precipitation Map from Fisheries and Environment Canada (1978)  
(Not to Scale)

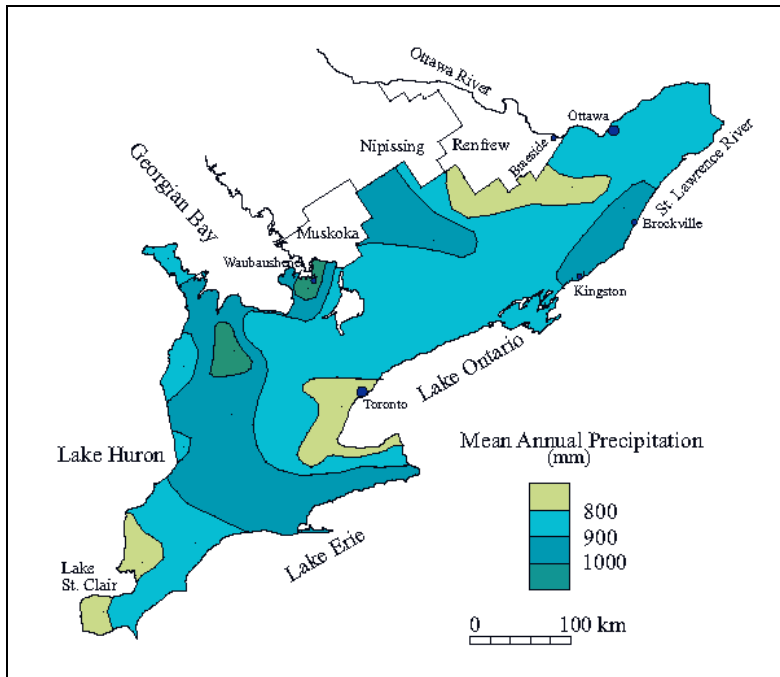


Figure 2.1b: Annual Precipitation Map from MNR (1984)

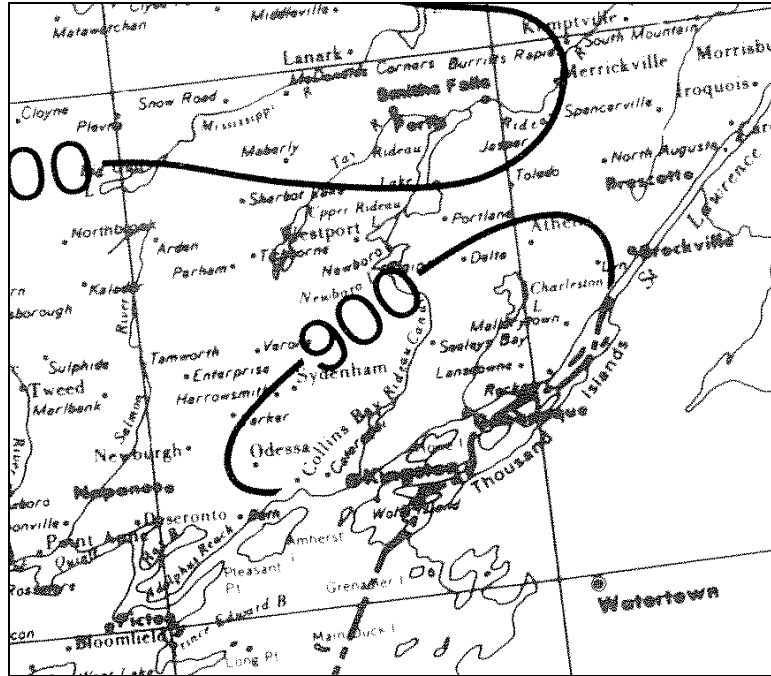


Figure 2.1c: Annual Precipitation Map from Moin & Shaw (1985)  
(Not to Scale)

In addition, the standard error of the data was calculated and used to compare the statistical range of the stations (Figure 2.2). As mentioned previously, the 18 stations are assumed to come from the same population based on the Kruskal-Wallis test. Figure 2.2 implies the same assumption, when considering the standard errors of the means.

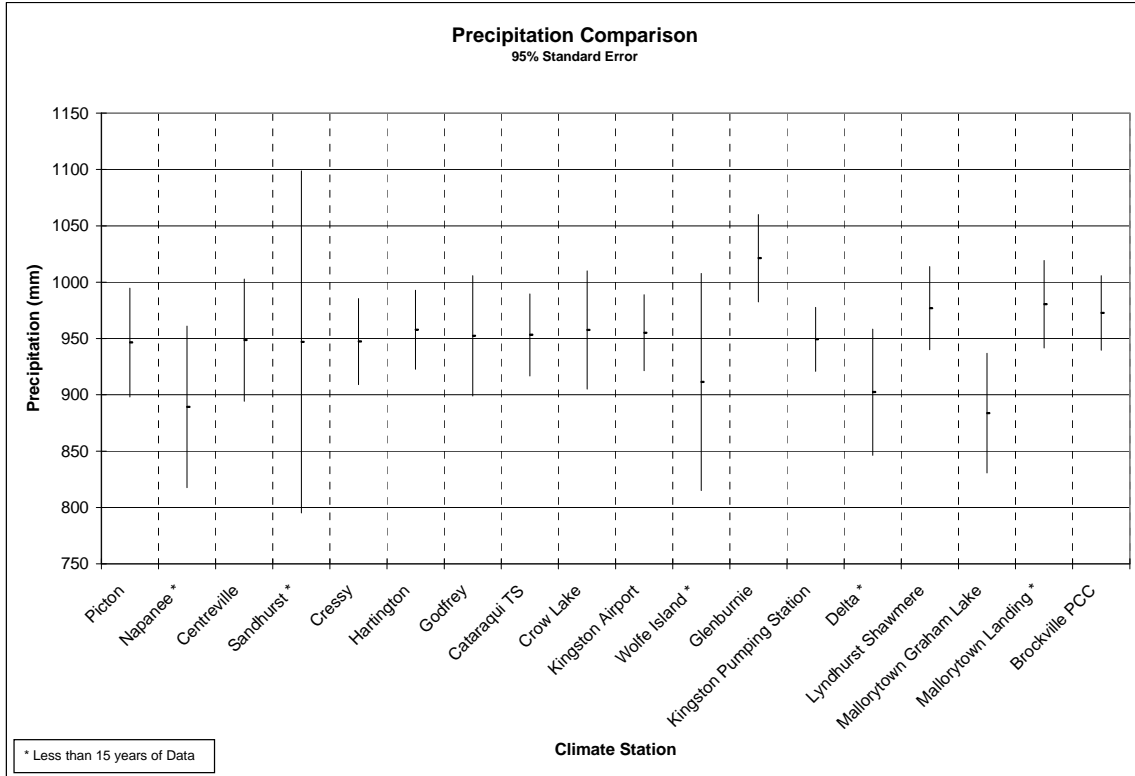


Figure 2.2: Annual Precipitation Comparison w/ Confidence Interval

Table 2.5 shows the mean annual precipitation for each station, years of record, the standard error, the estimated upper and lower limits of the population mean (using a 95% confidence interval via standard error estimates (Upper limit = Mean +  $t$  \* Standard Error)), and an estimate of the actual maximum precipitation. The uncertainty associated with individual precipitation measurements is accepted to be around 10%, that being attributed to undercatch of the gauge (Dingman, 1994), as well as other considerations, detailed in Section 3.1. So, the recorded individual station precipitation values could be as much as 10% different than what actually occurred.

Station	Mean Annual Precipitation (mm)	Years of Record	Standard Error (mm/%)	Upper Confidence Level (mm)	Lower Confidence Level (mm)
Picton	946	20	28 / 3%	995	898
Napanee*	889	12			
Centreville	949	17	31 / 3%	1003	894
Sandhurst*	947	6			
Cressy	947	32	23 / 2%	985	909
Hartington	958	33	21 / 2%	993	923
Godfrey	952	18	31 / 3%	1006	899
Cataraqui TS	953	29	21 / 2%	990	917
Crow Lake	958	17	30 / 3%	1010	905
Kingston Airport	955	28	20 / 2%	989	921
Wolfe Island*	911	8			
Glenburnie	1021	24	23 / 2%	1060	983
Kingston Pumping Station	949	34	17 / 2%	978	921
Delta*	902	12			
Lyndhurst Shawmere	977	23	22 / 2%	1014	940
Mallorytown Graham Lake	884	16	30 / 3%	937	831
Mallorytown Landing*	980	11			
Brockville PCC	973	32	19 / 2%	1006	940

Table 2.5: Mean Annual Precipitation with Uncertainties

(\*Less than 15 years of Data is unreliable for an estimate of standard error.)

The annual precipitation was also compared for the 52 stations in the Eastern Ontario region, and is shown in Figures B-1.1a to B-1.1c. While the precipitation at the stations is not necessarily the same, it can be seen that when annual precipitation is high at one station, it is generally high at all stations, and the same relation holds for drier years as well. This is due to the fact that the scale of the spatial variation in the annual precipitation is larger than the area of just the CSPA.

#### 2.1.1.2 Rain

Similar comparisons and analyses were completed for rain data, as for the precipitation data. It was again found through the Kruskal-Wallis test that the hypothesis of annual rain being from the same population could not be rejected. The weighted average annual rain was calculated as 782 mm.

#### 2.1.1.3 Snow

Again, similar comparisons and analyses were completed for snow data, as for the precipitation and rain data. However, the Kruskal-Wallis test rejected the hypothesis that the snow data is from the same population. The two lowest snow stations (Napanee and Wolfe Island) force this, the other 16 stations do not reject the hypothesis. The weighted average annual snow was calculated as 171 mm Water Equivalent.

There is additional snow data gathered by the CRCA, Rideau Canal, and Eastern Ontario Power. Over the winter months, snow course data is gathered every two weeks (not necessarily coincident at the three agencies) at 15 sites across the CSPA. The average depth of snow, as well as snow water equivalent is measured at each site. This data is used to forecast conditions (streamflows and water levels) for periods of melt and runoff over the winter, or for spring freshet.

#### 2.1.2 Temperature

As was the case with the precipitation data, the temperature data from the local climate stations was compared using Kruskal-Wallis, and as with the snow data, the hypothesis of the same population is rejected. Only 15 of the 18 climate stations have temperature data. A Mann-Kendall test was also done for each of the 15 stations. Cressy, Glenburnie, Lyndhurst and Brockville showed significant trend.

The Canadian Forestry Service has also prepared mapping of temperature values across Canada. A map of Eastern Ontario is shown in Figure A2.4a and the CSPA region is shown in Figure A2.4b. The weighted average mean annual temperature for the region is 7 °C. The uncertainty of the mean annual temperature value is between 0.5 °C and 1.5 °C (McKenney et al., 2006b).

In addition, Zhang et al. (2000) found an increasing trend in mean annual temperature across southern Canada (south of 55°N) on the order of 0.9°C over 100 years. There was a statistically significant trend across the overall country, though the Ontario region itself did not show a statistically significant trend.

### 2.1.3 Evapotranspiration

There is a general lack of evapotranspiration (ET) data available for the region, so an assumption, or calculation through other parameters, must be made to estimate ET.

There are two methods used to estimate ET, accounting for the fact that it is not a direct field measurement. As noted in Section 1.3, the simplified water budget equation is:

$$P - Q - ET = 0, \text{ or } ET = P - Q$$

Reasonable data exists for both precipitation (P) and runoff (Q), and therefore a reasonable estimation of ET is  $P - Q$ . This number was used as the starting point to estimate ET. The average precipitation across the CSPA is 954 mm and the average runoff across the CSPA is 452 mm, which makes the estimated  $ET = 502$  mm. This is referred to as “derived ET”, or  $ET_{\text{derived}}$ .

The other method is to calculate ET based on corresponding climate measurements. A number of ET estimation methods were explored (Blaney-Criddle, Hargreaves, Penman-Montieth, Turc, Thornthwaite) but most of those methods require more data than is readily available in the CSPA region (See Table D.2). Both Turc and Thornthwaite are based on precipitation and temperature values, and were used here to estimate ET. This is referred to as “calculated ET”,  $ET_{\text{Turc}}$  or  $ET_{\text{Thornthwaite}}$ . These methods are older methods, Thornthwaite originating in 1957, and Turc originating in 1961. Newer methods, updated with 50 years of additional research, should be better for estimates in this case. These additional methods will be explored in the Tier 1 and future Water Budget work.

The Turc method is described in the CCL Water Budget Guidance (2001) document, as well as Singh, 1993. This method needs only annual precipitation and average annual temperature values to estimate ET. Data from the 15 EC climate stations (both temperature and precipitation records) in the CSPA were used to estimate ET. These estimated values were very close to the predicted amount available for ET (Table 2.6 and 2.9). The weighted average ET from the Turc equation,  $ET_{\text{Turc}}$ , is 552 mm.

The Turc equation is:

$$E = P / \left[ 0.9 + (P/I_T)^2 \right]^{1/2}$$

Where:

E	=	annual evaporation (mm);
P	=	mean annual precipitation (mm);
$I_T$	=	$300 + 25T + 0.53T^3$ ; and
T	=	mean air temperature (°C).

Station	Evapotranspiration Estimate (mm)
Picton	580
Napanee	558
Centreville	541
Sandhurst	579
Cressy	588
Hartington	536
Godfrey	520
Cataraqui TS	523
Kingston Airport	530
Wolfe Island	571
Glenburnie	522
Kingston Pumping Station	594
Lyndhurst Shawmere	543
Mallorytown Landing	566
Brockville PCC	563
<i>Weighted Average</i>	552

Table 2.6: Turc Method ET Estimates

The Thornthwaite-Mather (1957) method was also used to estimate ET at some of the CSPA climate stations. This method uses monthly precipitation and temperature values, location (latitude and hours of daylight), as well as an estimate of soil water holding capacity (SWHC), to calculate ET. Soil water holding capacity is defined as “The moisture content at which all pores in the soils are filled with water; also referred to as saturation and occurs after prolonged rains before the gravitational “free” water has time to drain out.” (Thornthwaite and Mather, 1955).

SWHC was estimated using Table 3.1 from the MOE Stormwater Management Planning and Design Manual (SWMPDM) (2003), which was compiled for a watershed at latitude 45°N.

	Fine Sand	Fine Sandy Loam	Silt Loam	Clay Loam	Clay
Urban Lawns/Shallow Rooted Crops	50	75	125	100	75
Moderately Rooted Crops	75	150	200	200	150
Pasture and Shrubs	100	150	250	250	200
Mature Forests	250	300	400	400	350
Thin Soils over Bedrock	25	25	25	25	25

Table 2.7: Soil Water Holding Capacity (mm)  
from MOE, 2003 with the exception of Thin Soils over Bedrock

The SWHC is estimated using soil texture (sand, clay, etc.) and land cover (lawn, forest, crops, etc.). The soil texture values were taken from the County Soil Surveys (Gillespie et al., 1963, 1966, 1968), and the Land Cover 28 map (MNR, 2003) was used for land

cover. These were combined to create a map showing estimated SWHC across the CSPA (Figure A2.5). In addition, the Surficial Geology and Overburden Thickness maps were used to identify those areas with minimal soil cover over bedrock, which were assigned a lower SWHC value of 25 mm (based on agreement among Eastern Ontario SWP Regions and expert advice) to account for the reduced soil water capacity created by the thin soils. The county soils data map was overlain with the areas of minimal soil over bedrock, as shown on the Surficial Geology mapping. Then these layers were further overlain with the areas of greater than 1 m of overburden thickness as recorded in the WWIS (MOE, 2006c). The 25 mm SWHC was then applied to only those areas identified as having minimal soil (<1 m) over bedrock.

Environment Canada has a computer program that calculates monthly and annual ET values using the Thornthwaite method for climate stations using the historical data from the station. The program also contains modifications to account for retention of water in the snow pack, which is also then made available for evaporation when the snow melts. The stations in the CSPA that were available to run an ET estimate are listed in the following Table.

Picton*	Hartington*	Glenburnie*
Napanee*	Godfrey*	Kingston Pumping Station*
Centreville	Cataraqui TS*	Lyndhurst Shawmere*
Sandhurst	Kingston Airport*	Mallorytown Landing*
Cressy*	Wolfe Island*	Brockville PCC*

Table 2.8: Climate Stations Available for ET Estimation

\* Stations used for ET estimation.

Various SWHC values were run for each station, based on the values estimated in the area of the station. The resulting ET values for each station are shown in Table 2.9, and the full data sets are provided in Appendix D. These values were also used to create Figure 2.8, the relationship between ET and SWHC.

Station	Water / PET	25 mm	100 mm	150 mm	200 mm	250 mm	300 mm	350 mm	400 mm
Picton	624	460	529						
Napanee	616			575	592	602	608		614
Cressy	623			567	589	602	611		619
Hartington	611		540	570	588	598	604		609
Godfrey	608		544	572	587	596			606
Cataraqui	609		535	568	587	597	602		607
Kingston Airport	598		530	561	578	586	591		596
Kingston Queens*	603		512	546	569	582	591		599
Wolfe Island	617				601	601			614
Glenburnie	611		545	573	591	600	605		609
Kingston Pumping Station	634		546	581	602	615	623		630
Lyndhurst Shawmere	620			587	601	610			618
Mallorytown Landing	626			592	607	616		624	625
Brockville PCC	623			588	603	611		620	621
Mean (mm)	614	460	535	573	592	601	604	622	613
Area of CSPA (ha)	58865	111656	2894	85630	28489	3200	47689	9870	2249
Area Weighted Average ET (mm)	553								

Table 2.9: Evapotranspiration Values from EC Climate Stations (Thorntwaite Method)

\* Data from the station at Queen's University (1873-1938) was added as a comparison to the more recent data. It appears very similar.

The estimated  $ET_{\text{Thornthwaite}}$  values ranged from 460 to 630. ET also varies from month to month, which will be critical for the Tier 1 work, as well as varying across the CSPA with relationship to land cover, soil type, and latitude.

There is a direct relationship between Soil Water Holding Capacity and ET (regardless of the specific station), as can be seen in Figure 2.3, this allows for general estimation of  $ET_{\text{Thornthwaite}}$  at virtually any location in the CSPA, using the estimated SWHC.

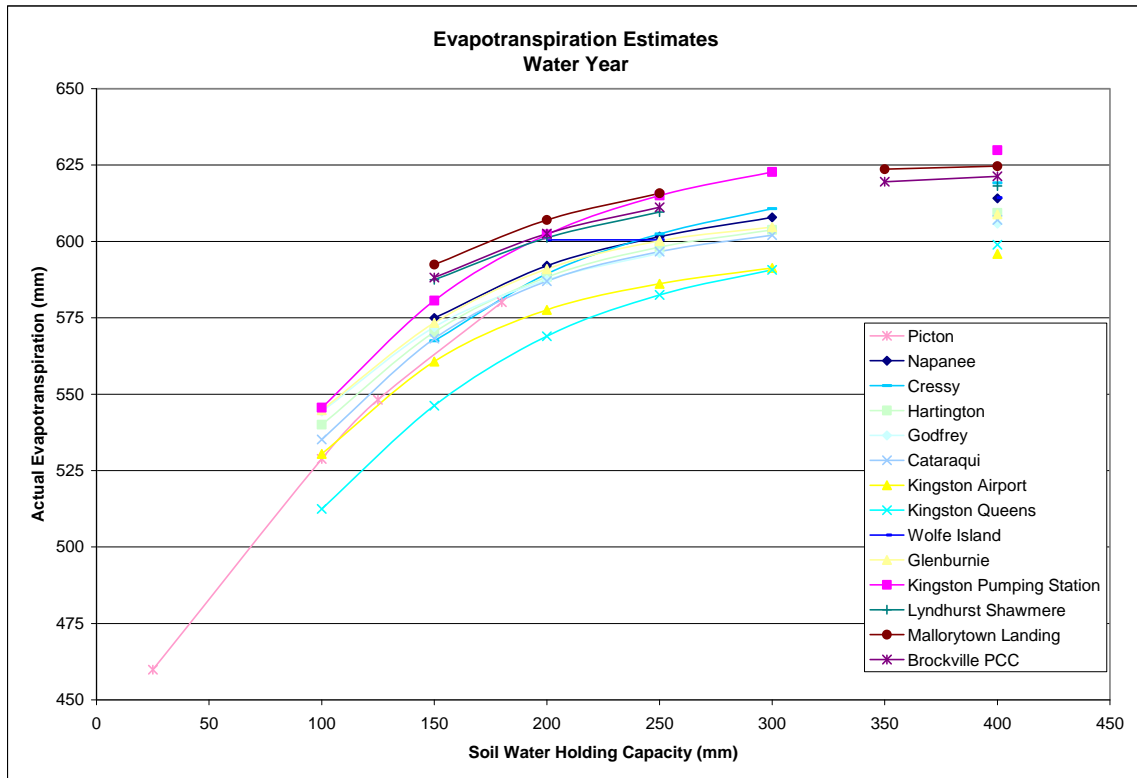


Figure 2.3: Soil Water Holding Capacity vs. Evapotranspiration

There is a large variation between the estimated ET values. With the direct relationship between ET and SWHC, the range of SWHC values at the individual stations is the largest contributor to the ET variation. It could also be because the SWHC, precipitation and runoff have all been averaged over the entire CSPA, and this has created uncertainty in the estimations. In addition, those stations closer to Lake Ontario generally have cooler temperatures over the summer due to lake breeze, which in turn keeps the ET lower. The variation in SWHC across the CSPA should be explored further in the Tier 1 report.

The Thornthwaite methodology was also used to create a CSPA wide ET map (Figure A2.6) using the precipitation and temperature mapping created by the Canadian Forestry Service, and the SWHC mapping as shown in Figure A2.5. The average ET for the CSPA from this map ( $ET_{\text{GIS w/ water}}$ ) is 553 mm. This mapping assumes that the open water surfaces and wetlands experience maximum ET, which is set to the Potential ET

parameter. In addition, ET was considered with the removal of open water surfaces ( $ET_{GIS\ w/o\ water}$ ), which was calculated at 502 mm.

In summary,  $ET_{derived} = 502\ mm$ ,  
 $ET_{GIS\ w/o\ water} = 502\ mm$   
 $ET_{GIS\ w/\ water} = 553\ mm$   
 $ET_{Turc} = 552\ mm$ , and  
 $ET_{Thornthwaite} = 553\ mm$ .

If the P and Q values are considered reasonable, then the  $ET_{derived}$  value is probably closest to the “true” value of ET. We believe this to be the case, based on the fact that the adjacent regions have very similar values for P, and there is no reason to suspect a bias in the Q values. Again, assuming this is the case, then the calculated ET values are overestimated by approximately 10%. This is supported by estimates done by Watt (2007), relating the mean annual flow of a stream in the CSPA to the Environment Canada Thornthwaite estimates of ET, where the ET estimate was seen to be too high.

In addition, if the P values are in fact underestimated by the as much as 10 % mentioned earlier, then  $ET_{derived}$  would increase, making it closer to the  $ET_{Thornthwaite}$  estimate.

The ET estimates do all compare favourably with previous ET estimation work shown in Figures 2.4a and b.



Figure 2.4a: Annual Evapotranspiration (lighter isoline) and Precipitation Map from Fisheries and Environment Canada (1978)  
 (Not to Scale)

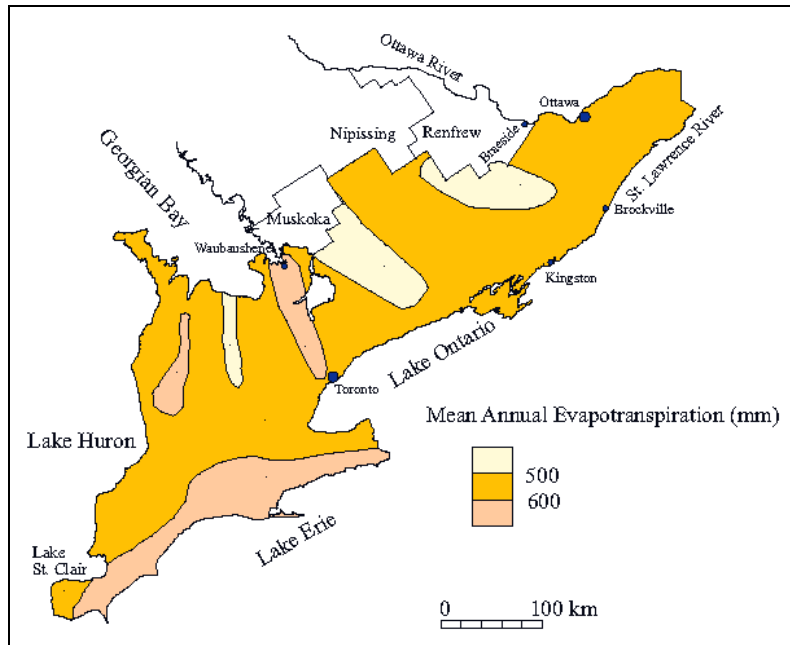


Figure 2.4b: Annual Evapotranspiration Map from MNR (1984)

### 2.1.3.1 Pan/Lake Evaporation

Evaporation is typically measured through the use of a circular pan filled with water. The water level is measured each day, which gives a direct measurement of evaporation of open water conditions. However, the conditions in the pan, and the conditions in an actual water body are different (water temperature is greater in the pan, and wind conditions vary from pan to lake), and pan evaporation is generally accepted to over-estimate actual lake evaporation. A correction factor, generally around 0.7 but it varies from lake to lake and over the course of a year (Winter, 1981), is used to convert measured pan evaporation to lake evaporation. Pan evaporation is an estimate of Potential Evapo(transpi)ration, which is calculated via the previous Thornthwaite estimates.

There is some information available from evaporation pans at climate stations. In the Eastern Ontario region, data was available for five stations, Peterborough - Trent University, Hartington, Kemptville, Morven and Ottawa.

The evaporation pans were in place between 1962 and 1998, and recorded daily evaporation. The Ottawa pan recorded from 1962 to 1998, the Morven and Hartington pans recorded data from 1968 to 1975, the Kemptville pan recorded from 1968 to 1995, and the Trent pan recorded from 1982 to 1992. Based on the limited data, an annual average evaporation value can be calculated, 786 mm, however, this value needs to be corrected to lake evaporation, and the value is approximately 592 mm. This value would only apply on areas of open water, which accounts for about 300 km<sup>2</sup> of the CSPA. That equals a volume of 1.78 x 10<sup>8</sup> m<sup>3</sup>, which, if apportioned over the entire 3568 km<sup>2</sup> of the CSPA, equals a depth of 50 mm. This is approximately 10 percent of the general estimation of evapotranspiration. More detailed data is included in Appendix D-1

The average daily lake evaporation was approximately 4 mm. However, this is misleading in that the evaporation pans were only operated during the warm season, so additional evaporation occurring between November and April is not measured, or accounted for, though it is expected to be minimal compared to the warm season months.

Station	May	Jun	Jul	Aug	Sep	Oct	Annual
Peterborough		156	180	142	85		564
Hartington	131	149	182	160	96	56	774
Morven	124	150	185	179	105	62	805
Kemptville	164	152	169	143	87	62	777
Ottawa	145	172	186	152	98	57	809
<i>Average</i>	<i>142</i>	<i>161</i>	<i>180</i>	<i>151</i>	<i>94</i>	<i>58</i>	<i>786</i>
<i>Mean Daily</i>	<i>4.6</i>	<i>5.4</i>	<i>5.8</i>	<i>4.9</i>	<i>3.1</i>	<i>1.9</i>	

Table 2.10: Pan Evaporation Data (mm)

Source: Environment Canada

Station	May	Jun	Jul	Aug	Sep	Oct	Annual
Peterborough		120	137	105	65		427
Kemptville	123	113	123	105	65	47	576
Ottawa	112	129	139	114	73	43	610
<i>Average</i>	<i>113</i>	<i>123</i>	<i>133</i>	<i>110</i>	<i>69</i>	<i>44</i>	<i>592</i>
<i>Mean Daily</i>	<i>3.6</i>	<i>4.1</i>	<i>4.3</i>	<i>3.5</i>	<i>2.3</i>	<i>1.4</i>	

Table 2.11: Lake Evaporation Data (mm)

Source: Environment Canada



Figure 2.5: Annual Lake Evaporation Map from Fisheries and Environment Canada (1978)  
(Not to Scale)

#### 2.1.4 Infiltration/Recharge

“Precipitation that falls on the land surface enters various pathways of the hydrologic cycle. Some water may be temporarily stored on the land surface as ice and snow or water in puddles, which is known as depression storage. Some of the rain or melting snow will drain across the land to a stream channel. This is termed overland flow. If the surface soil is porous, some rain or melting snow will seep into the ground by a process called infiltration.” (Fetter, 2001)

Infiltration is defined as “the entry into the soil of water made available at the ground surface, together with the associated flow away from the ground surface within the unsaturated zone” by Freeze and Cherry (1979), and “the process of water entry into a soil from rainfall, snowmelt, or irrigation” by Maidment (1993).

That water which infiltrates can then be further partitioned into recharge and runoff or streamflow. “Groundwater recharge can be defined as the entry into the saturated zone of water made available at the water-table surface, together with associated flow away from the water table within the saturated zone” (Freeze and Cherry, 1979).

“Streamflow is generated by a combination of (1) baseflow (return flow from groundwater), (2) interflow (rapid subsurface flow through pipes, macropores, and seepage zones in the soil), and (3) saturated overland flow from the surface of poorly permeable or temporarily saturated soil, or from permanently saturated zones near the channel system. Interflow and saturated overland flow together comprise quickflow, the rapid runoff during and after rainfall of “new” water.” It also goes on to state that while partitioning of baseflow and quickflow is done, isotope analysis indicates “that there is not, in practice, a clear separation between quickflow and baseflow.” Maidment, 1993.

No specific infiltration information is available for the CSPA. However, through the local Public Health Units, the percolation test results from septic system applications may be available, and could be used to estimate hydraulic conductivity across the CSPA.

In addition, recharge may be estimated using Tables 2 and 3 from MOEE (1995) (Tables 2.12, 2.13, 2.14 and 2.16 here), which relates recharge to slope, soil, and land cover factors, or similar techniques. However, this method appears to have been originally conceived as a method to ensure proper dilution of septic system effluent prior to reaching the water table, or a receiving water body. The Stormwater Management Planning and Design Manual (MOE, 2003) recommends using this method to account for lost infiltration/recharge from development sites. It is unclear whether this method is in fact acceptable for the purposes it is being used here, due to its original design, as well as the fact that the data groupings can not consistently be applied across the CSPA jurisdiction. In these cases, the factors have been modified to fit the CSPA specific conditions.

Description of Area/Development Site	Value of Infiltration Factor
<b>TOPOGRAPHY</b>	
Flat Land, average slope not exceeding 0.6 m per km	0.30
Rolling land, average slope of 2.8 m to 3.8 m per km	0.20
Hilly land, average slope of 28 m to 47 m per km	0.10
<b>SOIL</b>	
Tight impervious clay	0.1
Medium combinations of clay and loam	0.2
Open sandy loam	0.4
<b>COVER</b>	
Cultivated Land	0.1
Woodland	0.2

Table 2.12: Infiltration Factors, Table 2 from MOEE (1995)

Using the slope values as given in Table 2.12 will result in the CSPA being classified predominantly flat land, which will cause skewed estimates of the infiltration factor. However, as can be seen in Figure 2.6, the slope and infiltration factor essentially have a linear relationship, so the factors can be extrapolated to a slope range more representative of the CSPA.

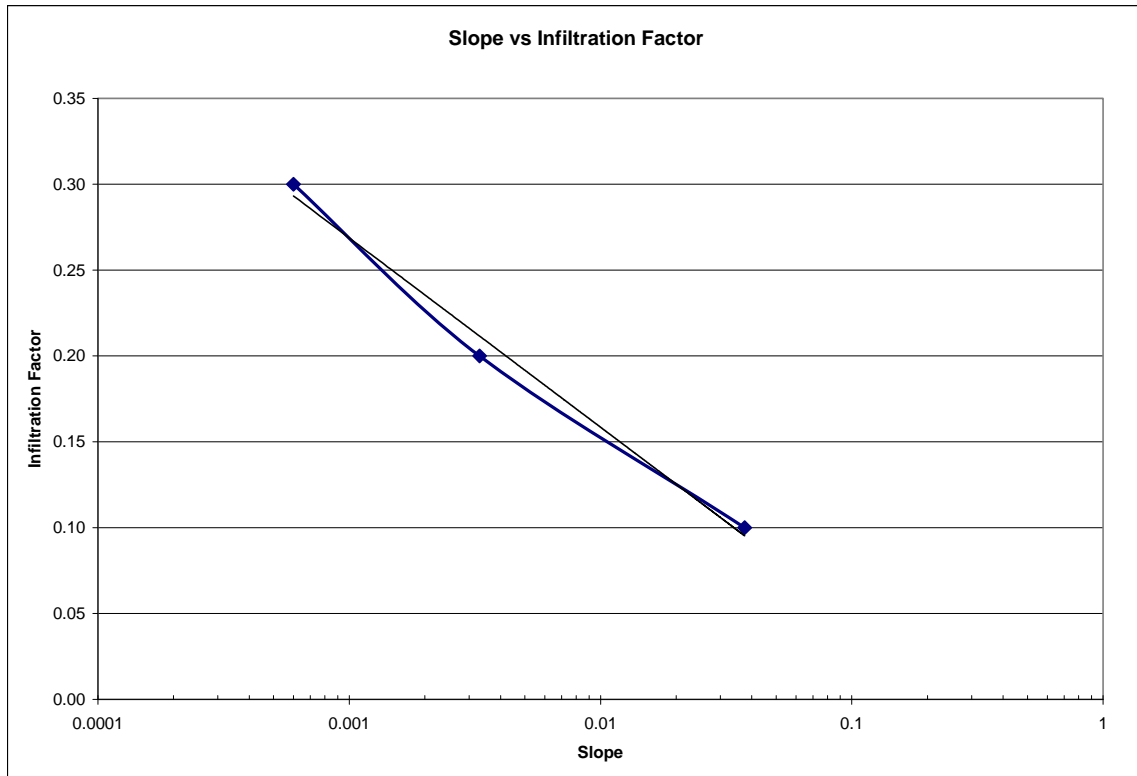


Figure 2.6: Slope vs. Infiltration Factor

As such, we redefined the slope classes as noted in Table 2.13 (similar to Quinte SWP, 2006), where the infiltration factor used is that from the midpoint of the category (Hilly

Land used from 3% to 9 %). A sensitivity analysis was completed regarding the groupings, and it was found that these 3 groups result in an overall weighted slope infiltration factor almost the same as using 5 or 7 equal groupings, or breaking down the entire 35 million individual slope values into groups. The full set of data and the sensitivity analysis is included in Appendix G.

<b>Topography</b>	<b>Infiltration Factor</b>
Flat Land, slope < 1.5%	0.170
Rolling Land, 1.5% < slope < 3%	0.120
Hilly Land, slope > 3%	0.075

Table 2.13: Slope Infiltration Factors

Table 2.12 also does not include an infiltration factor for thin soils over bedrock, which cover a large area of the CSPA. We have made an allowance for this, where the infiltration coefficients of 0.02 for Precambrian bedrock and 0.05 for Palaeozoic bedrock are added based on recharge studies in fractured rock (Milloy, 2006, Novakowski, 2006, Mississippi-Rideau SWP, 2006). The areas of thin soil over bedrock were determined the same way as for the SWHC calculations. Without this assumption, these areas are treated as having regular soils, and cause overestimates in the infiltration factors. The maps do show considerable jumps in some of these areas with thin soil over bedrock, due to the combination of mapping information used to establish the values. In reality, it is expected that changes would be much more gradual. Table 2.14 gives the modified soil factors.

<b>Soil</b>	<b>Infiltration Factor</b>
Thin soil over Precambrian bedrock	0.02
Thin soil over Palaeozoic bedrock	0.05
Tight impervious clay	0.1
Medium combinations of clay and loam	0.2
Open sandy loam	0.4

Table 2.14: Soil Infiltration Factors

Once values across the CSPA for each of the three individual infiltration factors have been determined, they are added together to create a combined infiltration factor. Figures A2.7 through A2.9 show the variation across the CSPA of slope, soil, and land cover, and Figure A2.10 shows the map adding all three factors together. The breakdown of the individual criteria across the CSPA is as follows:

Slope

- Less than 1.5% 42.3 % of CSPA
- Between 1.5% and 3% 20.7 % of CSPA
- Greater than 3% 28.2 % of CSPA
- Water 8.8 % of CSPA

Soil

- Thin soil over Precambrian 15.2 % of CSPA
- Thin soil over Palaeozoic 17.9 % of CSPA
- Tight impervious clay 20.2 % of CSPA
- Medium combinations of clay and loam 16.1 % of CSPA
- Open sandy loam 16.8 % of CSPA
- Other (water, no soil) 8.4 % of CSPA
- Wetlands/Organics 5.3 % of CSPA

Land Cover

- Cultivated Land 43.3 % of CSPA
- Woodland 45.9 % of CSPA
- Other (water, no soil) 10.7 % of CSPA

The average infiltration coefficient for the CSPA is 0.38, with the median value being 0.37. This is not much less from the values calculated previously without considering the thin soil over bedrock (mean of 0.44, median of 0.42). It would appear that this limited change is a function of the method itself, in that it equally weights each of the three infiltration factors, and also the fact that they are added together. Even when one of the factors would indicate limited infiltration, the other two could indicate greater infiltration, resulting in an overall larger infiltration value than expected, or than what occurs in reality. For instance, greater than 40% of the CSPA is classified as “flat”, and receives an infiltration factor of 0.17. Greater than 45% of the CSPA is classified as “woodland” and receives an infiltration factor of 0.2. Where these areas coincide (and given the large proportion of both, it is assumed to be quite common), the infiltration factor for soil could be zero, and the combined infiltration factor would still be the average across the CSPA. This is the major concern with using this method to estimate infiltration.

The infiltration factor is then used to divide the amount of “surplus water” (that which is left after ET) into recharge to groundwater and runoff to surface water bodies.

With an average annual precipitation value of 953 mm, and an ET<sub>GIS</sub> value of 549 mm, 404 mm of “surplus water” are left as a residual. In this case, the amount of precipitation that infiltrates to groundwater will be 154 mm (38 % of available water). The remainder of the surplus water (251 mm) can then be accredited to direct runoff.

ET Method	Surplus Water (mm)	Recharge (mm)	Runoff (mm)
ET <sub>derived</sub>	452	172	280
ET <sub>Turc</sub>	401	152	249
ET <sub>Thornthwaite</sub>	400	152	248
ET <sub>GIS</sub>	404	154	251

Table 2.15: Recharge and Runoff Estimates

However, only one of these methods accounts for the full 452 mm measured at the stream gauge stations (the one based on that number to begin with, ET<sub>derived</sub>). This could mean the ET estimate is too high, that there are errors in the measured data (possible via

uncertainty of measurements and gauges) or that there is groundwater discharge to the streams coming from outside the CSPA (assuming the water table levels are steady) or that groundwater withdrawals are depleting the groundwater storage, resulting in declining water table levels. It has been shown (Watt, 2007), that the Environment Canada Thornthwaite calculations for at least one stream in the CSPA overestimate annual ET by a value approaching the differences seen here between the derived ET and calculated ET.

Similar to what was mentioned in Section 2.1.3 with regards to P and ET, if the P value has been underestimated, then the recharge and runoff estimates above will also increase, again coming closer to the derived estimates.

<b>Soil Texture</b>	<b>Groundwater Recharge Rate (mm/yr)</b>
Coarse sand and gravel	250+
Fine to medium sand	200-250
Silty sand to sandy silt	150-200
Silt	125-150
Clayey silt	100-125
Clay	Less than 100

Table 2.16: Typical Groundwater Recharge Rates, Table 3 from MOEE (1995)

Using Table 2.16 and the land cover estimates above, a rough area-weighted estimate of recharge can also be calculated as follows:

Depth of Recharge (mm) =  
 (Percentage of Thin Soil over Precambrian Rock in the Total Area \* 20 mm +  
 Percentage of Thin Soil over Palaeozoic Rock in the Total Area \* 50 mm +  
 Percentage of Clay in the Total Area \* 100 mm +  
 Percentage of Silt/Sand in the Total Area \* 150 mm +  
 Percentage of Sand/Gravel in the Total Area \* 250 mm)  
 divided by the Percentage of Soil in the Total Area

Depth of Recharge (mm) =  
 (0.152\*20 + 0.179\*50 + 0.202\*100 + 0.161\*150 + 0.168\*250)/0.862  
 = (3 mm + 9 mm + 20 mm + 24 mm + 42 mm)/0.862  
 = 114 mm

This value is considerably lower than the value calculated using the infiltration factor method, and accounts for about 20% of “surplus water”.

The MOEE (1995) approach to recharge requires the assumption that the immediate subsurface layer, which receives the infiltrated water, is directly linked to the aquifer. This assumption may be true for a small field suitable for a septic tank and tile bed (which is the application for which the method was created to be used) or for small

watersheds with a metre of clay over fractured limestone (and not tile-drained), but it is certainly not generally the case for all watersheds in eastern Ontario. Making efforts to better understand the recharge in the CSPA will be an important part of Tier 1 work.

The average BFI (Neff at al., 2005a) for the CSPA streams is around 0.40. The mean annual runoff for the area is calculated at 452 mm, so the expected groundwater contribution would be 181 mm. This value appears reasonable when compared to the MOEE(1995) method.

Neff at al. (2005b) also looked at groundwater discharge in the Great Lakes basin, and estimated values for the CSPA tertiary watersheds. They used BFI and surficial geology to estimate groundwater recharge. This analysis does not account for regulation in the watersheds, assumes all BFI contribution was groundwater discharge, and used the PART method to calculate BFI, which generally results in a larger BFI value in Eastern Ontario watersheds. They estimated an annual recharge of 270 mm. This is much greater than their earlier report, and seems much too high for the CSPA.

BFI is discussed in more detail in Section 2.2.1.

However, research in the Tay River watershed has found that a very small percentage (as little as 2%) of precipitation recharges to groundwater in the 5 hectare field site (Milloy, 2006, Novakowski, 2006). In addition, the surface water and groundwater systems appear to be almost entirely unconnected at that location (Praamsma, 2006). This may or may not be the same case as in the CSPA, but the soil and bedrock conditions are similar between the two areas. Groundwater recharge specifically is discussed further in Section 2.4.4.

## 2.2 Stream Gauges

There are eight active stream gauge stations in the CSPA (Figure A2.11) operated by Water Survey of Canada (WSC), with one historic station now operated by Parks Canada-Rideau Canal. The period of record is variable, but is still helpful in estimating annual flows, and in the future relating rain events and calibrating the model.

The Environment Canada Hydrometric Data (HYDAT) database is used for all streamflow calculations. The HYDAT database does not include full-year data sets for the stations at Buells Creek, Chaffey's Lock, or Little Cataraqui Creek. However, the local organization maintaining the station may have additional data to fill the gaps.

<b>Station</b>	<b>HYDAT Period of Record</b>
Buells Creek	1989 to 2003, partial year
Cataraqui River at Chaffey's Lock*	1978 to 1997, partial year 1984 to 1997
Collins Creek	1969 to 2003
Little Cataraqui Creek, West Branch	1989 to 2000, reactivated in 2003, partial year
Lyn Creek	1970 to 1998, CRCA run to 2004, reactivated 2005
Lyndhurst Creek	1971-1978, reconstructed 2006
Millhaven Creek at County Road 4	1968 to 2003
Wilton Creek	1965 to 2003
Millhaven Creek at Sydenham	Constructed late 2005

Table 2.17: CSPA Stream Gauge Periods of Record

(\* Operated by Parks Canada)

The Hydrologic Atlas of Canada (1978) and Moin and Shaw (1985), both prepared Mean Annual Runoff maps. They are presented in Figure 2.7a and b. Table 2.18 shows the mean annual flow ( $m^3/s$ ), drainage area, and mean annual runoff (mm) for each of the stream gauge stations. All flows are calculated based on water year (October 1 to September 30). This allows comparisons that include a full snow season, rather than having snow that falls in December being counted towards flow in that calendar year, when it actually stays frozen on the ground, and contributes to the next calendar year's flows. This aspect will be critical for the Tier 1 work.

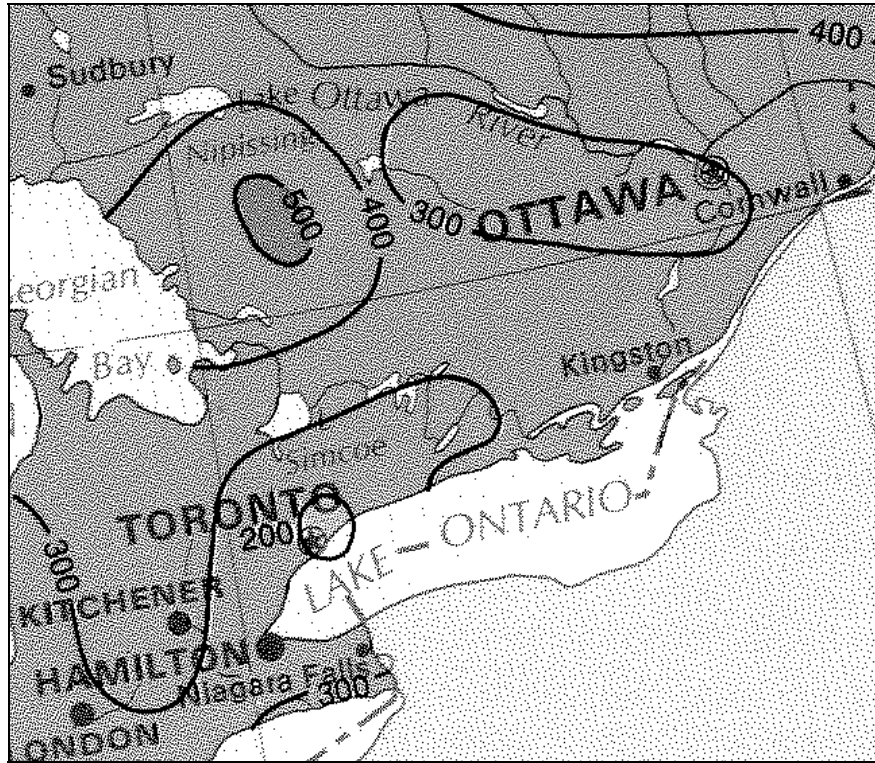


Figure 2.7a: Mean Annual Flow from Fisheries and Environment Canada (1978)  
(Not to Scale)

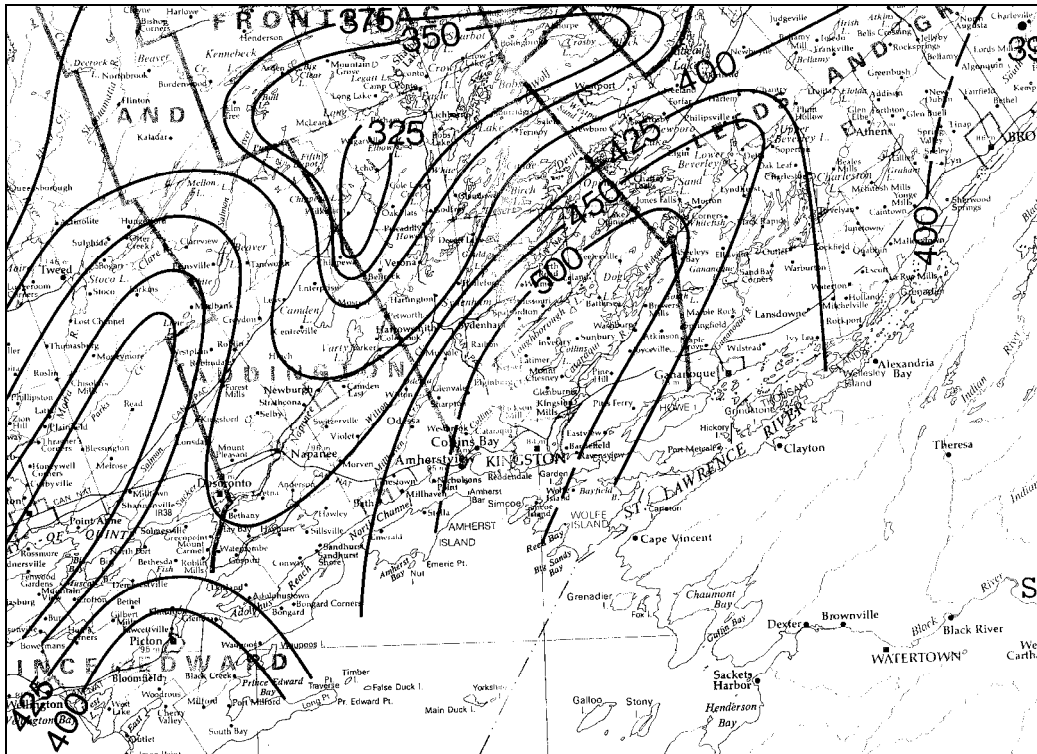


Figure 2.7b: Mean Annual Flow from Moin & Shaw (1985)  
(Not to Scale)

Station	Record Length (years)	Mean Annual Flow (m <sup>3</sup> /s)	Drainage Area (km <sup>2</sup> )	Mean Annual Runoff (mm)
Buells Creek* †	14	0.52	52	316
Cataraqui River at Chaffey's Lock*	6	5.24	399	415
Collins Creek	34	2.53	160	499
Little Cataraqui Creek, West Branch †	11	0.13	7.2	570
Lyn Creek	28	1.44	106	460
Lyndhurst Creek*	7	4.19	271	488
Millhaven Creek at County Road 4*	35	1.98	143	437
Wilton Creek	38	1.46	106	436
Mississippi River at Appleton*	85	31.3	2900	340
Moira River at Foxboro*	88	30.4	2620	366
South Nation River at Plantangenet*	73	43.0	3810	356

Table 2.18: Stream Gauge Mean Annual Flow

(\* Regulated, † Urbanizing Watershed)

The weighted average mean annual flow for the CSPA based on the values from Table 2.18 is 452 mm (458 mm without the two urban streams, 451 mm with only stations of greater than 10 yrs of record). The CSPA area is approximately 3568 km<sup>2</sup>, which converts to a volume of 1.61 x 10<sup>9</sup> m<sup>3</sup> of water. This is much higher than the large rivers in the surrounding area. However, in larger basins, the soil, slope and land cover conditions are more varied, and have an averaging effect on the runoff at the bottom of the watershed. The smaller watersheds of the CSPA have less varied conditions, resulting in runoff based on specific field conditions, which in the case of the CSPA is higher than surrounding larger watersheds.

The two urban streams (Buells and Little Cataraqui Creeks) have many storm sewer outfalls along them, presumably resulting in additional groundwater being channeled to the creeks (through inflow to the pipes from the surrounding ground, as well as sump pumps emptying into the network). In addition, with a high percentage of impervious surfaces, more precipitation is expected to be converted directly to runoff into the creek rather than infiltration into the ground.

In addition, the flow records for Buells and Little Cataraqui Creeks were not entirely based on HYDAT data. The archived stage data from the gauges was used (with the WSC created stage-discharge curve) to fill in the gaps in most years (6 months of almost every year). It is noted that those periods that have overlap between HYDAT and CRCA stage data do not necessarily agree. The CRCA data is not corrected to take into account ice cover, weed growth, or other field-noted issues which may be encompassed in the HYDAT data correction methods. This means that the flow data for these streams could be incorrect, though it appears that when compared directly, the corrected HYDAT flows and the calculated flows from the stage-discharge curve are within the accepted 5% uncertainty of the measurements. These two watersheds have also been experiencing

continued urbanization over the entire period of record of the stream gauge station, making year to year comparisons very difficult, as the upstream conditions are in a constant state of change.

Buells Creek, Cataraqui River, Lyndhurst Creek and Millhaven Creek are regulated water courses. None of these watersheds retain storage from one year to another, so the mean annual flow values should be comparable across the CSPA. However, water budget work on a temporal scale smaller than the annual scale will need to consider the storage aspects of the watersheds.

The mean annual flow values do compare well with the Moin & Shaw (1985) mapping. They are significantly higher than the Fisheries and Environment Canada (1978) values, but there was very little (if any) data used from these stream gauge stations for this map, as it was compiled from data originating in the late 1960s and early 1970s.

One thing that may cause discrepancies with different analyses of the data is the drainage area. Table 2.19 shows the difference between the HYDAT drainage area, and the drainage area as calculated via the MNR 2005 Digital Elevation Model (DEM). The original HYDAT drainage areas were estimated using hard copy topographic mapping (Arsenault, 2006). In two cases in the CSPA (Buells and Little Cataraqui Creeks) the discrepancies have been found to be quite large. In many cases, the land near the watershed divides is very flat, and the detail of the mapping contours was not fine enough to accurately delineate the watersheds. The MNR DEM is accepted to be better than topographic maps, but it is also not expected to be perfect, as the elevation contours are only 10 m contours, with 1 m interpolations. Of course more detailed elevation contour mapping will provide better watershed delineation, but the best delineation method would be through ground truthing of the areas in question.

Station	HYDAT Area (km <sup>2</sup> )	MNR DEM Area (km <sup>2</sup> )	Percent Difference
Buells Creek	13.1	52	297%
Cataraqui River at Chaffey's Lock	394	399	1.2%
Collins Creek	155	160	3.0%
Little Cataraqui Creek, West Branch	4.98	7.2	45%
Lyn Creek	111	106	4.4%
Lyndhurst Creek	271	271	0.1%
Millhaven Creek at County Road 4	150	143	4.8%
Wilton Creek	112	106	5.4%

Table 2.19: Stream Gauge Drainage Areas

Zhang et al. (2001) have also noted a trend in Canadian streamflow over the past 50 years. Mean annual flows are decreasing, though not at a statistically significant level in southern Ontario. Mean monthly flows are also decreasing, with the exception of March and April, which are increasing. These trends appear to be coincident with increasing temperatures and precipitation, which in turn results in increased evapotranspiration. Using the Mann-Kendall test (which has a possible bias according to Zhang et al. (2001)

in this case) only Little Cataraqui Creek and Millhaven Creek show a significant trend. However, the Little Cataraqui Creek basin has undergone continuous urbanization over its period of record and the period of record itself is short (only 11 years), making an accurate identification of a significant trend highly unlikely. The full test data is shown in Appendix E.

Figure 2.8 shows the mean annual flow record of each of the gauged streams in the CSPA, as well as the annual precipitation each year. It can be seen that years of high annual flow are not necessarily related to years of higher annual precipitation, though the stream flow hydrographs do generally follow precipitation.

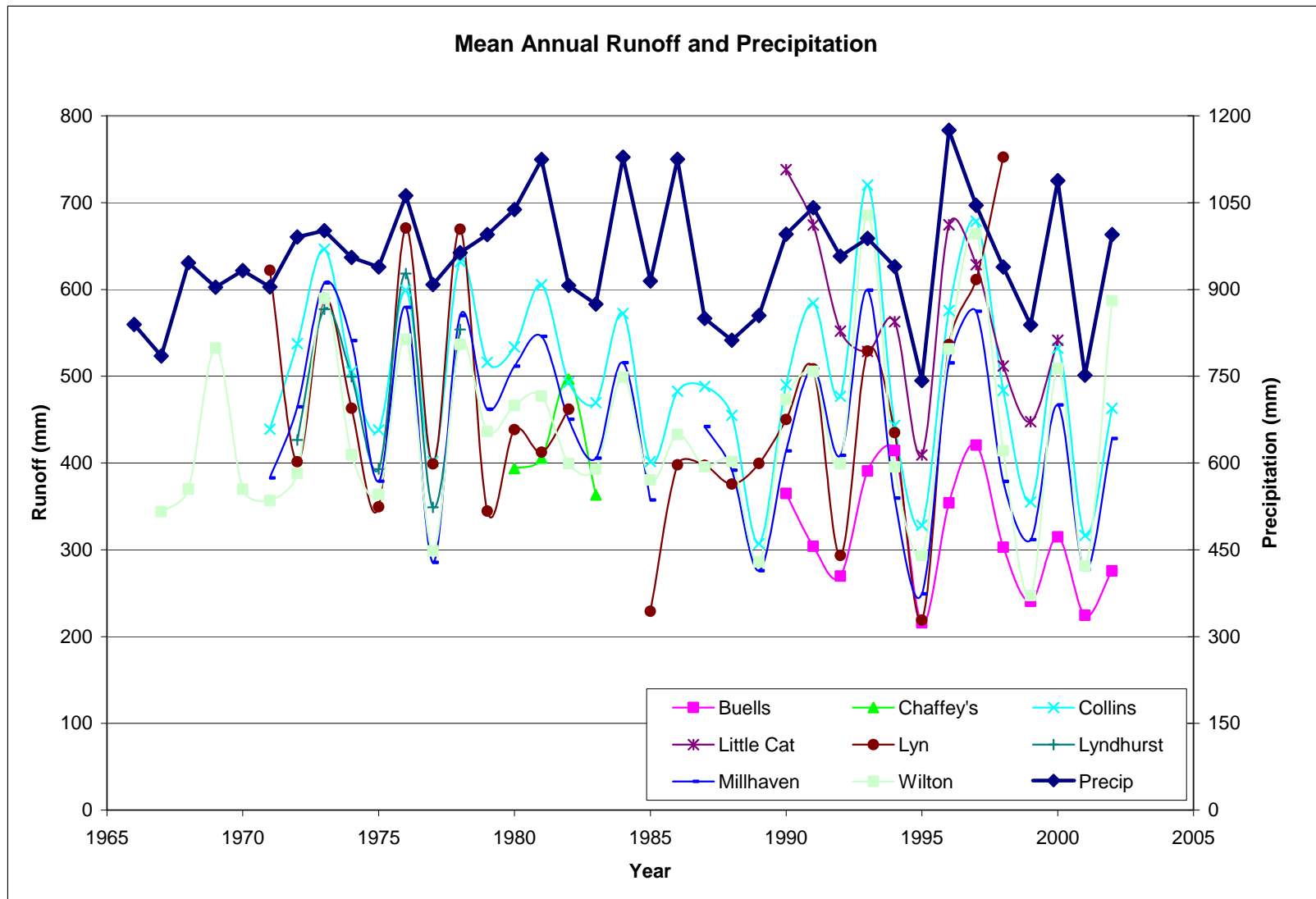


Figure 2.8: Mean Annual Runoff and Precipitation

Further figures are included in Appendix E, including individual figures of mean annual flow history for each station, average monthly flows for each station.

When considering water demand, the time of the lowest flow, and therefore least volume available for withdrawal, is important. Low streamflow typically occurs during the late summer or early fall in the CSPA. Table 2.20 gives the average month of low flow occurrence for each of the CSPA stream gauge stations, as well as the three longest running sites in Eastern Ontario. The annual low flows, and specific dates of occurrence, are included in Appendix E. Figure 2.9 shows the percentage of mean annual flow occurring in each month and shows the summer months as generally having the lowest flows. In some cases, the streams experience zero flow on a frequent basis, meaning they easily dry up, providing no water at all during times of stress.

<b>Stream</b>	<b>Low Flow Month</b>
Buells Creek	September
Collins Creek	August
Little Cataraqui Creek, West Branch	September
Lyn Creek	August
Lyndhurst Creek	September
Millhaven Creek at County Road 4	September
Wilton Creek	August
Mississippi River at Appleton	September
Moira River at Foxboro	August, September
South Nation River at Plantangenet	July, August, September

Table 2.20: Stream Low Flow Months

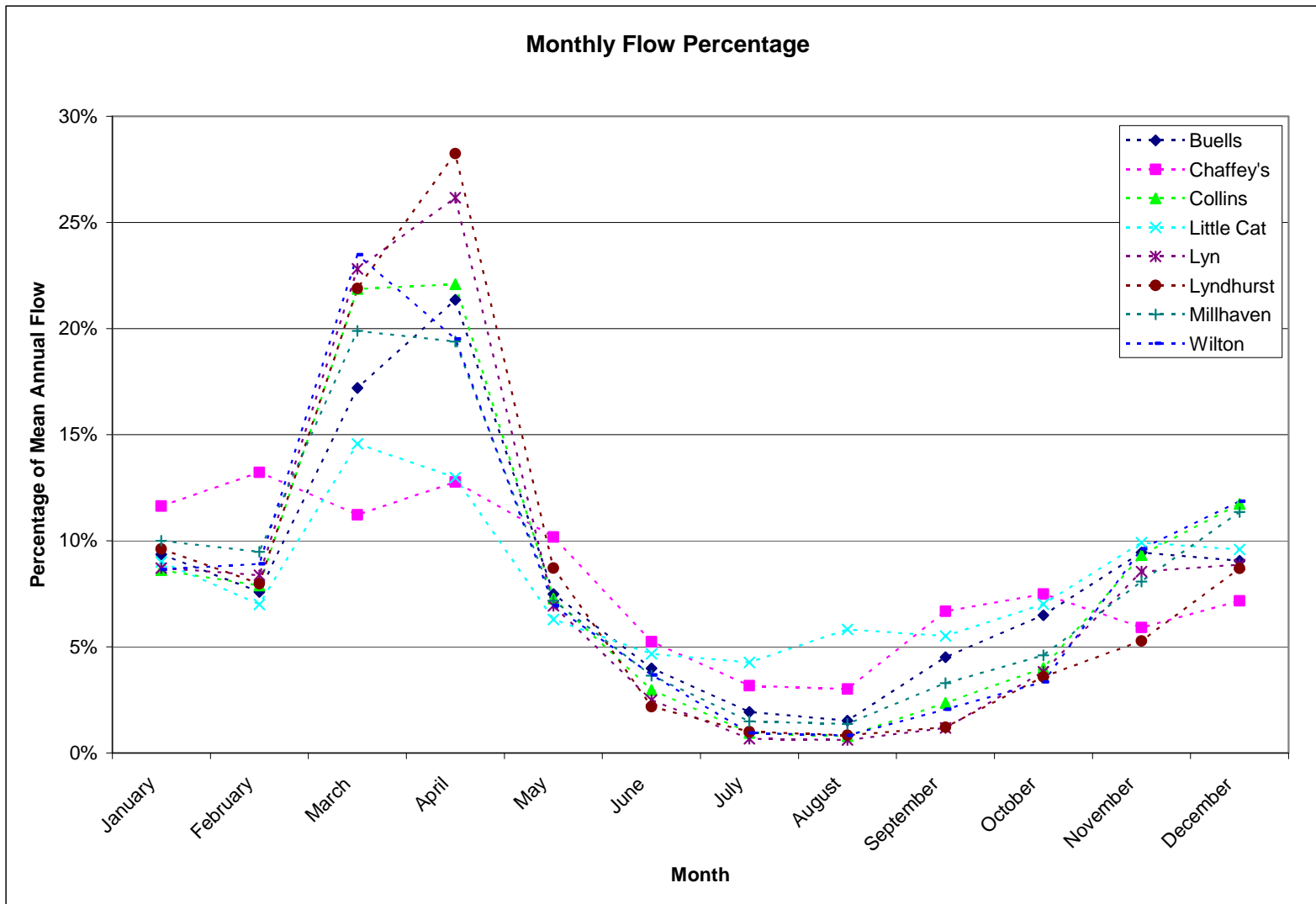


Figure 2.9: Monthly Percentage of Mean Annual Flow

2.2.1 Base Flow

Baseflow is typically estimated via a parameter called BFI (Base Flow Index), and is a dimensionless number. A stream with an annual BFI of 0.50 means that 50% of the annual flow is “baseflow”.

Baseflow consists of both direct runoff and groundwater discharge, and is not necessarily a measure of groundwater contribution to a stream. However, the term is generally defined as only a groundwater contribution. Fetter (2001) states that the “groundwater contribution to a stream is termed baseflow, while the total flow in a stream is runoff.” Maidment (1993) states: “Streamflow is generated by a combination of (1) baseflow (return flow from groundwater),(2) interflow (rapid subsurface flow through pipes, macropores, and seepage zones in the soil), and (3) saturated overland flow from the surface of poorly permeable or temporarily saturated soil, or from permanently saturated zones near the channel system. Interflow and saturated overland flow together comprise quickflow, the rapid runoff during and after rainfall of “new” water.”

Maidment (1993) also goes on to state, however, that while partitioning of baseflow and quickflow is done, isotope analysis indicates “that there is not, in practice, a clear separation between quickflow and baseflow.”

For the terms of this work, it is understood that the flow in CSPA watercourses is rarely, if ever, just due to groundwater discharge, and therefore the BFI term can not be deemed just a measure of groundwater contribution. In fact, in a detailed study of groundwater/surface water interactions of a fractured bedrock environment in the Niagara Peninsula, almost no groundwater discharge was seen to the stream (Oxtobee and Novakowski, 2002). This has also been seen in the Tay River watershed, just north of the CSPA (Praamsma, 2006). Groundwater-surface water interaction is discussed further in Section 2.4.5.

Work was done in 2005 jointly by the United States Geological Survey (USGS) and the National Water Research Institute (NWRI) to estimate base flow of all streams with stream gauging stations that drain to the Great Lakes (Neff et al., 2005). However, this study used six different baseflow estimation (hydrograph separation) techniques, which resulted in six different values for each stream. They estimated daily, monthly, and annual baseflow for the period of record of the stream gauges to 2000.

Stream	Annual BFI					
	HySep1	HySep2	HySep3	Part	BFlow	UKIH
Collins Creek	0.71	0.71	0.58	0.75	0.40	0.48
Lyn Creek	0.66	0.66	0.56	0.72	0.35	0.40
Millhaven Creek at County Road 4*	0.81	0.81	0.69	0.86	0.47	0.58
Wilton Creek	0.64	0.64	0.50	0.66	0.32	0.38

Table 2.21: USGS/NWRI BFI for CSPA Streams

(\*Regulated)

As such, these estimates were done for each of the stream gauge stations in the CRCA jurisdiction. As well, Moin & Shaw (1985) had created an Ontario map of BFI isolines. As can be seen in Table 2.21, the USGS/NWRI estimates for BFlow and UKIH are similar to the Moin & Shaw numbers, but the other techniques are much higher.

The report does not go into detail about the various separation techniques. However, to summarize:

- HySep is a hydrograph separation computer program based on the work of Pettyjohn and Henning (1979) and will calculate three separate methods, fixed interval, sliding interval, or local minimum.
- The PART method (streamflow PARTitioning) is based on the method detailed by Rutledge (1998).
- The BFlow method is also a computer program, created by Arnold and Allen (1999) based on the Rorabaugh hydrograph recession curve displacement method.
- The UKIH method would appear to be the baseflow estimation method developed by Gustard et al. (1992) at the United Kingdom Institute of Hydrology, though the report makes reference to modifications made by Piggott et al. (2005).

It is not clear whether any of these methods have limitations based on stream size, regulation, or geology, and therefore whether they are appropriate for the CSPA.

Caution should be taken when trying to interpolate or extrapolate baseflow values, as depending on the location on the stream, control structures, and physical parameters such as groundwater discharge and vegetation, there should be no comparisons at all.

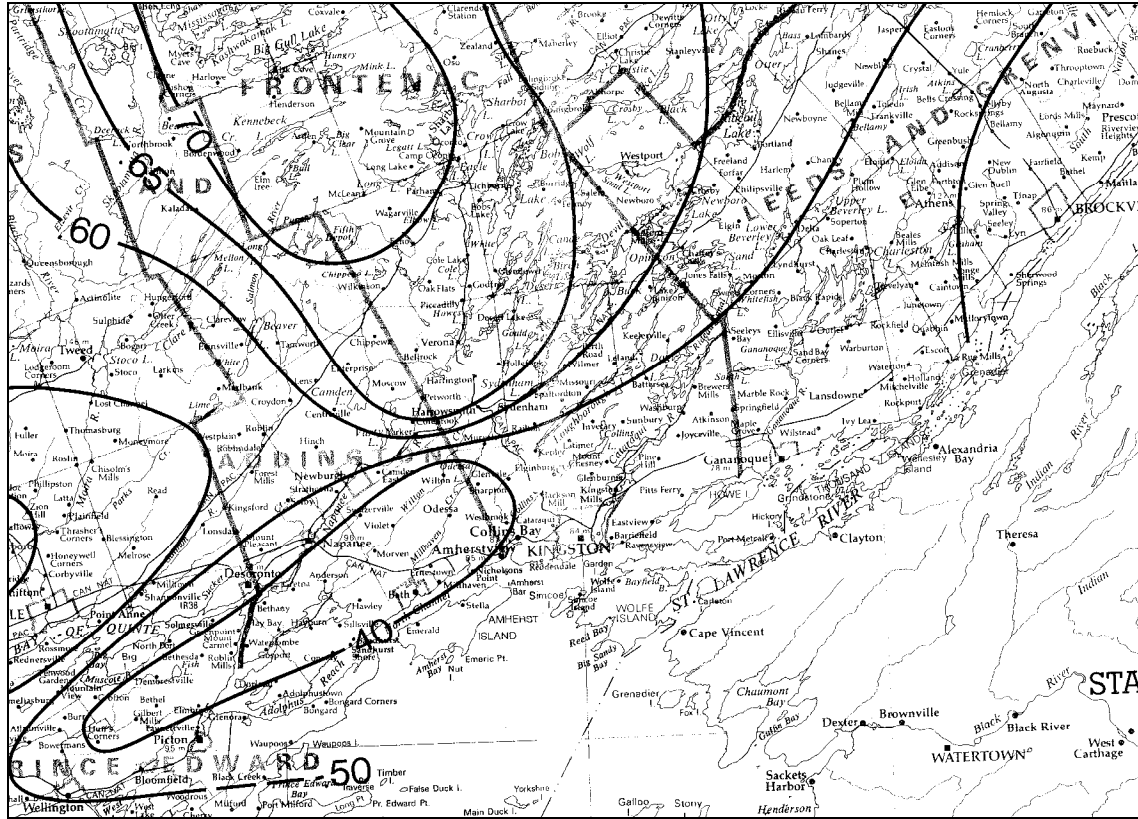


Figure 2.10: BFI Map from Moin & Shaw (1985)  
(Not to Scale)

### 2.3 Structure Water Levels

There are seven different agencies and organizations which own and operate major water control structures in the CSPA region, as well as keep records of those water levels. There have also been various other water control structures along the watercourses of the CSPA, dating back to the 1700's. Many of these have been removed or demolished, though there are still remnants in some places, and others have been rebuilt, and are included in this listing below.

The CRCA operates ten water control structures (one for the City of Kingston, and two for the City of Brockville), Loyalist Township operates two, the City of Kingston operates four, MNR-Kemptville operates three, the Rideau Canal operates six, and Fortis Ontario (formerly the Gananoque Light and Power company) operates twelve. The following list details each of the structures, which are shown in Figure A2.12.

Millhaven Creek has 4 water control structures.

- Sydenham Lake Dam (CRCA)
- Wilton Road Dam (CRCA)
- Potters Dam (Loyalist Township)
- Babcock Mill Dam (Loyalist Township)

Highgate Creek has two structures, with an additional one being constructed in 2006/07.

- Cataraqi West Subdivision Stormwater Retention Pond (City of Kingston)
- Zanette Stormwater Pond (City of Kingston)
- Highgate Creek Channelization (CRCA/City of Kingston)

Little Cataraqi Creek has one structure on the Main Branch, and two structures on the West Branch.

- Little Cataraqi Creek Dam (CRCA)
- Stormwater Pond B1S (City of Kingston)
- Lion's Civic Park Stormwater Pond (City of Kingston)

The Cataraqi River has twenty structures.

- Canoe Lake Dam (Fortis Ontario)
- Kingsford Lake Dam (Fortis Ontario)
- Bedford Mills (Fortis Ontario)
- Buck Lake Dam (Fortis Ontario)
- Newboro Locks (Rideau Canal)
- Newboro (Fortis Ontario)
- Chaffey's Locks (Rideau Canal)
- Chaffey's (Fortis Ontario)
- Davis Locks (Rideau Canal)
- Jones Falls Dam (Rideau Canal)
- Jones Falls Locks (Rideau Canal)
- Jones Falls Generation (Fortis Ontario)
- Morton Spill (Fortis Ontario)

- Loughborough Lake Dam (Fortis Ontario)
- Hart Lake Dam (Fortis Ontario)
- Upper Brewers Mills Locks (Rideau Canal)
- Upper Brewers Generation (Fortis Ontario)
- Lower Brewers Mills Locks (Rideau Canal)
- Kingston Mills Generation (Fortis Ontario)
- Kingston Mills Locks (Rideau Canal)

The Gananoque River has eight structures.

- Upper Beverly Lake Dam (MNR)
- Lyndhurst Dam (MNR)
- Temperance Lake Dam (CRCA)
- Marsh Bridge Dam (CRCA)
- Graham Lake Dam (MNR)
- Outlet Dam (Fortis Ontario)
- Marble Rock Dam (Fortis Ontario)
- Gananoque Dam (Fortis Ontario)

Lyn Creek has one structure at Lees Pond.

- Fred Grant Dam (CRCA)

Buells Creek has three structures.

- Broome-Runciman Dam (CRCA)
- Buells Creek Detention Basin (CRCA/City of Brockville)
- Booth Falls Channelization (CRCA/City of Brockville)

In general the dams are operated in the same fashion. Levels are lowered in the fall to provide a stable winter ice level, as well as storage volume for the spring freshet (to minimize potential for flooding). The levels typically peak in spring, during freshet, and stabilize in late spring. As flows start to decline, the discharge is reduced to maintain water levels at a stable level over the course of the summer. Then in the fall, the levels are lowered again for the winter.

The lakes that provide feeder volumes for the operation of the Rideau Canal and Fortis Ontario power generation deviate slightly from these operations in that once they hit their peak water level in the spring, they do not necessarily stabilize over the summer, but rather decline consistently over the summer to provide augmented flows to the Canal and power company.

These historical water levels, when combined with structure measurements and log settings, can help identify flow rates at their specific locations, which can then be related to precipitation values, to validate and calibrate the models.

Some of this data is already held by the CRCA, though more remains to be gathered for the Tier 1 Water Budget work.

## 2.4 Hydrogeology

Very little groundwater data has been gathered to date in the CSPA. It is anticipated that in addition to the existing Provincial Groundwater Monitoring Network (PGMN), hydrogeological reports prepared for subdivision development, landfill monitoring, and other development projects may provide a reasonable basis for estimating the groundwater parameter values for the water budget. These reports may be available from municipalities, or from the MOE. In addition, there was a groundwater monitoring program run by the MOE in the 1970s and 80s (including as many as 30 wells), however, the data is unavailable to the CRCA at this time.

Groundwater that originates in the CSPA may be migrating to neighbouring source protection areas, given the topography and geology of the CSPA. The Frontenac Axis acts as a topographic high and is flanked by more permeable Palaeozoic layers that slope gently towards the east and west. Groundwater flux to neighbouring source protection areas will be investigated further in the Tier 1 Water Budget work.

### 2.4.1 Fractured Bedrock

Much of the CSPA is characterized by shallow overburden over fractured bedrock. Bedrock geology influences the water quantity of the groundwater that flows through it. In the CSPA, the bedrock aquifers predominantly consist of Precambrian metamorphic and igneous rocks, and Palaeozoic limestones, dolostones, sandstones, and shales.

Groundwater flow through fractured rock occurs predominantly through single fractures in local and regional scales (e.g. Berkowitz, 2002; Tsang and Neretnieks, 1998). Field scale studies in fractured rock hydrogeology are ubiquitous (Oxtobee and Novakowski, 2002, Zanini et al., 2000, Yager and Kappel, 1998, Rosenberry and Winter, 1993); however the behavior of groundwater flow through fractured rock on regional scale is not well documented (Gleeson, 2007). Field-scale studies do show, however, that bedrock fractures are difficult to identify and that flow through individual fractures is fast (Milloy, 2006; Praamsma, 2006, Zanini et al., 2000). Therefore, bedrock aquifers are inherently vulnerable to contamination and provide challenges with regard to quantifying groundwater recharge parameters in water budget exercises.

The Precambrian and Palaeozoic bedrock will have different effects on the groundwater quantity in the CSPA. As mentioned above, groundwater will flow primarily through fractures whether in Precambrian or Palaeozoic bedrock. Precambrian igneous and metamorphic rocks are particularly impermeable to water, save for flow through fractures. Palaeozoic limestones and sandstones are more permeable, however fractures are still the dominant form of water (and contaminant) transport.

Precambrian rocks become less fractured and more mineralized with increasing depth, which makes it difficult to procure sufficient water quality and quantity at great depths. The Palaeozoic sandstones of the Nepean Formation produce very high quality groundwater, where the limestones and dolostones of the March, Shadow Lake, Gull River, Bobcaygeon, and Verulam Formations are generally good but can have sulphide

pockets in the interbedded shale layers that give water a “rotten egg” smell. Generally, groundwater in CSPA is “hard” from calcium and magnesium minerals leaching from the bedrock to the water.

In the CSPA, very little overburden overlies the bedrock aquifers. Less permeable overburden, such as silt, clay or till, can provide a barrier and offer protection to a fractured bedrock aquifer. A vertical bedrock fracture that is exposed at surface or covered by very permeable overburden, such as sand or gravel, produces a preferential pathway for groundwater and likewise, contamination.

2.4.2 PGMN Wells

There are currently seven wells in the CSPA as part of the current PGMN. The water level data generally spans the period 2002 to 2006, with up-to-date information expected as the project progresses. Following is a geologic borehole description of each well. All wells were cased to at least 6m below ground surface (bgs) except Well GA222, for which there was no available well record and therefore, the casing depth is unknown. The location of the wells is shown in Figure A2.13.

GA 278

Well GA 278 is located near the Cooligan Marsh, which is a significant headwater area that may have a large impact of water levels and water quality. David (1985) notes that the lithology and folds in the underlying Precambrian rock influence the piezometric levels in the area. Surface flow in this area drains towards the Gananoque River.

GA 278 was drilled on January 30, 2003 by Air Rock Drilling Limited. The well was advanced to 28.37 mbgs. Water bearing areas were found at 15.24 mbgs, 22.86 mbgs, and 26.21 mbgs and the recommended pumping rate was 114 L/min (30 gpm). The lithology was recorded as follows:

<b>Lithology</b> (recorded by Golder & Assoc.)	<b>Depth</b> (mbgs)
Topsoil	0-0.15
White-grey Limestone	0.15-3.05
White-grey, sandy Limestone	3.05-6.10
Grey, sandy Limestone/Dolostone	6.10-9.15
Grey Quartz Sandstone, with some limestone/dolostone	9.15-28.37 End of Hole (EOH)

Table 2.22a: Well GA 278 Lithology and Depth

GA 383

Well GA 383 is located near the Town of Greater Napanee and represents the location where depth to bedrock is greatest. The overburden lithologies are low producing, fine-textured, glaciolacustrine units and the well was cased into the Palaeozoic limestone bedrock of the Verulam Formation.

GA 383 was drilled on September 23, 2003 by Chalk Well Drilling Limited. The well was advanced to 17.98 mbgs. A water bearing area was found at 16.15 mbgs and the

recommended pumping rate was greater than 114 L/min (30 gpm). The well was cased with 16.61 m of pipe, including stickup. The lithology was recorded as follows:

<b>Lithology</b> (recorded by driller)	<b>Depth</b> (mbgs)
Brown Clay	0-6.71
Grey Clay and Sand	6.71-9.14
Grey Sand and Clay	9.14-15.85
Brown Shale Limestone	15.85-16.15
Brown Limestone	16.15-17.98 (EOH)

Table 2.22b: Well GA 383 Lithology and Depth

#### GA 334

Well GA 334 is located in Sweet's Corners, near Lyndhurst. It is located in an area where little sandy overburden overlies the Precambrian rocks of the Frontenac Axis.

GA 334 was drilled on March 7, 2003 by Air Rock Drilling Limited. The well was advanced to 30.50 mbgs. A water bearing area was found at 24.69 mbgs and the recommended pumping rate was 30 L/min (8 gpm). The lithology was recorded as follows:

<b>Lithology</b> (recorded by Golder & Assoc.)	<b>Depth</b> (mbgs)
Sand	0-1.98
Granite	1.98-30.50 (EOH)

Table 2.22c: Well GA 334 Lithology and Depth

#### GA 365

Well GA 365 is located in Loyalist Township and is drilled in the low yielding Palaeozoic Gull River Formation, near the contact of the Bobcaygeon Formation.

GA 365 was drilled on June 25, 2003 by Chalk Well Drilling Limited. The well was advanced to 19.81 mbgs. A water bearing area was found at 9.14 mbgs and the recommended pumping rate was greater than 13 L/min (3.5 gpm). The lithology was recorded as follows:

<b>Lithology</b> (recorded by driller)	<b>Depth</b> (mbgs)
Brown Clay	0-1.98
Brown Sand	1.98-2.29
Grey Limestone	2.29-19.81 (EOH)

Table 2.22d: Well GA 365 Lithology and Depth

#### GA 222

Well GA 222 is located within Frontenac Provincial Park and represents groundwater information for a large portion of the CSPA that would go otherwise unmonitored. The well is located in the Precambrian rocks of the Frontenac Axis. The area has limited soil cover, except a few small pockets of gravely sandy loam (see the surficial geology map: Figure 2.30) that is well to rapidly drained.

There is no well record for GA 222. The well depth has been recorded as 22 mbgs by the CRCA Environmental Technician. The well is noted to have a low estimated transmissivity.

#### GA 200

Well GA 200 is located near Athens and was drilled into the Palaeozoic March Formation.

GA 200 was drilled on September 19, 2003 by Dave's Well Drilling Limited. The well was advanced to 18.29 mbgs. A water bearing area was found at 16.46 mbgs and the recommended pumping rate was greater than 23 L/min (6 gpm). The lithology was recorded as follows:

<b>Lithology</b> (recorded by driller)	<b>Depth</b> (mbgs)
Brown topsoil	0-1.22
Grey Limestone	1.22-7.01
Grey Limestone	7.01-18.29 (EOH)

Table 2.22e: Well GA 200 Lithology and Depth

#### GA 279

Well GA 279 is located within the Mac Johnson Wildlife Area, near Brockville at the contact of the Palaeozoic Nepean and March Formations. There are several pits and quarries in the area, along with a wetland complex.

GA 279 was drilled on January 30, 2003 by Air Rock Drilling Limited. The well was advanced to 18.60 mbgs. Water bearing areas were found at 12.19 mbgs and 13.12 mbgs and the recommended pumping rate was 57 L/min (15 gpm). The lithology was recorded as follows:

<b>Lithology</b> (recorded by Golder & Assoc.)	<b>Depth</b> (mbgs)
Gravelly Topsoil	0-0.46
Grey, sandy Limestone/Dolostone	0.46-13.10
Grey interbedded Sandstone/ Limestone/ Dolostone	13.10-18.60 (EOH)

Table 2.22f: Well GA 279 Lithology and Depth

### 2.4.3 Groundwater Levels

Figure 2.11 (a through g) show the daily water level from October 1, 2004 to September 30<sup>th</sup>, 2005 (except for wells GA 200 and 279 where only 2003/2004 data was available for the same time period), as well as the daily precipitation amounts for the nearest Environment Canada station.

It should be noted that the water levels are corrected for barometric pressure effects (as the loggers are not vented to the atmosphere), although this is through only one

barometric station in the CSPA, which could still result in discrepancies between the measured data and actual data.

Some trends can be observed through analyses of the yearly well hydrographs and the precipitation records. In general, all wells react to precipitation and snow melt events. However, over the summer months, there is very little, and sometimes no, response to precipitation events. In these cases, the water coming from precipitation is likely captured in the unsaturated soil zone and subjected to evapotranspiration before it can reach the water table and raise the water table level. In addition, most of the wells experience their lowest levels around September, which is generally the same time as the watercourses.

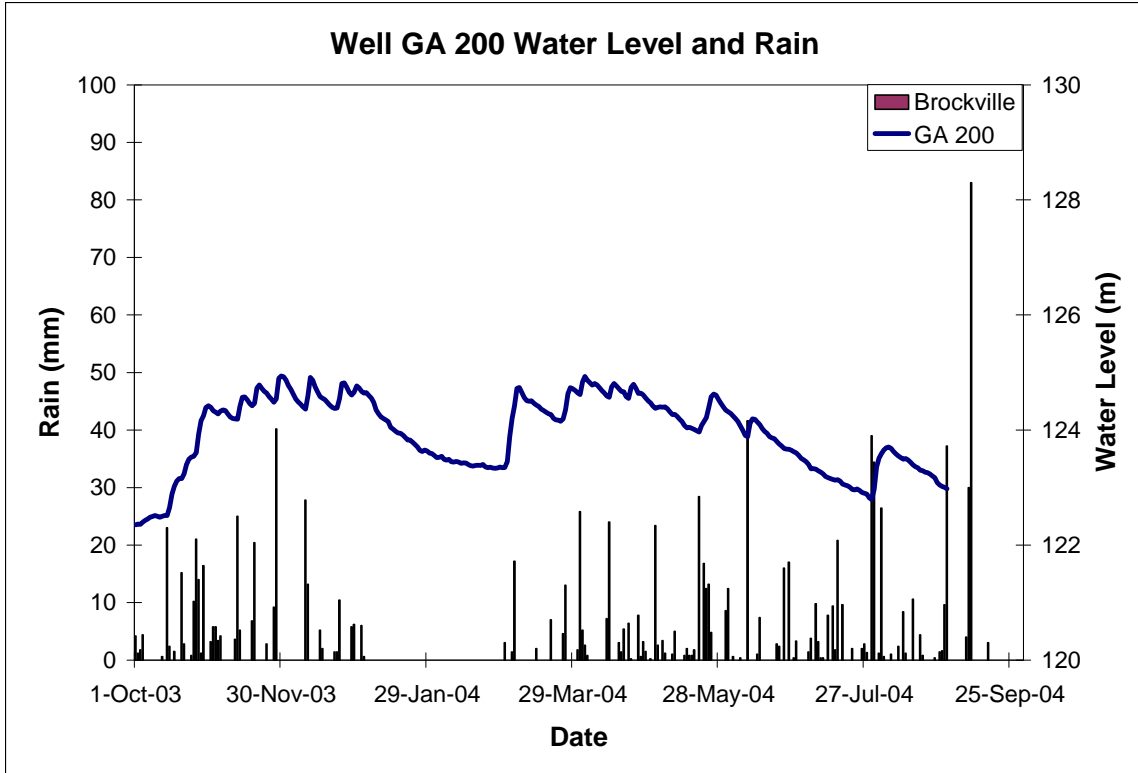


Figure 2.11a: Well GA 200 Levels and Brockville Precipitation Record, 2003/2004

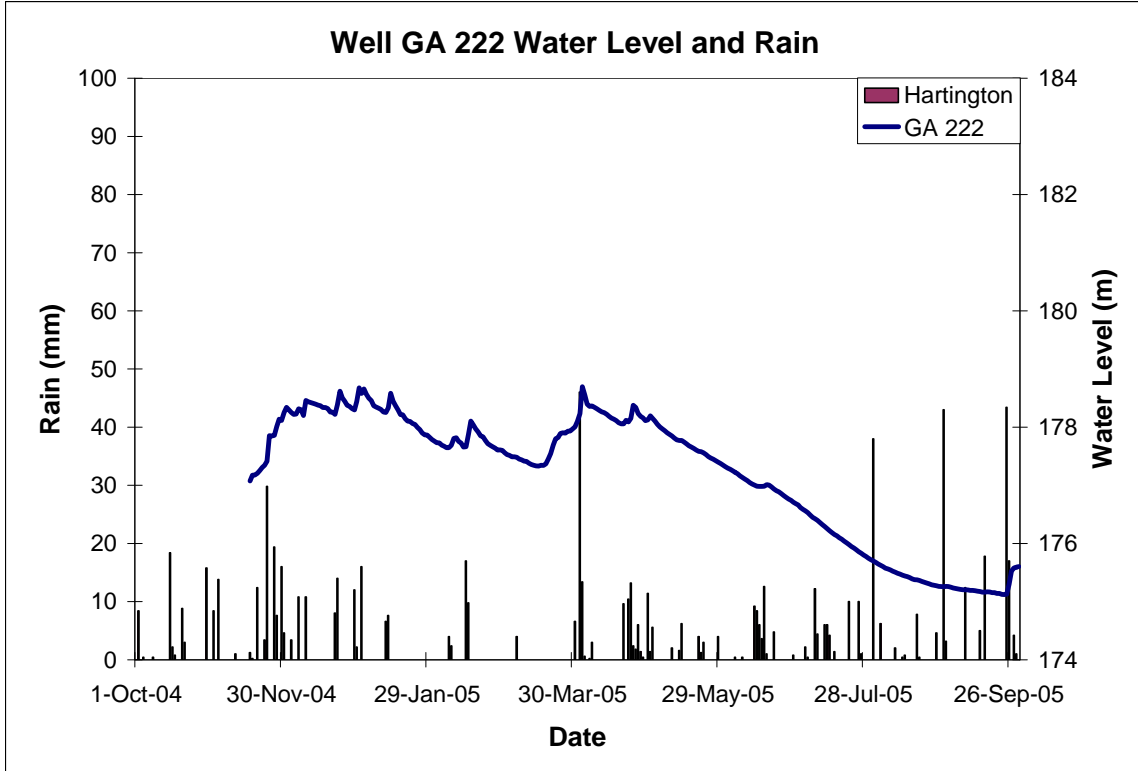


Figure 2.11b: Well GA 222 Levels and Hartington Precipitation Record, 2004/2005

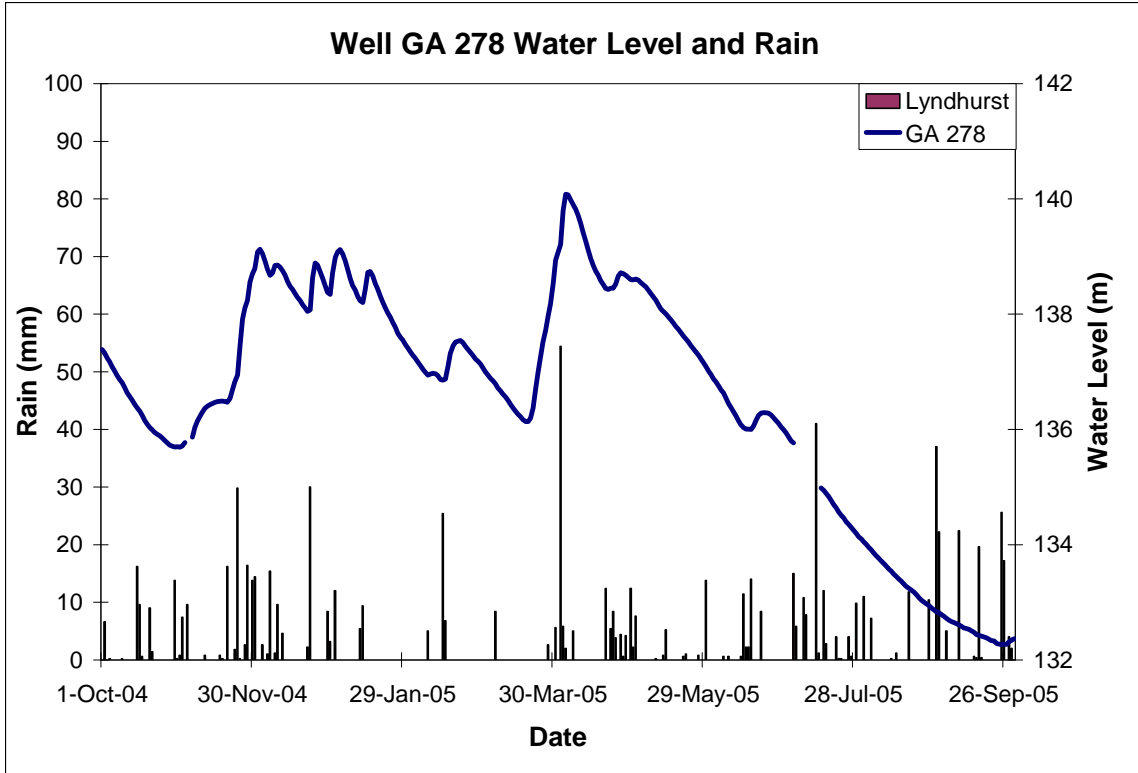


Figure 2.11c: Well GA 278 Levels and Lyndhurst Precipitation Record, 2004/2005

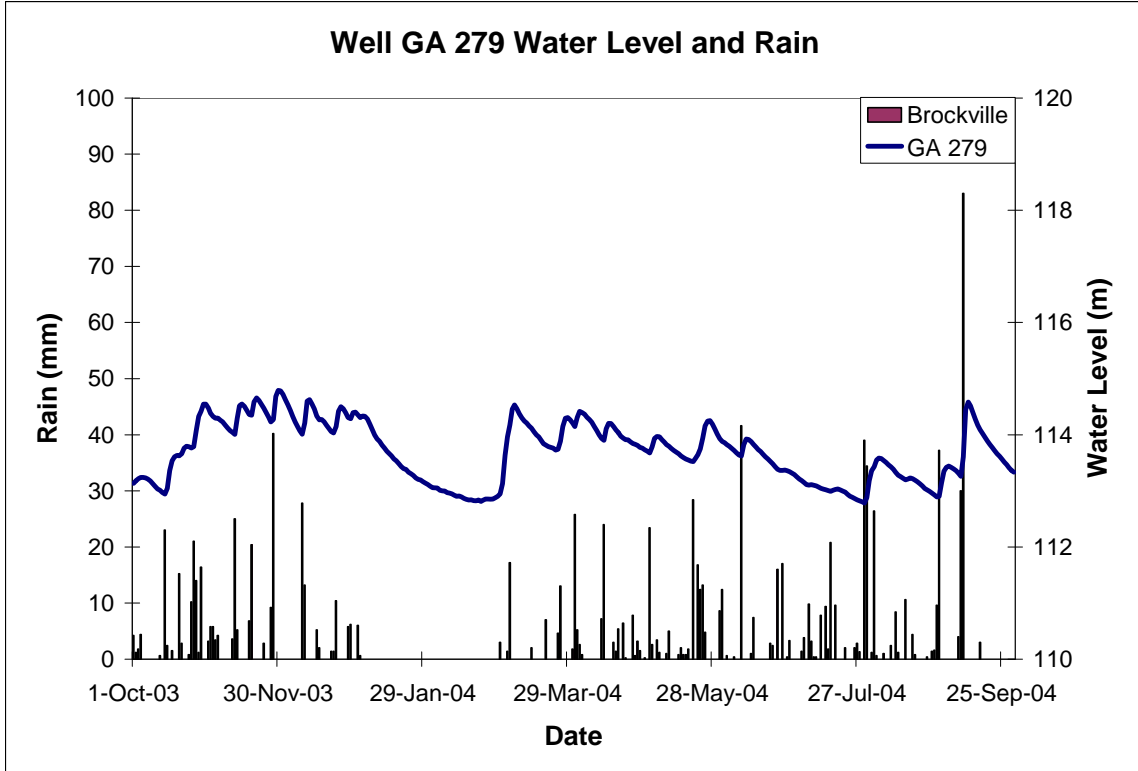


Figure 2.11d: Well GA 279 Levels and Brockville Precipitation Record, 2003/2004

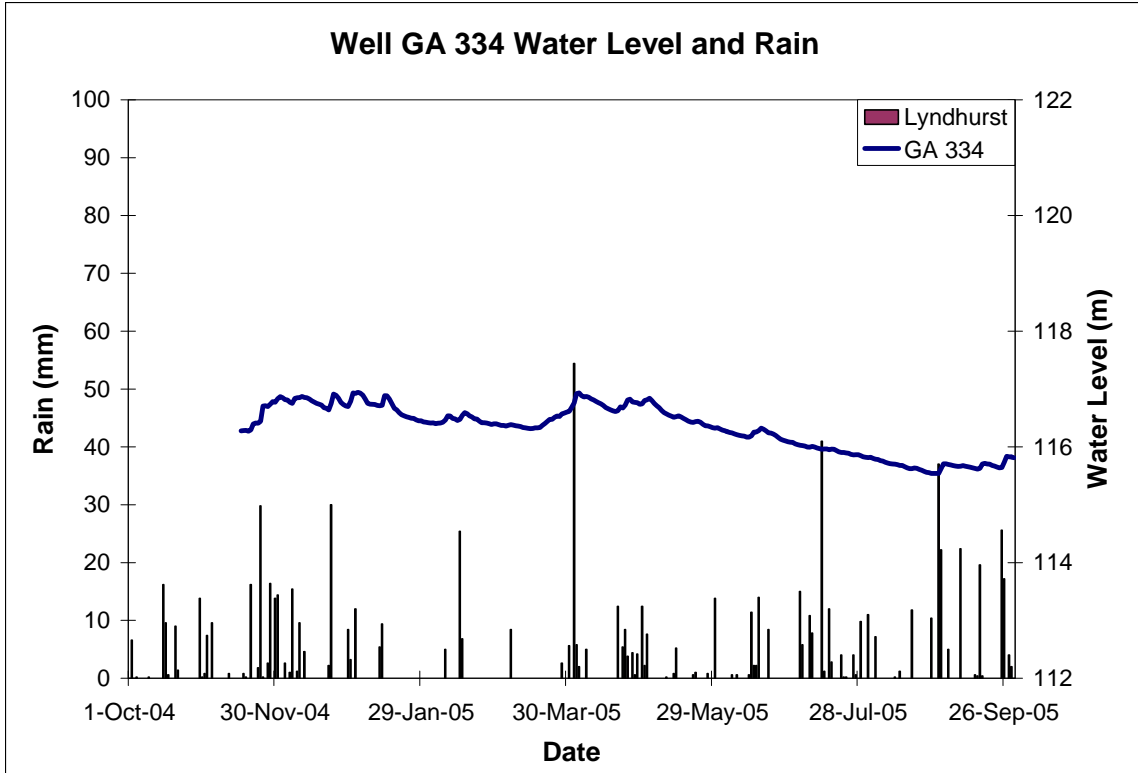


Figure 2.11e: Well GA 334 Levels and Lyndhurst Precipitation Record, 2004/2005

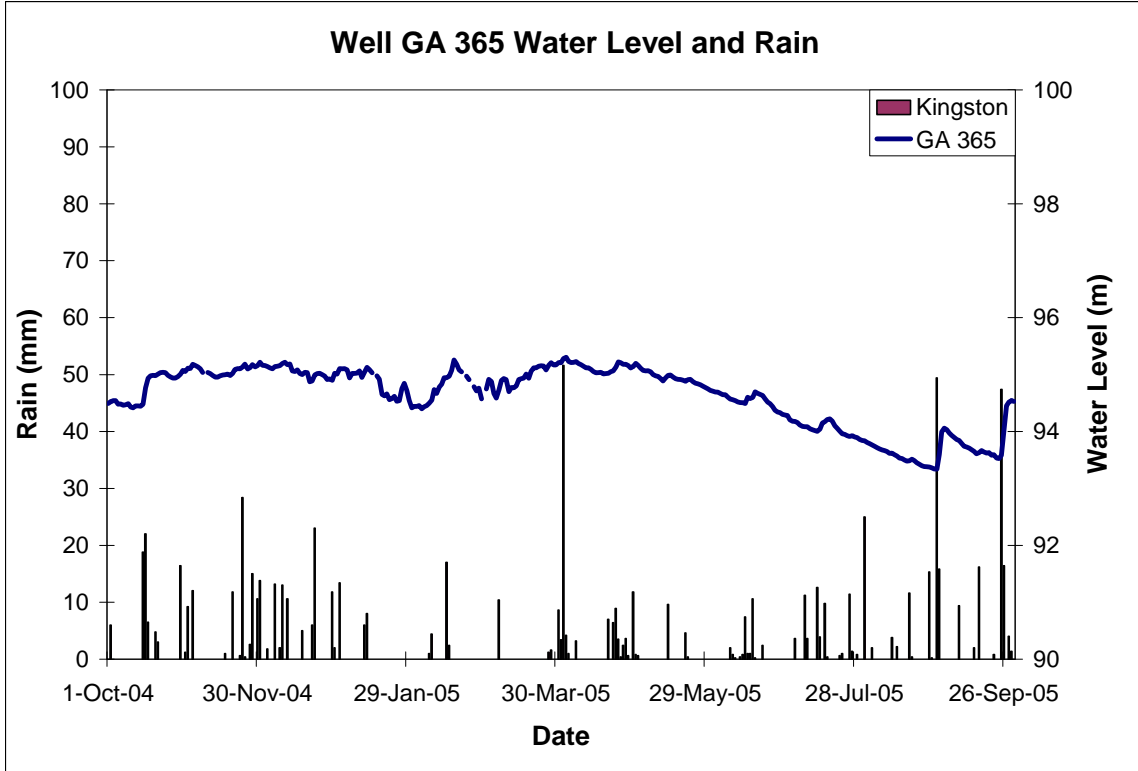


Figure 2.11f: Well GA 365 Levels and Kingston Precipitation Record, 2004/2005

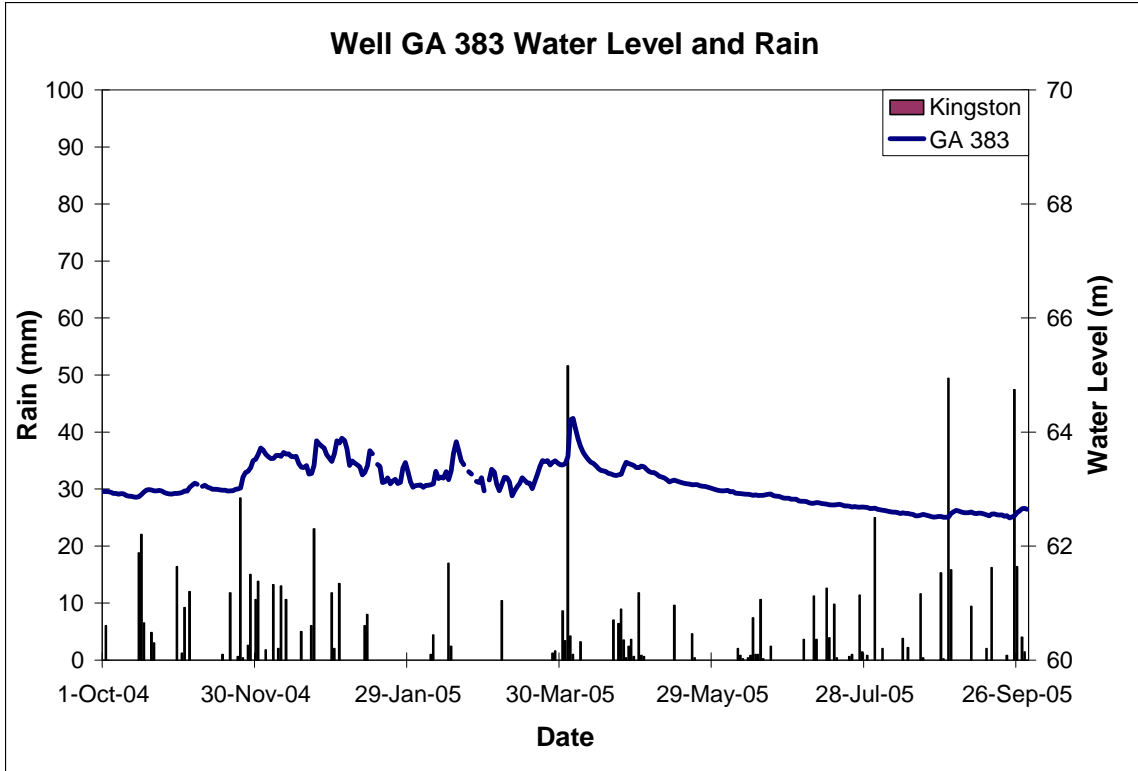


Figure 2.11g: Well GA 383 Levels and Kingston Precipitation Record, 2004/2005

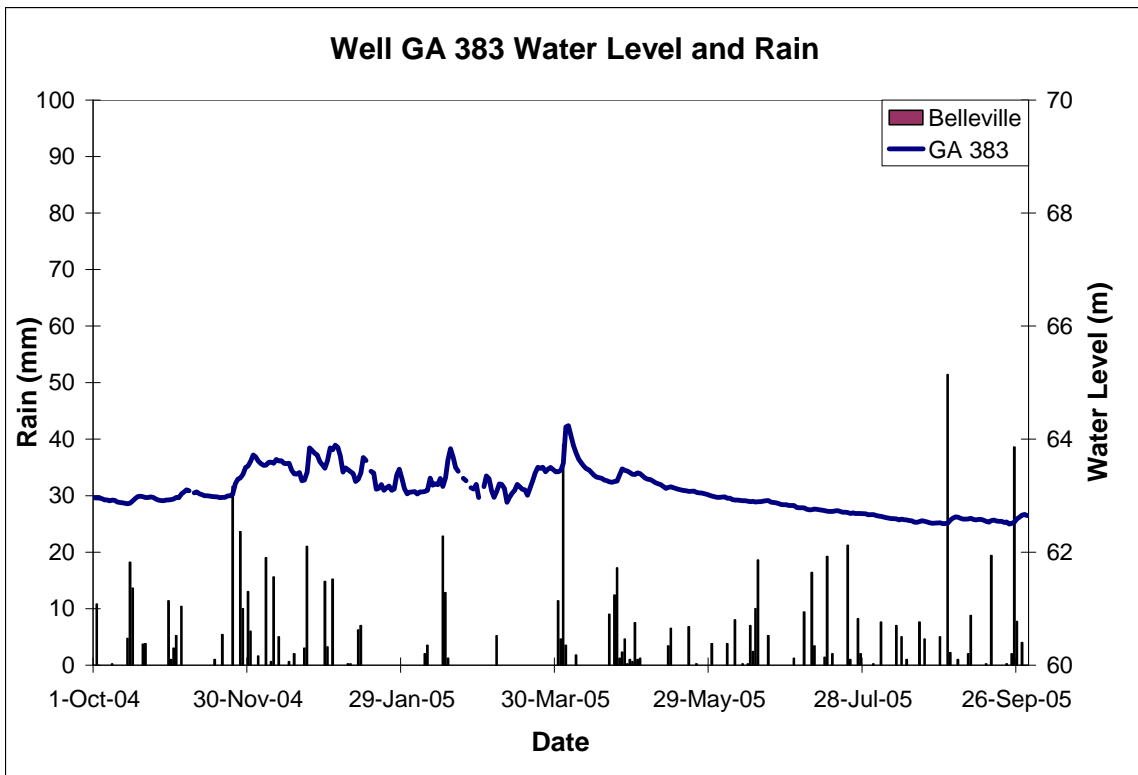


Figure 2.11h: Well GA 383 Levels and Belleville Precipitation Record, 2004/2005

#### 2.4.4 Groundwater Recharge

The water table fluctuation method (Healy and Cook, 2002) was used to calculate the percentage of precipitation from a specific rain event that recharges the water table in the PGMN wells (where water level data was available). The water table fluctuation method states that:

$$R = S_y \times \Delta h$$

Where R is recharge,  $S_y$  is the specific yield of the aquifer, and  $\Delta h$  is the rise, in metres, of the piezometric surface during a given time period. In this case, a period of approximately two weeks was used for two different rainy periods in different seasons for the purpose of comparison.  $S_y$  values were assumed based on previous hydraulic testing and recharge studies completed in fractured bedrock environments. The following  $S_y$  values were assumed for the PGMN wells completed in Precambrian and Palaeozoic bedrock:

- Precambrian - 0.001 (Milloy, 2006)
- Palaeozoic - 0.01 (Novakowski, 2006)

The percentage of rainwater (%R) that recharges the aquifer was then calculated as:

$$\% R = \frac{R}{P} \times 100 \%$$

Where P is the total precipitation over the same given time period (as  $\Delta h$ ). Precipitation values were calculated from the rain gauge located closest to the well.

The percentage of recharge for the periods of November 17 to December 1, 2004 and May 16 to 27, 2004 are shown in Tables 2.23a and 2.23b, respectively. The percentage of precipitation that reaches the water table varies significantly between the wells (0.6 – 24 %). Given that five of the wells are completed in Palaeozoic bedrock and two of the wells are completed in Precambrian bedrock, the percent recharge values change an order of magnitude between the wells. Also, the rain gauges are not located at the well sites, which can cause uncertainty in the precipitation measurements. Rain gauges at each well site may help decrease uncertainty in the recharge calculations.

Results indicate that Well GA 278 exhibits an extraordinary recharge response to rain events. However, Figure 2.11c also depicts that GA 278 disperses the recharge in a very short time period following a rain event. Given that the driller expected the well to produce > 114 L/min (30 gpm), it appears that the well has very high transmissivity and can likely disperse the recharge further a field much more quickly than the other wells.

It is recommended for the Tier 1 water budget that more recharge calculations are completed to give a more complete, numerical understanding of recharge in the CSPA.

	GA 222	GA 278	GA 334	GA 365	GA 383
Total Precipitation (m)	0.09	0.10	0.10	0.08	0.08
Water Level Rise (m)	1.18	2.30	0.55	0.22	0.63
% recharge	1.3	24	0.6	2.6	7.5

Table 2.23a: Percentage of Recharge - November 17 to December 1, 2004

	GA 200	GA 222	GA 278	GA 279	GA 334	GA 365	GA 383
Total Precipitation (m)	0.08	0.07	0.07	0.08	0.07	0.06	0.06
Water Level Rise (m)	0.66	0.76	1.17	0.73	0.44	0.30	0.39
% recharge	8.4	1.1	16	9.3	0.6	5.1	6.7

Table 2.23b: Percentage of Recharge - May 16 to 27, 2004

Figure 2.12 illustrates the groundwater levels for all PGMN wells from October 2002 to April 2006. While there is not a great deal of data available for comparison, it appears that most of the stations experience the same general rise and fall each year, which supports the assumption made at the beginning of the report that groundwater levels are steady. The exceptions to this steady state are Wells 222 and 278, where it appears that the water level is falling over time.

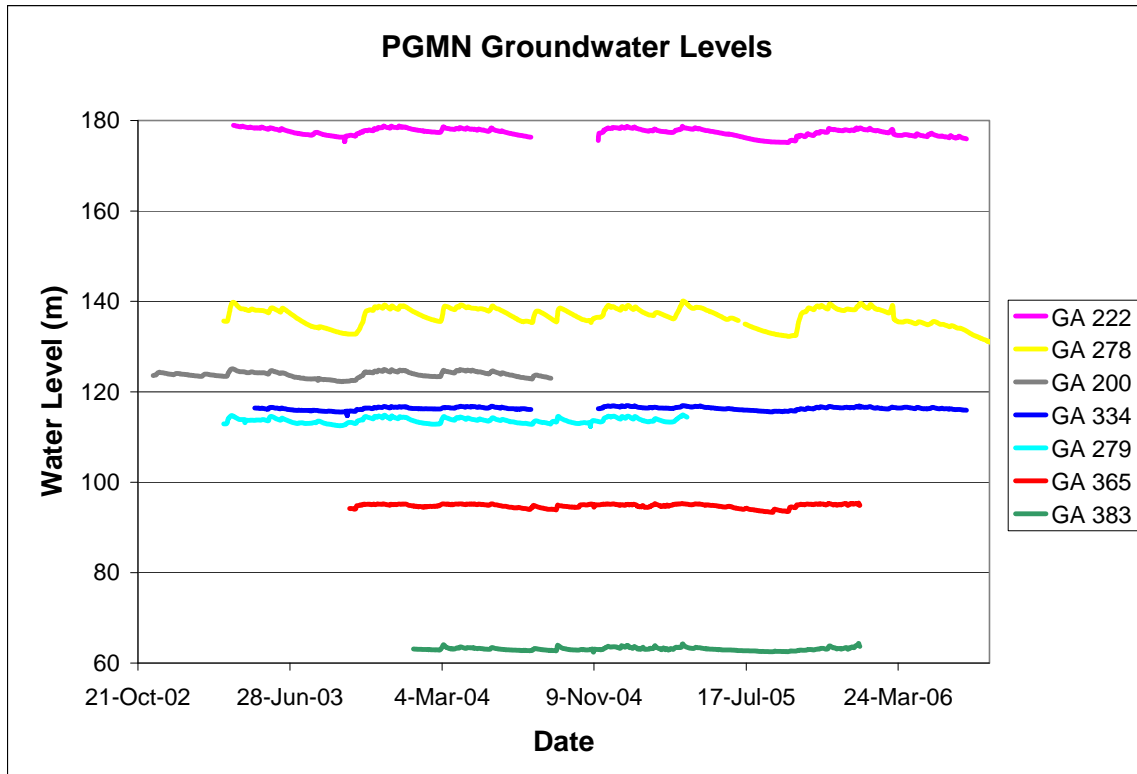


Figure 2.12: PGMN Water Levels - October 2002 to April 2006

Appendix F contains annual water level graphs for each individual PGMN well.

#### 2.4.5 Groundwater-Surface Water Interaction

As previously discussed, groundwater discharge can account for a significant percentage of streamflow (e.g. Sklash and Farvolden, 1979; Larkin and Sharp, 1992; Winter 1999; Sophocleous, 2002), especially in a porous media setting. In fractured rock settings, it is less common to find groundwater discharge into a stream (Oxtobee and Novakowski, 2002; Praamsma, 2006). Streamflow field discharge observations and precipitation records were used to establish possible groundwater discharge locations within the CSPA.

From spring to fall (May to October) 2006, streamflow measurements were collected at 138 sites within the CSPA. Many of the sites were visited more than once. All sites were assigned a “lowest” water level distinction of dry, no flow, minimal flow or measurable to represent their lowest water level condition during the spring-summer field season. “Dry” corresponds to a stream site drying up for a period during the field season, “no flow” corresponds to stagnant, “minimal flow” means a trickle flow and “measurable” means that streamflow measurements were possible throughout the season. These distinctions can assist in assessing whether streams were supplied by groundwater at the data collection site. Data from streams controlled by dams are omitted as the flow measurements may not necessarily reflect that of the stream. These include Millhaven Creek, Lyndhurst Creek, Lyn Creek, Buells Creek, and the Gananoque River

During dry stream flow periods, groundwater discharge can be observed directly on streambeds (Oxtobee and Novakowski, 2002) if the piezometric surface is high. Therefore, during the dry summer periods, it can be assumed that groundwater discharge is limited if no surface flow is observed. Several sites (from summer 2006) were labeled as “dry” for their lowest water level distinction. The majority of these sites were labeled as such during the driest period of the field season, August, where there was the least amount of precipitation. However, streamflow was present at these sites following precipitation events in the spring. This indicates that streamflow for these sites is likely attributable to mostly direct precipitation rather than groundwater discharge. Little Creek and Glenvale Creek are examples of streams that contain bedrock sites which became dry this past summer. Flow did not return to these sites until early fall after large amounts of rainfall. Figures 2.13a and 2.13b illustrate bedrock sites on Little Creek during the spring-summer field season.



Figure 2.13a: Bedrock Streambed Site, Little Creek, August 8, 2006



Figure 2.13b: Stream Site, Little Creek  
Left: August 8, 2006, Right: August 23, 2006

Some streams maintained streamflow throughout the spring-summer field season, suggesting the possibility of groundwater discharge. Table 2.24 illustrates possible groundwater discharge stream sites within the CSPA. (A detailed description can be found in Appendix D). The data from Table 2.24 indicates that groundwater discharge locations are dispersed within CSPA and not concentrated in specific areas. However, there did not appear to be any groundwater discharge west of Wilton creek (West portion of Lake Ontario study area) as all stream sites seem to be situated on or east of Wilton Creek. Figure D.9 in Appendix D shows the bedrock of the CSPA with the sample sites (and low flow condition) overlain. Further investigation and additional data from future years will assist in determining whether groundwater discharge sites are concentrated in specific areas.

Creek	Creek Bottom	
	Bedrock	Porous Media
Wilton Creek	✓	✓
Collins Creek	✓	✓
Highgate Creek	✓	✓
Little Cataraqui Creek (West Branch)		✓
Little Cataraqui Creek (Main Branch)		✓
Moore’s Creek	✓	
Grass Creek		✓
Stocking Hill Creek	✓	
Farnham Creek		✓
Cooligan’s Creek		✓
Plumhollow Creek		✓
Foster’s Creek		✓
North Wiltse Creek		✓
LaRue Creek		✓
Jones Creek	✓	✓
Butler’s Creek		✓

Table 2.24: Streams with Possible Groundwater Discharge Sites (West to East)

The geology of a streambed can influence the probability of groundwater discharge into streams. The geology of streambeds within the CSPA is comprised of Palaeozoic and Precambrian bedrock, porous media or both. As illustrated above, numerous sites with a porous media streambed were flowing during the spring but became dry in August. For the majority of these sites, flow measurements were possible following a precipitation event. When the sites became dry, it was usually preceded by a period of no precipitation (for a week prior to the measurement) or a minimal amount of precipitation (less than 5 mm in the previous week). These sites were disregarded as groundwater discharge sites as they became dry during the spring-summer field season.

## 2.5 Physical Land Characteristics

Various physical land characteristic data has been obtained through the Ontario Geospatial Data Exchange, and has been mapped across the CSPA and included in the Watershed Characterization document. The following sections use that information with regards to water budget implications.

### 2.5.1 Bedrock Geology

There are seven general bedrock types in the CSPA. These are (from oldest to youngest) the Precambrian igneous and metamorphic rocks of the Canadian Shield, and the Palaeozoic sedimentary rock of the Nepean (sandstone), March (dolostone and sandstone), Shadow Lake (limestone), Gull River (limestone), Bobcaygeon (limestone), and Verulam (limestone) Formations (Figure 2.14 and A2.14).

#### 2.6.1.1 Precambrian Geology

The metamorphic Precambrian rocks of the CSPA were originally deposited as sediments and consolidated into sedimentary rocks between approximately 1100 and 950 million years before present (Davidson and vanBreeman, 2000; Greggs and Gorman, 1976). Metamorphism occurred when these sedimentary rocks were deeply buried under many more layers of sediments and sedimentary rocks. During deep burial the rocks were penetrated by magma that produced igneous rocks and further deformed the metasediments. Later, andesite and diabase dykes intruded both the metasediments and igneous plutons. Erosion later uncovered all the metamorphic and igneous rocks and dykes, bringing them to the surface. Between 800 and 600 million years ago, a mountain building episode called the Grenville orogeny produced very high mountains in the CSPA, which have slowly eroded to their present height (Greggs and Gorman, 1976).

The Grenville orogeny occurred as a northeast trending fold system that runs northwest/southeast from Algonquin Park to the Adirondack Mountains in New York State (Greggs and Gorman, 1976). Precambrian rocks underlie the entire CSPA and form the basement geological unit and are exposed at surface as part of the Frontenac Axis. Within the CSPA, the Axis exists from east to west between Kingston and Brockville, varying between 25 and 50 km in width, and exists throughout the CSPA from the northwest to southeast.

In geologic nomenclature, the Precambrian rocks of the CSPA are part of the Frontenac Terrane of the Central Metasedimentary Belt. The metasediments include schist, gneiss, amphibolites, quartzite, and marble, while the igneous rocks include quartz monzonites, granites, diorites, gabbro, diabase, and andesite. In some places, the intruding igneous plutons created mixtures of metamorphic and igneous rocks called migmatites (Greggs and Gorman, 1976; Wilson, 1946).

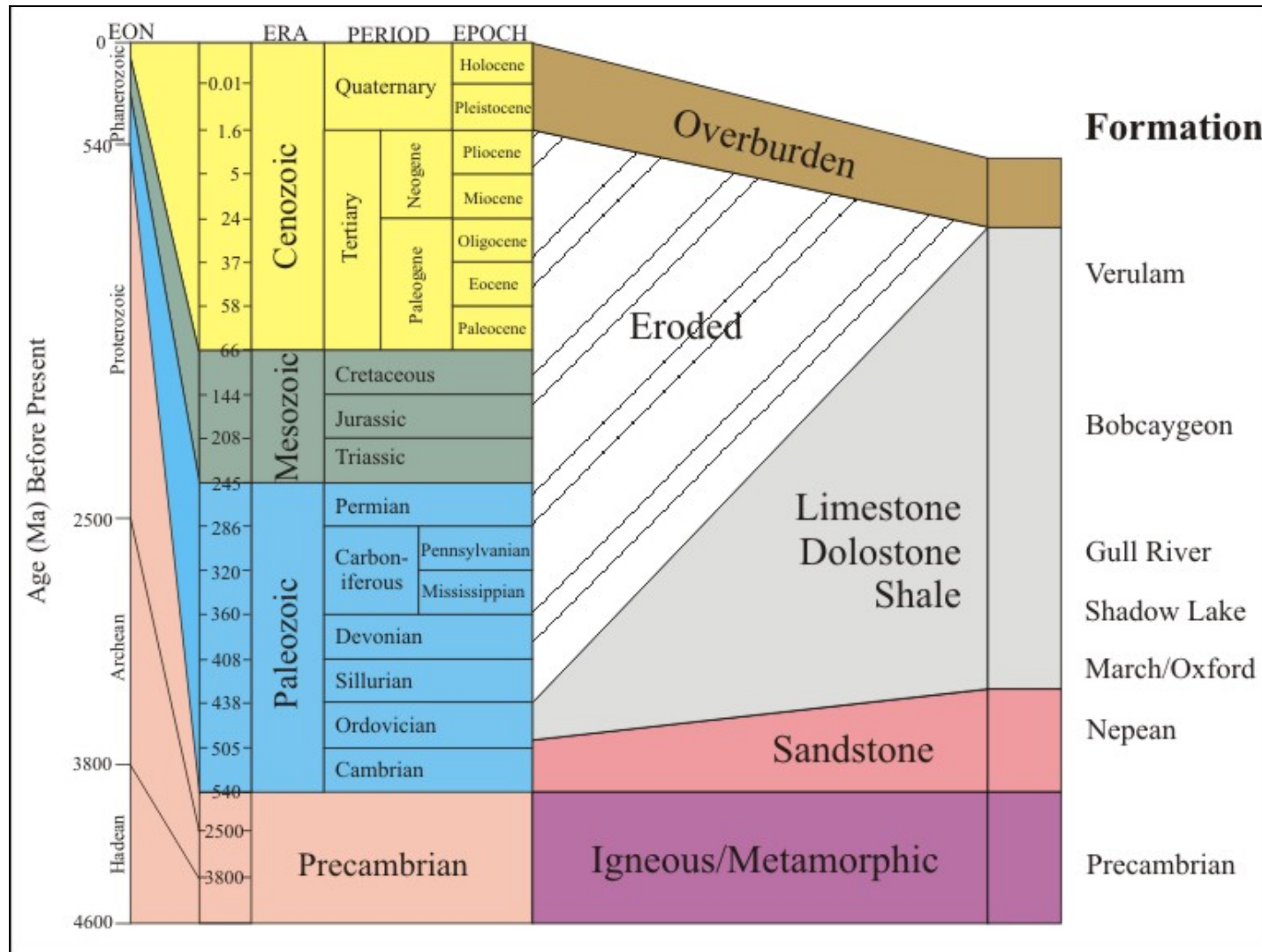


Figure 2.14: Geological Time Scale and Geological Events in the CRCA

### 2.6.1.2 Palaeozoic Geology

During the Palaeozoic Era, approximately 500 million years before present, Eastern Ontario was inundated with a shallow ocean that deposited eroded sediment from the Precambrian landmass along its shorelines. The sediment now exists as a series of flat lying sedimentary rocks that represent the shallow water depositional environment from 500 million to 450 million years before present.

The Palaeozoic strata occur in the CSPA northeast and southwest of the Frontenac Axis. Six Formations exist in the CSPA: Nepean, March, Shadow Lake, Gull River, Bobcaygeon, and Verulam. Each Formation is discussed in the following sections and Figure 2.15 details the general bedding structure of the bedrock.

#### Nepean Formation

The coarse conglomerates and sandstones of the Nepean Formation were mainly deposited east of the Frontenac Axis. The Nepean Formation consists of well-sorted interbedded quartz sandstones and conglomerates that were deposited on top of the Precambrian rock. The conglomerate beds occur in the lower portion of the formation near the Precambrian/Palaeozoic contact, becoming finer grained in the upper reaches of the unit. Iron rich mineral grains found in the sandstone unit include pyrite, magnetite, and ilmenite. Dissolution of these minerals and their precipitation in the form of iron staining on the sand grains likely contributes to the high iron content observed in water produced from this formation. Outcrops can be found north of Kingston at the Park of Pillars and east of the Frontenac Axis (Liberty, 1971).

#### March Formation

Conformably overlying the Nepean Formation are the quartz sandstones and dolostones of the March Formation. As opposed to the Nepean Formation, the quartz sandstones of the March Formation are cemented by dolomitic material (Greggs and Gorman, 1976). Interbedded sandstones decrease in frequency and thickness towards the top of the formation.

#### Shadow Lake Formation

The Shadow Lake Formation is comprised of limestone beds that overlie the Precambrian rock and Nepean Formation southwest of the Frontenac Axis. It is evident at surface in places along the interface between the western limestone plain and Precambrian shield.

#### Gull River Formation

The Gull River Formation lies above the Shadow Lake Formation and is divided into four members (named A, B, C, D), all limestone. The areal extent of this formation includes the entire Town of Greater Napanee, Loyalist Township (mainland & Amherst Island), most of the City of Kingston (excluding the eastern part of the former Pittsburgh Township), and the southern half of South Frontenac Township. The upper three members of this formation are fossiliferous.

Bobcaygeon Formation

The Bobcaygeon Formation lies above the Gull River Formation and is comprised of alternating fine calcarenitic limestone and sublithographic limestone. The strata are highly fossiliferous. The extent of this formation includes the southwestern quadrant of Loyalist Township and the majority of the Town of Greater Napanee.

Verulam Formation

The Verulam Formation lies above the Bobcaygeon Formation and is typified by the alternation of limestone and shale (Liberty, 1971). The Verulam Formation outcrops in the southern portion of the Town of Greater Napanee and the southwestern quadrant of Loyalist Township. This is the youngest bedrock formation in the area. This formation can also contain many fossils.

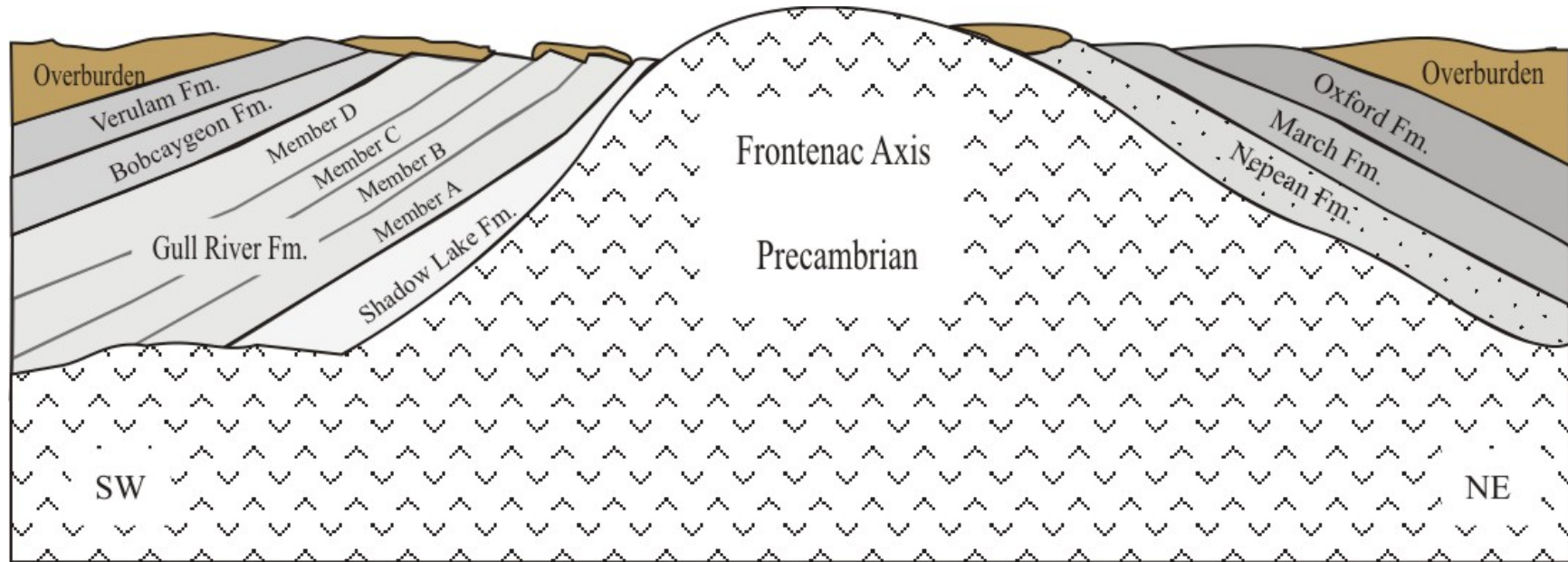


Figure 2.15: Schematic Geological Cross-Section of the CRCA showing Palaeozoic Bedrock Formations overlying Precambrian Bedrock from southwest to northeast (not to scale)

### 2.5.2 Surficial Geology

Deposition of overburden is a result of the last period of glaciation in North America (the Wisconsinan glaciation) which ended approximately 10,000 years ago. Glaciers transported large quantities of eroded Palaeozoic and Precambrian rocks from the north and deposited them in the form of till sheets and drumlins over much of the bedrock surface. As the glacier ablated and receded, glacial melt waters transported sand and gravel to the ice margin where they were deposited as eskers and fan-like outwash features.

The mass of the ice also depressed the earth's crust, allowing for inundation of the area by the Atlantic Ocean. This ancient arm of the ocean, which covered a large proportion of the CSPA east of the Frontenac Axis, was called the Champlain Sea (approximately 13,000 to 10,000 years ago). The sea deposited clays and silts over the underlying tills and esker deposits. As the earth's crust rebounded, outlets were formed that drained the Champlain Sea. The lowering water level resulted in the exposure of elevated till areas such as drumlins. These till "islands" were reworked by wave action to form sand and gravel beaches. As the Champlain Sea further receded, an increased amount of till was exposed allowing for increased amounts of sediments to be reworked.

Around the same time, as the crust continued to rebound, and the glacial ice continued to recede, a precursor to Lake Ontario, Lake Iroquois, was formed (approximately 13,000 to 10,000 years ago). The lake was essentially an enlargement of the present Lake Ontario. It formed because the St. Lawrence River was blocked by the ice sheet near the Thousand Islands. The level of the lake was approximately 30 m above the present level of Lake Ontario. The lake drained southeast to the Atlantic Ocean. The melting of the ice dam resulted in a lowering of the lake to its present level, and an outlet change to the St. Lawrence River.

Several different types of sediment were deposited in differing glacial conditions. Alluvium, organic deposits, sand and gravel, sand, clay and till are outlined below and in Figure A2.15, which is a generalized surficial geology map, developed from a compilation of overburden geological maps provided by The Ministry of Northern Development and Mines. The sediment descriptors in the text are slightly different than those on the map, and Table 2.25 is provided to clarify the descriptions.

<b>Figure 2.30 Surficial Geology Grouping</b>	<b>General Text Grouping</b>
2 - Precambrian Bedrock	Precambrian Bedrock
4 - Palaeozoic Bedrock	Palaeozoic Bedrock
5 – Undifferentiated Till	Till
6 – Ice-Contact Stratified Deposits	Sand and Gravel
7 – Glaciofluvial Deposits	Sand and Gravel
8 – Fine Textured Glaciolacustrine Deposits	Clay
9 – Coarse –Textured Glaciolacustrine Deposits	Sand and Gravel
10 – Fine Textured Glaciomarine Deposits	Clay
11 – Coarse Textured Glaciomarine Deposits	Sand and Gravel
14 – Coarse-Textured Lacustrine Deposits	Sand and Gravel
17 – Eolian Deposits	Silt
19 – Modern Alluvial Deposits	Alluvium
20 – Organic Deposits	Organic Deposits

Table 2.25: Surficial Geology Grouping

Alluvium

Alluvium deposits are found sporadically along the major watercourses in Leeds-Grenville County, including the St. Lawrence River. They consist of silty or sandy organic rich material.

Organic Deposits

Muck and other organic rich soils are widespread over much of the CSPA, as a result of poor drainage and/or a shallow water table. Thickness of the organic deposits is usually less than a few metres.

Sand and Gravel

Coarse sand and gravel deposits are present in several areas. One significant deposit appears just to the east of the CSPA as a semi-linear feature extending from east of Kemptville down to Maitland. This deposit consists of a core of sand and gravel, flanked by sand and silt. The sand and gravel core formed as a glacial esker. In some areas the sand and gravel exist as ice-contact stratified moraines, produced as a result of the development of a subglacial outwash fan. The sides of both the eskers and the outwash deposits were reworked by wave action of the Champlain Sea resulting in the extension of permeable sands outward from the centre of the ridge.

### Sands

Shallow marine sands were deposited as a result of wave reworking of the exposed tills during the regression of the Champlain Sea. The result was a discontinuous blanket of surficial sands in the eastern part of the region. The thickness of the sand generally increases towards the east. The sand plain is punctured in many places by outcroppings of drumlinized till. Other sand deposits exist as eolian dunes formed by reworking of the exposed marine sands after regression of the Champlain Sea.

### Clay

Clay is found across the region. The clay was deposited during the inundation of the area by the Champlain Sea causing the deposition of clay and silts in protected locations such as bedrock valleys or depressions in the underlying drumlinized terrain. The thickness of the clay is quite variable and depends largely upon the depth of the depressions in which the clay was deposited.

The large area of clay north of Gananoque was deposited in a glaciolacustrine environment when that portion of the Precambrian shield was inundated by glacial Lake Iroquois, the predecessor of Lake Ontario. Flooding resulted in the deposition of silts and clays between the localized exposed highs of the Canadian Shield. Basal sands and gravels are often located at the contact between the clay and the underlying shield. Clay thicknesses up to 60 metres have been observed in isolated locations.

### Till

Till, in the form of drumlins and ground moraines, is widespread throughout the region. Till thickness ranges from <1 metre to more than 10 metres in some drumlin fields in the east. Deposits greater than 1 metre in thickness are mapped as Till Plain. Reworking of the till islands formed as part of a drumlin field provided the development of gravel beaches on the west-facing portions of the islands. These beaches have been documented to be up to 15 metres thick (Sharpe, 1979).

The area was subject to glaciation during the Wisconsinan (10,000 years ago) era. Associated glacial till deposits (i.e., unconsolidated sediments deposited directly by the glacier) identified at surface and elsewhere are interpreted to be overlain by glaciolacustrine deposits of clay, silty clay, and near shore deposits of silt and sand. Notable fine-textured glaciolacustrine deposits exist in the eastern half of the City of Kingston and the southern half of the Town of Greater Napanee. Based on available data, the major creek and river valleys in the area contain the greatest thickness of overburden, characterized primarily by glaciofluvial deposits. These sediments (coarse silt to gravel) are well sorted and stratified (Funk, 1977).

Drumlins are present throughout the Town of Greater Napanee and north of Highway 401 in Loyalist Township. These drumlins belong to the Quinte drumlin field. They are characterized by their low relief and elongated ridge like nature (Funk, 1977). Two basic types of drumlin are present: those composed entirely of till and those with a stratified sand and gravel core.

### 2.5.3 Physiography

Chapman and Putnam (1984) identify four separate physiographic regions in the CSPA (Inset, Figure A2.16). They are: Smiths Falls Limestone Plain, Leeds Knobs and Flats, Algonquin Highlands and Napanee Limestone Plain.

#### Smiths Falls Limestone Plain

The Smiths Falls Limestone Plain follows the northeastern region of the CSPA to Upper Rideau Lake where it meets a small undrumlined till plain in the Westport-Newboro area. The limestone plain contains several bogs and marshes. Another small till plain can also be found in the Chantry and Brockville areas. The Smiths Falls Limestone Plain is the smallest physiographic region within the CSPA, covering an area of approximately 609 km<sup>2</sup> or 17 percent of the total CSPA area. The land elevation ranges from 70 to 140 m GSC. It is characterized by shallow soil overlying mainly limestone or dolostone rock. Many parts of the area are poorly drained as evident by the occurrence of bogs, especially in the geographic townships of Kitley, Elizabethtown, the northern portions of Yonge and Escott, and the eastern third of Rideau Lakes. Deeper soils are present in some areas as a result of old beach deposits, isolated drumlins, and clay deposits that have filled depressions in the bedrock surface.

#### Leeds Knobs and Flats

The Leeds Knobs and Flats region lies in Leeds and Frontenac geographic counties north of the St. Lawrence River and the Thousand Islands (between Gananoque and Brockville and extending north to Crosby) and consists of rock knobs washed bare by the Champlain Sea and channels between them that contain deep and weakly calcareous clay beds. The largest area of clay lies west of the village of Lansdowne in the geographic Lansdowne Township.

The total area of this region is approximately 1080 km<sup>2</sup>, or 30 percent of the total CSPA area. Rock ridges protruding through relatively thick soils characterize this region. The soils consist of clay that was deposited during flooding of the area by the former glacial Lake Iroquois. The resulting land texture is of bare rock protruding through relatively level terrain. The elevation of this physiographic region usually ranges from 70 to 100 m GSC, but is higher along rock ridges.

#### Algonquin Highlands

The elevated land in the western side of Rideau Lakes Township and the eastern portion of South Frontenac Township, is referred to as part of the Algonquin Highlands. The Algonquin Highlands are the upper part of the Frontenac Axis. This region, encompassing approximately 740 km<sup>2</sup> (or 21 percent of the total CSPA area), is characterized by shallow sandy or stony soils and a relatively rugged topography. Bedrock outcrops throughout the region form numerous localized topographic highs. This area has the highest elevation (approximately 209.0 m GSC) in the CSPA, as measured near Canoe Lake. Numerous large lakes such as Newboro Lake, Opinicon Lake and Sand Lake formed in the irregular depressions in the Precambrian bedrock.

### Napanee Limestone Plain

The Napanee Limestone Plain is similar to the Smith Falls plain. It encompasses approximately 1130 km<sup>2</sup> (or 32 percent of the total CSPA area), including the western side of the City of Kingston, the southwestern corner of South Frontenac Township, and Loyalist Township as well as the Town of Greater Napanee. It is characterized by very shallow soils, and some alvars, although deeper glacial till does occur in some stream valleys, there are also some shallow depressions of stratified clay.

Map P2715 (OGS, 1984) (Figure A2.16) divides the CSPA into three primary Physiographic Regions. The northeast and northwest areas of the region are characterized as limestone plain. The eastern portion of South Frontenac, western portion of Rideau Lakes, and northern portion of Leeds and the Thousand Islands are characterized by shallow till and rock ridges. Clay plains exist along major river valleys in the west (i.e., Cataraqui River and Wilton Creek) as well as along the southern portions and Lake Ontario/St. Lawrence River shoreline of the region. Other smaller physiographic regions occur across the area, including bare rock ridges and shallow till in the vicinity of Perth Road Village, peat and muck north of Gananoque and Brockville, sand plain north and east of Brockville, till plain east of Brockville, kame moraine near Lyndhurst, an esker near Seeley's Bay, and drumlins scattered throughout the Town of Greater Napanee and Loyalist Township.

Across the CSPA, overburden thickness (Figure A2.17) is generally less than one metre, with exposed bedrock visible in some areas on the limestone plain and the Precambrian shield. The exceptions to this are river and creek valleys where notable thickness of overburden occurs. Localized accumulations of overburden also occur in the east end of the City of Kingston, the west end of the Town of Greater Napanee south of Hay Bay, northwest of Elgin, southeast of Athens, near Mallorytown, and northwest of Lansdowne.

Karst and fractured bedrock are common features in the limestone plain. Fractures in the limestone bedrock have been observed by Funk (1977) to generally be oriented in a northeast to southwest direction. They control the drainage in the regional watersheds, guiding the general southwest flow pattern.

#### 2.5.4 Soil Characteristics

The Interim Watershed Plan (CRCA, 1983) describes the soils in the Kingston to Brockville corridor as generally shallow and tending to be acidic. The major soil types are Lansdowne and Napanee clay, as well as Farmington loam.

The southern portions of the CSPA (near Lake Ontario and the St. Lawrence River) predominantly consist of clay, while those areas further north are predominantly loam and sandy loam combinations (Figure A2.18a). This is probably related to the elevation, and the deposition of finer sediments by Lake Iroquois and the Champlain Sea.

A detailed description of the soils in each watershed is included in the Watershed Characterization report, while only the detailed map is included here (Figure 2.18b) (Gillespie et al., 1963, 1966, 1968). The percentage area of each soil type is shown in

Table 2.26, and it can be seen that the largest soil types are Loam, Sandy Loam, and Clay.

Soil Type	Percentage of CSPA Area
Loam	29.4%
Sandy Loam	27.4%
Clay	23.5%
Water	8.4%
Silty Loam	3.1%
Muck	2.9%
Clay Loam	1.0%
Rock Outcrop	0.7%
Peat	0.7%
Marsh	0.7%
Urban - Kingston	0.3%
Bottom Land	0.2%
Unclassified	1.6%

Table 2.26: Soil Characteristic Percentage of Total Area

As mentioned in Section 2.5.6, the largest total land cover in the CSPA is Agriculture, followed by forest and swamp. Relating those land covers to soil type (detailed in the Watershed Characterization report), the largest land cover/soil type is agriculture on clay soil (18%) followed by agriculture on loam (17%), and then forest and swamp on sandy loam (9% each). The rest of the land cover/soil type comparisons vary below 5%, with the higher combinations coming in the high general land cover categories of agriculture, forest and swamp.

### 2.5.5 Topography

In the CSPA, elevation generally decreases in the southwestward direction, towards Lake Ontario and the St. Lawrence River (See Figure A2.19). Most of the watercourses in the CSPA originate in those elevated areas near the Frontenac Axis. As such, the highest elevation in the region occurs in the northwest, near Canoe Lake, at around 209.0 m GSC, while the stream bed elevation at the stream mouths is around 74.2 m GSC.

Amherst Island (Loyalist Township) and the Frontenac Islands are relatively flat, owing to their geologic origin as part of the bed of the predecessor lakes to Lake Ontario.

### 2.5.6 Land Cover/Use

The CRCA has used the Provincial Land Cover 28 geospatial data to characterize the CSPA (Figure A2.20), though the classes have been grouped together for ease of display as shown in Table 2.27.

<b>Figure 2.27 Land Cover Grouping</b>	<b>LandCover28 Grouping</b>	<b>Percentage of Total CSPA Area</b>
Water	Water	8.2 %
Bedrock	Bedrock	0.9 %
Other	Mudflats	4.3 %
Forest	Forest – Dense Deciduous	22.2 %
	Forest – Dense Coniferous	
	Forest Depletion – burns	
	Forest Depletion – cuts	
Swamp	Marsh – Intertidal	20.1 %
	Marsh – Inland	
	Swamp – Deciduous	
	Swamp – Coniferous	
	Fen – Open	
Settlement	Settlement and Developed Land	1.6 %
Agriculture	Pasture and Abandoned Fields	42.6 %
	Cropland	

Table 2.27: Land Cover 28 Combinations for Soil/Land Cover Comparison with Land Use Percentages in the CSPA

The land cover data could be as much as 20 years old (it is an amalgam of data from 1986 to 1997, with most from the early 1990's), and may not reflect current land use/cover, and certainly can not predict future information. But, given the uncertainty of other data sets, it is probably reasonable to use. The land cover data set can also be used to identify modeling parameters for subwatersheds of the CSPA. There is also consideration for analysis of historical air photos, or satellite imagery, to establish historical land use values, and changes. This could then be used to create models reflecting historic or possibly pre-settlement conditions, and could be used with population growth estimates to extrapolate into the future as well.

As is shown in Table 2.27, the predominant land use in the CSPA is agriculture, with forest and swamp as the next largest areas.

The Central Cataraqui Natural Heritage Study (CRCA, 2006b) found that forested area is increasing in the City of Kingston and Loyalist Township. However, this increase comes due to the retirement of agricultural land, and new trees planted or natural regrowth. At the same time, settlement areas are increasing. Both of these increases imply that agricultural land area is decreasing.

2.6 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.

2.6.1 Permits To Take Water

There are 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 (See Figure A2.21). The full permit listing is included in Appendix E.

The estimated total annual volume of water currently withdrawn across the CSPA is almost  $32.7 \times 10^7 \text{ m}^3$ . However, 88% of that is taken from Lake Ontario (82%) and the St. Lawrence River (6%), and is not necessarily directly related to this water budget (Figure 2.16).

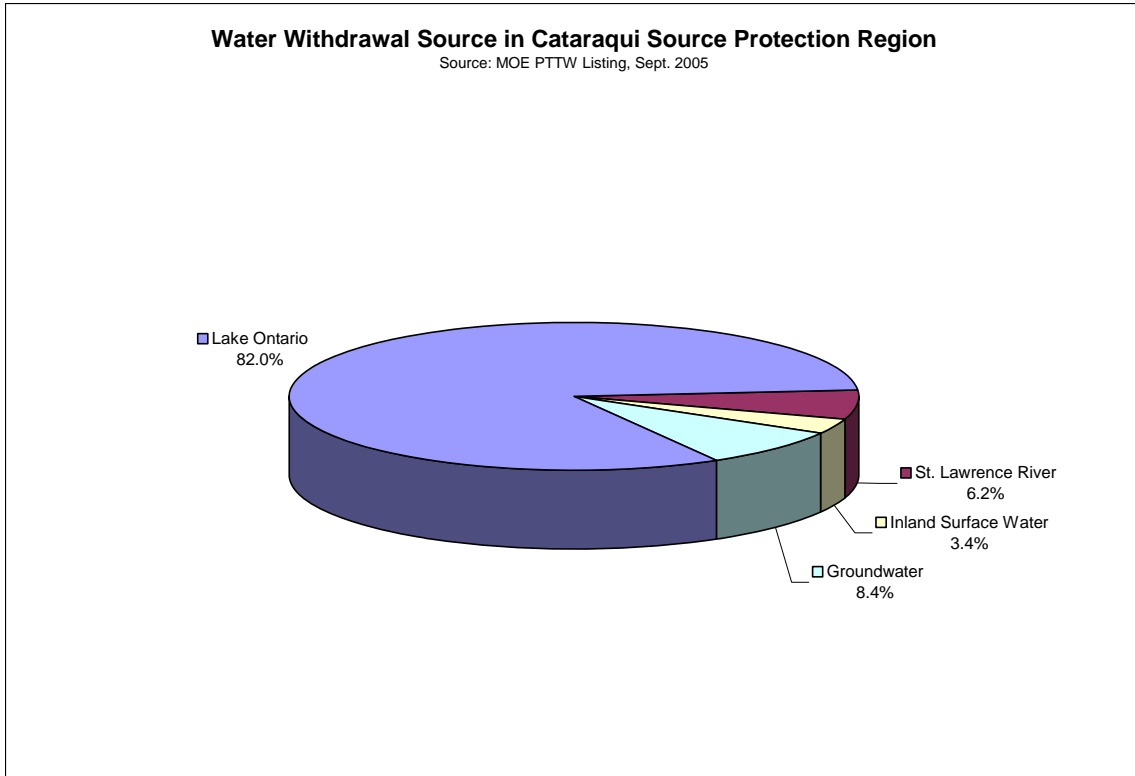


Figure 2.16: Water Withdrawal Source

Of the remaining 12%, 3.4% ( $1.10 \times 10^7 \text{ m}^3$ ) is taken from inland surface water sources, and 8.4% ( $2.74 \times 10^7 \text{ m}^3$ ) is taken from groundwater sources (not including domestic water wells).

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. The maximum daily permitted withdrawal values are multiplied by a monthly use factor, as per Table 2.28.

There are of course, expected to be withdrawals that are subject to a PTTW, but do not have one, and are therefore not accounted for in the above estimations. An initial assumption that there are as many nonpermitted uses as permitted uses will be used. Further revision may be warranted, depending on how this number relates to overall water use.

Figure A2.21 shows the locations of the PTTW in the CSPA, as well as the breakdown between surface and groundwater takings. Figure E.1a shows a breakdown of the permits by sector, and Figure E.1b shows a breakdown of the permits by taking volume. The Ducks Unlimited, and other similar wetland creation permits are included on these maps, and are generally the larger volume takers, strictly speaking to the permit values. However, in most cases the volume is a one time taking to fill the wetland, and there are minimal, if any, actual takings after that initial volume.

Specific Purpose	January	February	March	April	May	June	July	August	September	October	November	December
Aquaculture	1	1	1	1	1	1	1	1	1	1	1	1
Bottled Water	1	1	1	1	1	1	1	1	1	1	1	1
Golf Course Irrigation	0	0	0	0	1	1	1	1	1	1	0	0
Mall/Business	1	1	1	1	1	1	1	1	1	1	1	1
Other - Commercial	1	1	1	1	1	1	1	1	1	1	1	1
Snowmaking	1	1	0	0	0	0	0	0	0	0	0	1
Other - Dewatering	1	1	1	1	1	1	1	1	1	1	1	1
Other - Industrial	1	1	1	1	1	1	1	1	1	1	1	1
Pits and Quarries	1	1	1	1	1	1	1	1	1	1	1	1
Aggregate Washing	0	0	0	0	1	1	1	1	1	1	1	0
Cooling Water	1	1	1	1	1	1	1	1	1	1	1	1
Food Processing	1	1	1	1	1	1	1	1	1	1	1	1
Manufacturing	1	1	1	1	1	1	1	1	1	1	1	1
Other - Industrial	1	1	1	1	1	1	1	1	1	1	1	1
Heat Pumps	1	1	1	1	1	1	1	1	1	1	1	1
Other - Miscellaneous	1	1	1	1	1	1	1	1	1	1	1	1
Recreational	0	0	0	0	0	1	1	1	1	0	0	0
Groundwater	1	1	1	1	1	1	1	1	1	1	1	1
Campgrounds	0	0	0	0	1	1	1	1	1	1	1	0
Communal	0.8	0.75	0.82	0.82	0.89	0.86	0.97	1	0.95	0.95	0.87	0.84
Other - Water Supply	0.8	0.75	0.82	0.82	0.89	0.86	0.97	1	0.95	0.95	0.87	0.84
Institutional	1	1	1	1	1	1	1	1	1	1	1	1
Municipal	0.8	0.75	0.82	0.82	0.89	0.86	0.97	1	0.95	0.95	0.87	0.84
Agriculture	0	0	0	0	1	1	1	1	1	1	0	0

Table 2.28: Actual Water Use Monthly Correction Factors (GRCA, 2004)

2.6.2 Municipal

There are thirteen municipal water treatment systems in the CSPA. Eight supplies remove water from Lake Ontario (Napanee, Sandhurst, Bath, Amherstview, Kingston Township, City of Kingston) or the St. Lawrence River (Gananoque, Brockville), one supply draws from an inland lake (Sydenham), with the remaining four drawing groundwater (Lansdowne, Cana Subdivision, Miller Manor Apts. and Valley View Court Apts.). In 2000, the municipal supply for Odessa was transferred from Millhaven Creek to Lake Ontario (Amherstview). In addition, the Federal Penitentiary at Joyceville (Pittsburgh/Joyceville Institution) has its own water supply system drawing from the River Styx on the Cataraqui River.

As yet, actual taking information has not been able to be obtained from the municipalities. Table 2.29 shows the maximum daily withdrawals based on the Permit to Take Water listing. The PTTW data will be used to estimate water withdrawals of the municipal supplies. The annual withdrawal is calculated assuming that the average daily withdrawal over the year is half of the maximum withdrawal. The Tier 1 work will use actual withdrawal data, if it is available at that time.

System	Source	Maximum Daily Withdrawal (m <sup>3</sup> )	Annual Withdrawal (m <sup>3</sup> )
Napanee	Lake Ontario	12,000	2,190,000
Sandhurst	Lake Ontario	600	55,000
Bath	Lake Ontario	3,800	696,000
Amherstview	Lake Ontario	9,000	1,640,000
Kingston Township	Lake Ontario	118,000	21,500,000
City of Kingston	Lake Ontario	39,500	7,220,000
Gananoque	St. Lawrence River	10,200	1,870,000
Brockville	St. Lawrence River	36,400	6,640,000
Joyceville	Colonel By Lake	1,200	219,000
Sydenham	Sydenham Lake	1,300	235,000
Odessa*	Millhaven Creek	2,000	404,000
Cana	Groundwater	300	50,000
Lansdowne	Groundwater	1,400	263,000
Miller Manor Apts.	Groundwater	70	8,000
Valley View Apts.	Groundwater	70	8,000

Table 2.29: Municipal Treatment Plant Withdrawal Volumes

(\* Mothballed)

From a CSPA conceptual water budget perspective, those municipal takings from Lake Ontario and the St. Lawrence are not necessarily a factor. However, some of this water will be used for irrigation (lawns, gardens) and will infiltrate the ground and recharge the groundwater. Much of this water will be near shorelines, and will have minimal impact on general CSPA groundwater levels.

The Lake Ontario water volume withdrawn for municipal purposes is estimated to be  $3.33 \times 10^7 \text{ m}^3$  per year. This supplies the Town of Greater Napanee, Village of Sandhurst, Village of Bath, Loyalist Township, and the City of Kingston.

The St. Lawrence River water volume withdrawn for municipal purposes is estimated to be  $8.51 \times 10^6 \text{ m}^3$  per year. This supplies the Town of Gananoque, and City of Brockville.

The inland surface water volume withdrawn for municipal purposes is estimated to be  $2.35 \times 10^5 \text{ m}^3$  per year. This supplies the Village of Sydenham. An additional  $2.19 \times 10^5 \text{ m}^3$  is withdrawn by the Federal Penitentiaries.

The inland groundwater volume withdrawn for municipal purposes is estimated to be  $3.30 \times 10^5 \text{ m}^3$  per year. This supplies the Cana Subdivision in Kingston, the Village of Lansdowne, the Miller Manor Apartments in Front of Yonge Township, and the Valley View Court Apartments in Athens.

There are an additional  $2.78 \times 10^6 \text{ m}^3$  per year withdrawn from inland surface waters, and  $7.24 \times 10^4 \text{ m}^3$  per year from groundwater for public supplies.

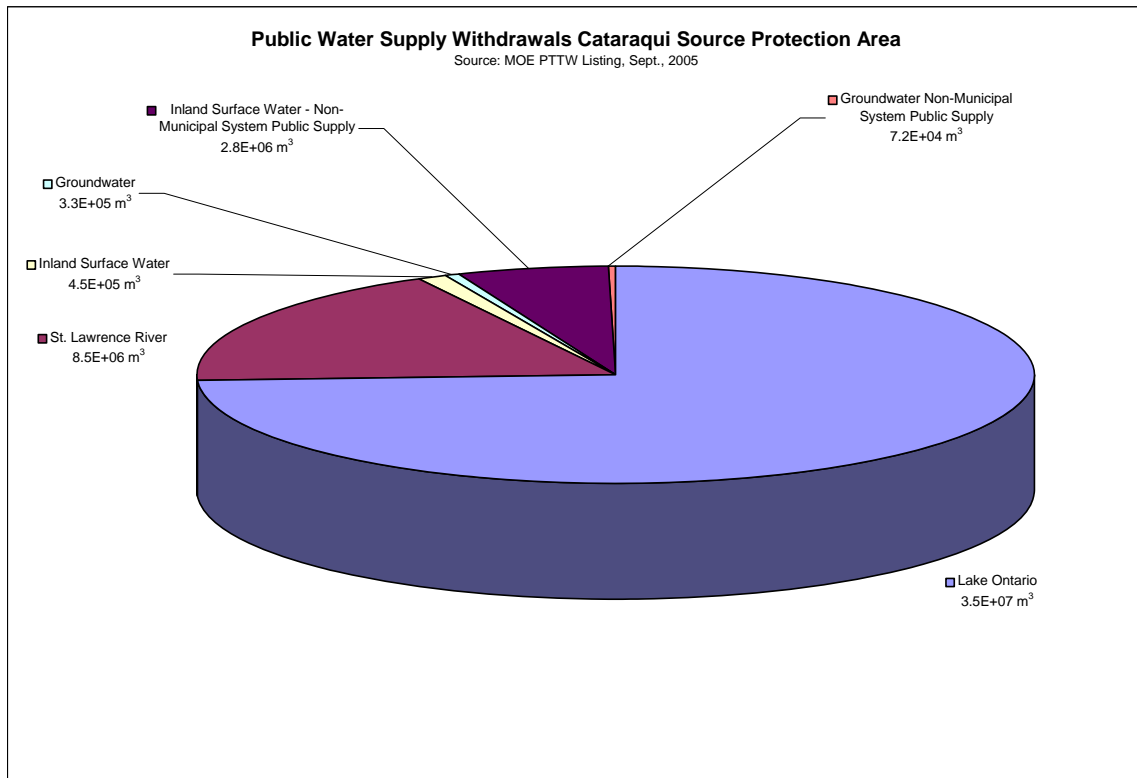


Figure 2.17: Public Water Supply Withdrawal Source

Figure A2.22 shows the location of the municipal treatment system intakes, as well as those wells classified as public water supply and municipal water supply in the water wells database or PTTW listing.

### 2.6.2.1 Water Wells

There are almost 25,000 wells across the CSPA (MOE, 2006c). These are a mixture of residential, agricultural, commercial/industrial, and institutional uses, as well as abandoned wells.

Use Category	Number of Records	Percentage
Domestic	20213	81.3%
Stock	1327	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	1513	6.1%
Total	24855	100.0%

Table 2.30: Water Well Use Breakdown (MOE, 2006c)

There are approximately 20,200 private residential wells in the CSPA (MOE, 2006c), and there are approximately 67,300 residents in the CSPA (Environment Canada, 2001) not on municipal services, which equals roughly 3.3 persons/well. The StatsCan Rural Analysis Bulletin estimates approximately 2.75 persons/household, the Mississippi-Rideau SWP group calculated 2.85 persons/well for their watersheds, and the Quinte SWP group calculated 3 persons/well for their watersheds. Estimating a withdrawal volume of 0.175 m<sup>3</sup>/person/day (MOE, 2001), the total withdrawal would be 4.30 x 10<sup>6</sup> m<sup>3</sup>. This volume is approximately 16% of the PTTW groundwater withdrawals. There are no withdrawal estimates available for other categories of wells. Figure A2.23 shows the extent of wells across the CSPA.

Figure E.2a shows the distribution of domestic wells across the CSPA, and Figure E.2b shows the distribution of the other wells. There are a number of wells used for agricultural purposes (stock, irrigation) and a large portion either not used, or lacking a designation. The wells used for agriculture, commercial, or municipal supply purposes are also included on the maps showing those specific uses.

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.

### 2.6.3 Industrial

Direct industrial water takings are generally located either along the Lake Ontario/St. Lawrence shoreline, and take directly from the surface source, or are in a location with a municipal supply, and use water from this source. As such, they will have little effect on most of the water budget process, since Lake Ontario/St. Lawrence River are outside the Water Budget area, and municipal takings being accounted for in a separate category.

The large industrial users with a PTTW are shown in Figure A2.24. They include:

- Lafarge (Lake Ontario)
- Lennox & Addington Generating Station (Lake Ontario)
- Celanese (Lake Ontario)
- 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)

### 2.6.4 Commercial

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 there were once aquaculture companies in the region, one near Gananoque, and one near Mallorytown.

There are also a number of dewatering activities in quarries around the region, which can be lumped 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

Those commercial users with a PTTW, or a well with a commercial use designation, are shown in Figure A2.24.

### 2.6.5 Agricultural

There are four agricultural operations in the CSPA that are large enough to require a PTTW, but most are too small. However, data is available from 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.

These three sources of information were used to create Figure A2.25, which shows the agricultural water use per area according to the MNR data, agricultural PTTW user locations, as well as those water wells which have been noted to have an agricultural use.

Summing the MNR data for the entire CSPA, the volume of use is  $1.2 \times 10^6 \text{ m}^3$ , which is equal to an approximate depth of 0.3 mm spread over the CSPA.

### 3.0 Data Uncertainty

As is noted in previous sections, there are uncertainties related to the measured climate data and the streamflow data, as well as the calculated ET values. Individual precipitation gauges have a 10% uncertainty (Dingman, 1994) (Snow values alone can have as much as 30% uncertainty), while streamflow has a 5% uncertainty (Dingman, 1994, Arsenault, 2006). Much of the uncertainty is actually due to bias common to all measurement sites (Hogg, 2007).

The uncertainty of the data itself can generally be quantified, but the uncertainty in the parameter values created through various methods (Thornthwaite ET, MOEE 1995 recharge, etc.) is unknown, and could be quite substantial. These methodologies should be used with caution.

#### 3.1 Precipitation

Uncertainty in precipitation measurements are typically related to undercatch, that is, the gauge measuring less precipitation than actually occurred. Uncertainty in precipitation data (longer term, not individual events) is generally accepted at around 10%, with the uncertainty of rain data also around 10%, and the uncertainty of snow data higher, as much as 30%. The cause of the uncertainty is related to a number of factors, such as (Mekis & Hogg, 1999, Winter, 1981, Dingman, 1994):

- Instrument error – between 1 and 5% of total catch, high intensity events can also overwhelm tipping bucket rain gauges, with water spilling out of the buckets and not being measured.
- Change in measurement techniques – modifications to the gauge, or measurement with the gauge.
- Observer error – the observer can introduce error through inaccurate measurement, timing of observation, and transcription of data.
- Location – obstructions, tall trees, road spray, etc. can all affect the amount of precipitation that reaches the gauge. Station relocation will also increase uncertainty.
- Height above the ground – ground surface is thought to be the best elevation for true measurement, this can account for 5 to 15% uncertainty over the long term, and as much as 75% for an individual event.
- Wind/wind shield – lack of wind shield can cause an undercatch of as much as 20%.
- Splash - from the surrounding ground if the gauge is placed near the ground surface.
- Evaporation - from the gauge reservoir, not a problem with tipping bucket gauges.
- Gauge wetting - precipitation needed to wet the surfaces in the initial stages of an event.
- Calibration - Inadequate calibration of the gauge can lead to improper measurement.
- Snow to water conversion - Typically assumed as a factor of 0.1, which is not correct in all cases.

- Melting of snow – snow can be melted and measured by gauges, which introduces uncertainty due to possible evaporation when the snow is heated.
- Low intensity rainfall – too little precipitation to be recorded by the gauge.

### 3.2 Streamflow

Uncertainty in streamflow data is generally accepted at around 5%, and is also caused by a number of factors, such as (Winter, 1981, Dingman, 1994, Arsenault, 2006):

- Observer error – inaccurate measurement, improper use of the equipment.
- Calibration/efficiency of the meter.
- Selection of sampling points – the greater number of points selected, the lower the uncertainty in the calculated flow.
- Measurement of the cross-sectional area.
- Stage-discharge curve uncertainty/unstable control.
- Cross-section location.

### 3.3 Evaporation/Evapotranspiration

The uncertainty of ET values are more difficult to quantify in this case, as a variety of measured data is used to estimate ET rather than it being measured directly. Based on experience with this data, Hogg (2007) estimated that an uncertainty of 5% for ET would not be unreasonable. Winter (1981) estimates the uncertainty of annual lake evaporation values to be less than 10%. This uncertainty is related to:

- Evaporation pan water temperature greater than lake water temperature.
- Wind conditions different near pan than over lake.
- Use of only one set of pan data for an entire lake, where conditions vary so much that multiple pans should be used.
- Location of pan onshore, while evaporation is taking place over lake.
- Coefficient to convert pan data to actual lake evaporation data.
- Maintenance – pans need daily maintenance to maintain accuracy of measurement.

The ET data also has uncertainty associated with inadequacy of the empirical relationship of  $ET = P - Q$  (Hogg, 2007).

### 3.4 Water Use

In this water budget, the PTTW water use has been modified to account for seasonal water use changes between sectors, however, consumptive use has not been considered, which is assumed to cause the water use volume estimated to be larger than the actual case. In addition, it has been assumed that there are as many non-permitted water uses as there are permitted uses, and the water use estimates have been doubled.

The uncertainty of water use is probably quite large, and in this work, is estimated at 100% (the water use volumes have been doubled). However, with the small volume of water use in relation to evapotranspiration or streamflow, even this large uncertainty

causes quite minimal uncertainty in the overall average annual CSPA-wide water budget (~1%).

### 3.5 Groundwater

In this water budget, there are a number of assumptions related to groundwater which can result in uncertainty to the water budget. The assumed balance of groundwater in vs. groundwater out may in fact be untrue, resulting in an imbalance of the overall water budget. Depending on whether groundwater in is greater than groundwater out, or vice versa, this may serve to bring the overall IN and OUT components of the water budget closer together.

### 3.6 CSPA Uncertainties

Considering the specific CSPA data values:

Attributing the 10 % uncertainty strictly to undercatch, and assuming the average value of precipitation has the same uncertainty as the individual stations, then:

Mean Annual Precipitation = 954 mm      Uncertainty (10 %) = 95 mm

For the precipitation values, that gives a range from 954 mm to 1049 mm that would be within the uncertainty of the data. The average annual precipitation value (including 10% uncertainty) of each of the 18 stations used in this analysis falls within that range. The standard error of the full set of data, 18 stations, 360+ values, 30+ years, is 6 %.

Mean Annual Runoff = 452 mm      Uncertainty (5 %) = 23 mm

For the streamflow values, the uncertainty range is from 429 mm to 475 mm. Of the eight stations, only two fall outside this range when considering the 5% uncertainty of their average values. They are the two urban stations (Buell's below the range and Little Catawqui Creek above the range). It is not clear exactly what may be causing the discrepancy, but these two stations are expected to be atypical due to hard surface runoff, storm sewer drainage, drainage area inconsistencies, a short period of record with incomplete years, and the continuing urbanization of the watersheds.

As was discussed in Section 2.2, there are known drainage area discrepancies with these two stations. A reduction in drainage area of 22 % for Buell's, and an increase of 14 % for Little Cat, would bring their range of values within the overall uncertainty range. It is quite possible that the reason the data falls outside the uncertainty range is that the drainage area estimates are indeed still incorrect.

The standard error of the full set of data, 8 stations, 160+ values, 30+ years, is 9 %.

Coming back to the simplified water budget equation from Section 1.3,

$$P = ET + SW_{out}, \text{ or } ET_{derived} = P - Q$$

Using the calculated values above, the  $ET_{\text{derived}}$  is 502 mm. This value is lower (10 %) than the ET estimates using climate data and the Thornthwaite and Turc equations. The uncertainty of ET can be calculated via the following equation:

$$Uncty_{ET} = \sqrt{Uncty_P^2 + Uncty_Q^2} \quad Uncty_{ET} = \sqrt{95^2 + 23^2} \quad Uncty_{ET_{\text{derived}}} = 98$$

The uncertainty of most of the other data is not necessarily quantified, but is expected to be less than the precipitation and streamflow data uncertainties.

As stated above, the greatest percentage uncertainties are likely in the withdrawal estimates, as the PTTW listing includes the maximum allowable taking, which is generally estimated by the proponent to be the maximum ever needed over the course of the permit life. However, given the relative volume of the taking compared to the climate parameters, the overall uncertainty is fairly small.

#### 4.0 Water Budget Values

The values for the average annual water budget are shown in Table 4.1 and Table 4.2, as well as in a block diagram in Figure 4.1.

Parameter	Flux (mm/yr)	Uncertainty (mm)	Volume (Gm <sup>3</sup> /yr)	Uncertainty (Gm <sup>3</sup> )
Precipitation	954	95	3.40	0.34
Groundwater In from Quinte/Rideau Watersheds	?		?	
Total	954		3.40	

Table 4.1: Water Budget Parameters and Values - IN

Parameter	Flux (mm/yr)	Uncertainty (mm)	Volume (Gm <sup>3</sup> /yr)	Uncertainty (Gm <sup>3</sup> )
Evapotranspiration, ET <sub>Thornthwaite</sub>	553		1.97	
Evapotranspiration, ET <sub>Turc</sub>	552		1.97	
Evapotranspiration, ET <sub>derived</sub> *	502	98	1.79	0.35
Evapotranspiration, ET <sub>GIS w/o water</sub>	502		1.79	
Evapotranspiration, ET <sub>GISw/ water</sub> **	553		1.97	
Lake Evaporation (Included in ET)	50		0.18	
Runoff (Includes GW discharge)	452	23	1.61	0.08
Surface Water Withdrawals <sub>PTTW</sub>	3		0.01	
SW Withdrawals <sub>Nonpermitted</sub>	3		0.01	
Groundwater Withdrawals <sub>PTTW</sub>	8		0.03	
GW Withdrawals <sub>Nonpermitted</sub>	8		0.03	
Private Well Withdrawals	1.2		0.004	
Agricultural Withdrawals	0.3		0.001	
Groundwater Out to Lake Ontario/St. Lawrence River	?		?	
Total*	978		3.49	
Total**	1028		3.67	

Table 4.2: Water Budget Parameters and Values – OUT

(\* Using ET<sub>derived</sub>, \*\* Using ET<sub>GISw/ water</sub>)

There is a discrepancy between the volume of water in versus the volume of water out of between 0.09 and 0.27 Gm<sup>3</sup>/yr (3 to 8 % of precipitation), which is within the accepted uncertainties of the data. This may be corrected (or minimized) if individual watersheds are examined, as will be done for the Tier 1 report.

It is assumed that most of the surface, groundwater and private withdrawals will be returned to the watershed after use. This also may account for a small portion of the discrepancy, as over the course of a year, some of this water may be accounted for multiple times. But the overall volume of withdrawals is so small compared to the natural processes, that the effect is quite small on the regional CSPA scale. At the

watershed or subwatershed scale of Tier 1, during a low precipitation month, these withdrawals may make up a greater percentage of the water budget.

As mentioned in the previous sections, with the wide variation of precipitation, streamflow, and evapotranspiration values, a discrepancy at the CSPA scale was expected.

There has been no quantification of groundwater into or out of the CSPA to this point, and there is no reason to refute our original assumption that  $GW_{in} = GW_{out}$ . However, based on the mapping from the two CSPA groundwater studies, it appears that groundwater may enter from the north-west (Napanee River watershed) and from the north (Rideau River watershed). Hopefully, this can be confirmed between the Conservation Authorities, as work progresses. It is a specific goal of the Tier 1 work to identify movement of groundwater between SWP Regions, as well as individual watersheds and subwatersheds of the CSPA.

It is also expected that groundwater exits the CSPA to Lake Ontario and the St. Lawrence River. Given the stratigraphy of the bedrock, it is also possible (as mentioned in Section 2.4) that precipitation which falls on the CSPA recharges to the bedrock layers, and flows into adjacent SWP regions.

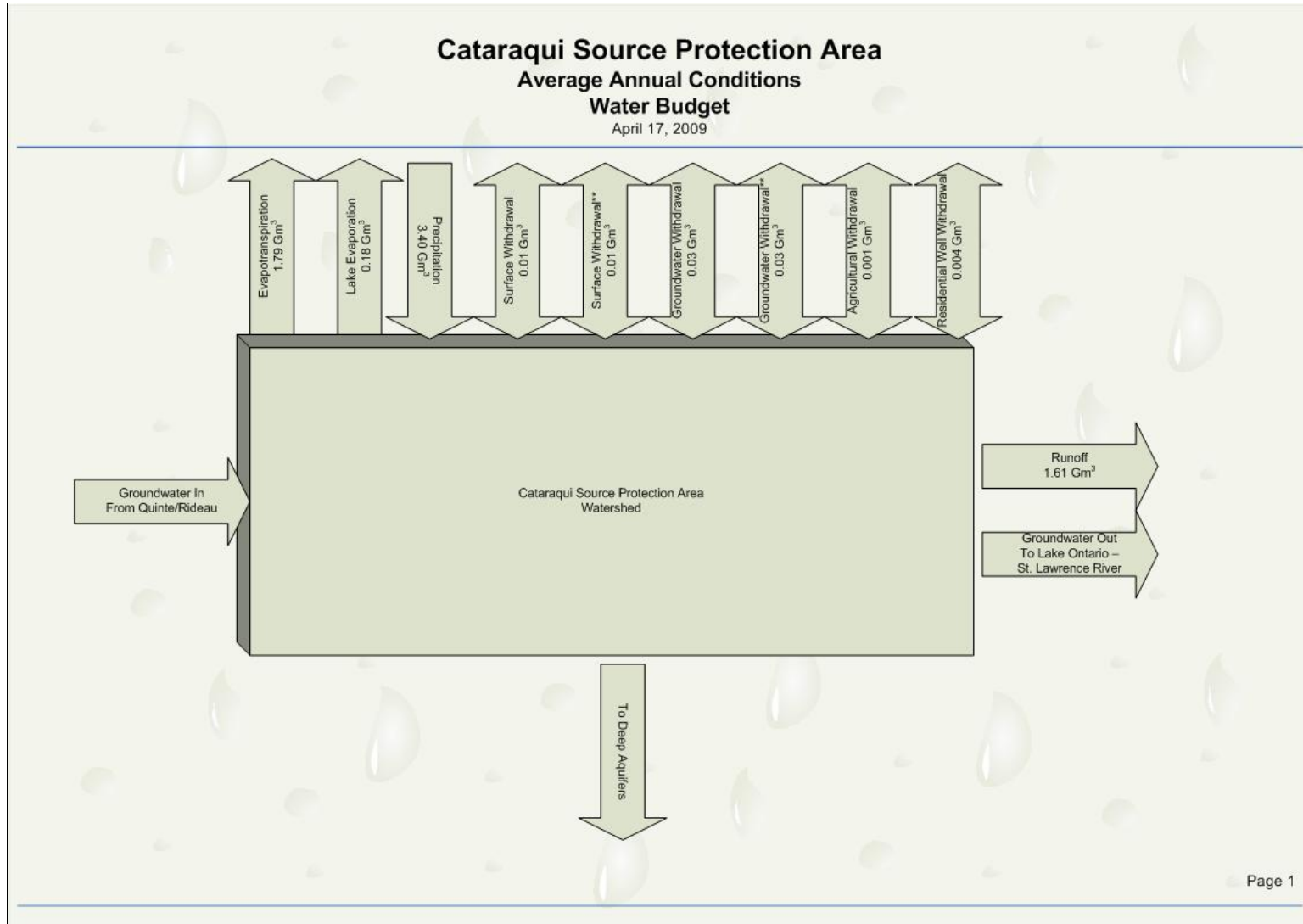


Figure 4.1: Average Annual Water Budget Block Diagram

## **5.0 Areas of “Stress”**

It is known that some streams and private wells go dry in periods of dry weather. It is expected that this generally occurs in August and September, as was noted in Sections 2.2 (Hydrology) and 2.4 (Groundwater). Specific subwatersheds will be evaluated for potential stress in Tier 1 (Figure A9.1).

There is a need to look at finer scales for the Tier 1 work. A monthly data, or smaller, time scale, and individual watershed, or subwatershed spatial scale will help identify those areas where stresses may be expected to occur. This more detailed examination should also quantitatively confirm the anecdotal information that has been gathered by the CRCA on dry areas.

## 6.0 Areas for Further Work

Subwatersheds may require more detailed water budget modeling, both from a surface and groundwater perspective. These areas are important because they are not specifically examined in the Conceptual report.

Areas to consider for future water budget work are detailed below:

### Millhaven Creek

- There is a new (2006) water treatment plant intake on Sydenham Lake.
- There is an existing water treatment plant intake in Odessa that has not been in service since 2001. The supply for this plant, Millhaven Creek, has run dry at least once since 1970.
- There is a wastewater treatment plant discharge in Odessa.

### Gananoque River

- The Village of Athens has considered constructing a water treatment plant, with possible intake from Charleston or Wiltse Lakes, or perhaps groundwater.
- The discharge from the Town of Gananoque sewage lagoons goes to Stockinghill Creek, and then the Gananoque River.
- The many lakes of the Gananoque River have many cottages/residences, which may be taking water from the lake, or discharging waste back to the lake.
- There has been an ongoing issue in 2004, 2005 and 2006 regarding a Golf Course withdrawing water from the river, and local residents concerned with the levels, and their access to the water, as well as the local power company, which needs the water to generate power.

### Buells Creek

- Buells Creek has many (near 100) Storm Sewer outfalls, as well as industrial outfalls.
- There are many recreation areas and school yards along the creek throughout the city.

### Little Cataraqui Creek

- There are many storm sewer outfalls along the creek.
- There are many recreation areas along the creek throughout the city.
- The creek mouth is adjacent to the Kingston West water and wastewater treatment plants

### Cataraqui River

- The Joyceville Penitentiary water plant intake is on the Cataraqui River.
- Many of the lakes of the Cataraqui River have cottages/residences, which may be taking water from the lake, or discharging waste back to the lake.

Figure A6.1 shows the density of wells across the CSPA. Given the lack of groundwater information in the CSPA, additional work is needed on recharge studies, including rain

gauges at the existing PGMN well sites and more monitoring wells drilled to produce a more extensive water level data set for recharge monitoring. This additional information will support future water budget work.

## 7.0 Field Program

Our field program includes gathering additional data to fill the following information gaps:

- Streamflow
- Precipitation
- Temperature
- Soil Moisture
- Soil Infiltration
- Groundwater Levels
- Structure Water Levels
- Evapotranspiration

138 stream locations were visited between May 2006 and October 2006, where flow, temperature, substrate, and vegetation information were collected (Figure A7.1). This work will continue in the 2007 field season, and beyond. Stream temperature is also being monitored at a number of sites to look for cold-water fisheries, as well as groundwater discharge to the streams.

Details of the field information are contained in Section 2.4.5 and Appendix E.

## 8.0 Information Gaps

We are aware of the following key information gaps:

- Evapotranspiration
- Infiltration/Recharge
- Stream Gauges in the central watersheds
- Water use – actual taking data

Additional data gaps are identified in Appendix C of the Watershed Characterization Report.

It is the goal of the SWP team to try to fill these gaps with continued searches for data, as well as enhanced field monitoring. These may not be filled for the current incarnation of the Water Budget work, but should help to maintain continued improvement in the water budget knowledge across the CSPA.

## 9.0 Discussion and Next Steps

The Conceptual Water Budget report summarized the water budget for the entire CSPA, under average annual conditions. The following objectives, as laid out in Section 1.1, have been met:

- The water budget parameters for the average annual conditions were quantified.
- The interaction of the various water budget parameters was detailed.
- The temporal and spatial scales were set.
- The CSPA was divided into logical study areas.
- The most appropriate model or models to begin Tier 1 work has been identified as a spreadsheet model. Future phases may require more intricate modeling.

Given the temporal (average annual) and spatial (full CSPA) scales specified in this report, the ultimate modeling which best suits the CSPA watersheds can not yet be identified. This will, again, be better explored with the Tier 1 (and further) work. Information gaps have been identified. Specifically, it is unlikely that any complex models will be needed at this time, as there are minimal inland municipal drinking water systems, and minimal data to support model development/calibration. Perhaps, on a subwatershed basis, more detailed modeling will be required, and this will be assessed through Tier 1, and future, work.

Given that the conceptual report was initiated to look at average conditions for the CSPA, this objective could not be met through these conditions. But, the groundwork has been laid to further explore this work in the Tier 1 or future water budget reports.

Subwatershed stress will be evaluated in the Tier 1 Water Budget report. The Tier 1 report will need to consider:

- Monthly data for precipitation and streamflow,
- Watershed specific values for climate and withdrawal data,
- Snow and lake storage, as well as structure operations,
- Actual water use data, and
- Groundwater storage\*, flow into and out of the watershed.

\*It is felt by the Peer Review Team involved in the review of this document that consideration of groundwater storage is critical to the complete examination and understanding of the water budget of the CSPA, even though it is not explicitly considered in the guidance documents.

Some of this work has been started, as it was necessary to summarize the data presented in this Conceptual report.

Each individual watershed (twelve) will be evaluated on a monthly water budget basis for the Tier 1 report. In addition, select subwatersheds should be evaluated on a monthly basis, such as specific subwatersheds that currently have a municipal residential drinking water system (e.g. Sydenham Lake, or the Lansdowne area). At this time, there are five

inland municipal residential drinking water systems and numerous inland public and municipal intakes and wells.

There are four specific screening questions noted in the Guidance Modules:

- Is the water supply from an international or inter-provincial waterway or from a large inland water body only?
- What is the required level of numeric modeling?
- Are both groundwater and surface water models needed?
- Are there sub-watershed-wide water quality threats and issues that require complex modeling to assist with their resolution?

To answer those specific questions, based on the Conceptual Water Budget:

- Of the thirteen municipal water supply systems in the CSPA, eight of them are from international waters. The other five are from inland sources, both surface water and groundwater.
- The ultimate level of numerical modeling has not yet been determined, but it is expected that in most cases, a spreadsheet model will suffice for the CSPA. A spreadsheet model is planned for the Tier 1 Water Budget work. However, specific systems/areas may require more detailed modeling, with numerical models, and the Tier 1 Water Budget work should identify these areas.
- There are both surface and groundwater systems in the CSPA, so both surface and groundwater models would be needed, if models are in fact needed, this will again be identified in the Tier 1 Water Budget.
- At this time, no specific subwatershed water quality threats and issues have been identified that require complex modeling. However, there are known areas, threats and issues which may require complex modeling in conjunction with the Source Water Protection program.

While the Conceptual Water Budget report has not fully quantified the water budget for the CSPA, it has laid the groundwork, and provided an opportunity to explore all the data sources and water connections throughout the CSPA.

## 10.0 References

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## 10.1 Map Data References

### **General Ontario Mapping Data**

From *Ontario Geospatial Data Exchange*.

- Roads
- Water – lakes and streams
- Political Boundaries
- Cities/Towns/Villages

### **Figure A1.2 CSPA Watersheds and Study Areas**

### **Figure A2.1 Historic Environment Canada Climate Stations**

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### **Figure A2.2 Environment Canada Stations with calculated Climate Normals**

Environment Canada, 2003. *Climat Database*. Environment Canada, Downsview, ON.

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### **Figure A2.3a Canadian Forestry Service Precipitation Map - Eastern Ontario**

McKenney, D.W. 2006. *Precipitation and Temperature Mapping across Canada*. Natural Resources Canada, Canadian Forestry Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON.

### **Figure A2.3b Canadian Forestry Service Precipitation Map - Cataraqui Source Protection Area**

McKenney, D.W. 2006. *Precipitation and Temperature Mapping across Canada*. Natural Resources Canada, Canadian Forestry Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON.

### **Figure A2.4a Canadian Forestry Service Temperature Map - Eastern Ontario**

McKenney, D.W. 2006. *Precipitation and Temperature Mapping across Canada*. Natural Resources Canada, Canadian Forestry Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON.

**Figure A2.4b Canadian Forestry Service Temperature Map - Cataraqui Source Protection Area**

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**Figure A2.5 Soil Water Holding Capacity Map**

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**Figure A2.6 Evapotranspiration Map**

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#### **Figure A2.7 CSPA Slope**

MNR. 2003. *Digital Elevation Model of Ontario*. Ministry of Natural Resources, Peterborough, Ontario.

#### **Figure A2.8 CSPA Soils**

Gillespie, J.E., R.E. Wicklund, and B.C. Matthews, 1963. *The Soil Survey of Lennox and Addington County. Report No. 36 of the Ontario Soil Survey*. Ontario Department of Agriculture and Food & Canadian Department of Agriculture. Toronto, Ontario & Ottawa, Ontario.

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#### **Figure A2.9 CSPA Land Use**

MNR. 2003. *Land Cover 28 Mapping*. Ministry of Natural Resources, Peterborough, Ontario.

#### **Figure A2.10 MOEE Infiltration/Recharge Coefficient Map**

MOEE. 1995. *MOEE Hydrogeological Technical Information Requirements for Land Development Applications*. Ministry of Environment and Energy. Toronto, Ontario.

#### **Figure A2.11 Stream Gauge Locations**

Environment Canada, 2005. *Hydat Database*. Environment Canada, Burlington, ON.

**Figure A2.12 Provincial Groundwater Monitoring Network Well Locations**

CRCA. 2006. *PGMN Data*. Cataraqui Region Conservation Authority, Glenburnie, ON.

Environment Canada, 2003. *Climat Database*. Environment Canada, Downsview, ON.

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MOE. 2006c. *Water Well Information System Database*. Ministry of Environment. Toronto, ON.

**Figure A2.13 Structure Locations**

CRCA. 2006. *Water Control Structure Data*. Cataraqui Region Conservation Authority, Glenburnie, ON.

**Figure A2.14 Land Use**

MNR. 2003. *Land Cover 28 Mapping*. Ministry of Natural Resources, Peterborough, Ontario.

**Figure A2.15 Bedrock Geology**

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**Figure A2.16 Surficial Geology**

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**Figure A2.18 Overburden Thickness**

Dillon. 2001. *Leeds-Grenville County Groundwater Study*. United Counties of Leeds-Grenville, Brockville, ON.

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**Figure A2.19a Soils Overview**

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**Figure A2.19b Soils Detailed**

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**Figure A2.20 Topography**

MNR. 2003. *Digital Elevation Model of Ontario.* Ministry of Natural Resources, Peterborough, Ontario.

**Figure A2.21 Water Use – Permit To Take Water Locations Surface Water vs. Groundwater Takings**

MOE. 2005. *Permit to Take Water Listing.* Ministry of the Environment, Kingston, ON.

**Figure A2.22 Municipal Water Supplies**

MOE. 2005. *Permit to Take Water Listing.* Ministry of the Environment, Kingston, ON.

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**Figure A2.23 Water Wells**

MOE. 2006c. *Water Well Information System Database.* Ministry of Environment. Toronto, ON.

**Figure A2.24 Industrial/Commercial Water Supplies**

MOE. 2005. *Permit to Take Water Listing.* Ministry of the Environment, Kingston, ON.

MOE. 2006c. *Water Well Information System Database*. Ministry of Environment. Toronto, ON.

**Figure A2.25 Agricultural Water Supplies**

de Loe, R. 2002. *Agricultural Water Use in Ontario by Watershed: Estimates for 2001*. Prepared for the Ontario Ministry of Natural Resources, Peterborough, ON

MOE. 2005. *Permit to Take Water Listing*. Ministry of the Environment, Kingston, ON.

MOE. 2006c. *Water Well Information System Database*. Ministry of Environment. Toronto, ON.

**Figure A6.1 Well Density**

MOE. 2006c. *Water Well Information System Database*. Ministry of Environment. Toronto, ON.

**Figure A7.1 Field Sites**

CRCA. 2006. *2006 Field Season Data*. Cataraqui Region Conservation Authority, Glenburnie, ON.

**Figure A9.1 Tier 1 Sites**

CRCA. 2007. *Cataraqui Source Protection Area Conceptual Water Budget*. Cataraqui Region Conservation Authority, Glenburnie, ON.

**Figure E.9 Field Sites with Bedrock Geology Underlay**

Bedrock Geology Map – Figure A2.15

CRCA. 2006. *2006 Field Season Data*. Cataraqui Region Conservation Authority, Glenburnie, ON.

**Figure F-1a Water Use - Permit To Take Water Locations by Sector**

MOE. 2005. *Permit to Take Water Listing*. Ministry of the Environment, Kingston, ON.

**Figure F-1b Water Use - Permit To Take Water Locations by Taking Volume**

MOE. 2005. *Permit to Take Water Listing*. Ministry of the Environment, Kingston, ON.

**Figure F-2a Domestic Wells**

MOE. 2006c. *Water Well Information System Database*. Ministry of Environment. Toronto, ON.

**Figure F-2b Other Wells**

MOE. 2006c. *Water Well Information System Database*. Ministry of Environment. Toronto, ON.