

Our File: 03-1813



October 20, 2004

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Attention: Mr. Bryon Keene, P.Eng
Project Manager - Quinte Regional Groundwater Study

RE: Quinte Regional Groundwater Study - Final Report

Dear Mr. Keene:

We are pleased to present our Final Report for the Quinte Regional Groundwater Study. On behalf of our team, I wish to thank Quinte Conservation, the Steering Committee and members of the Technical Advisory Group for the opportunity to conduct this most interesting study on the Quinte area.

Overall, this study has shown that groundwater is a vital source of both potable and non-potable water for the area's residences and businesses, and therefore merits protection from both a quality and quantity perspective. The results of this study will enable the community to better understand the regional groundwater system, and to wisely develop management strategies for the protection of this most valuable resource.

Yours sincerely,

DILLON CONSULTING LIMITED

A handwritten signature in blue ink, appearing to read "Darin Burr".

Darin Burr, M.Sc., P.Geo.
Project Manager

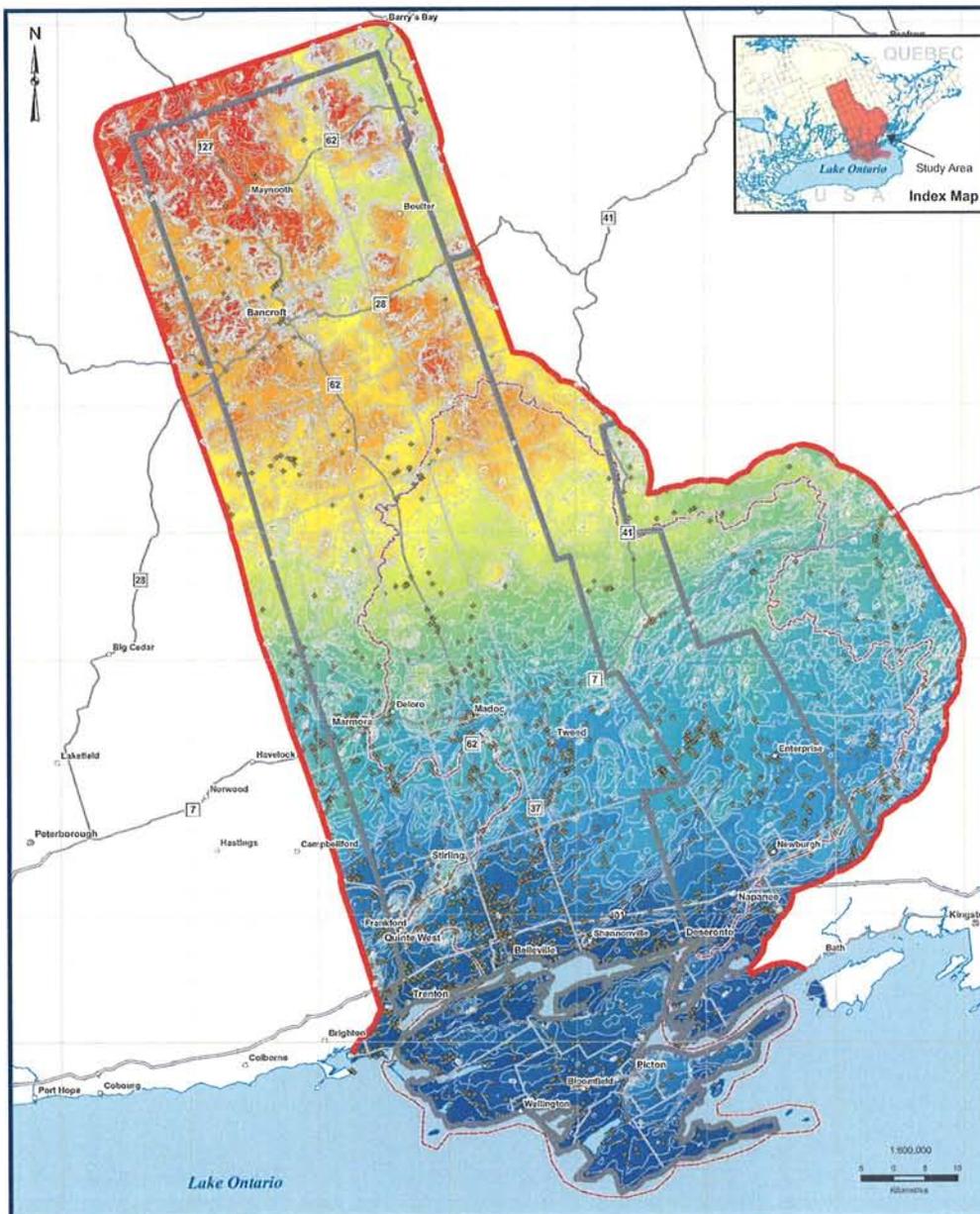
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QUINTE REGIONAL GROUNDWATER STUDY

Final Report
October, 2004



Prepared for:

Quinte Conservation

Prepared by:

Dillon Consulting Limited

In Association with

Golder Associates Ltd.
Lissom Earth Sciences
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EXECUTIVE SUMMARY

The Ontario Ministry of the Environment has teamed up with local municipalities, Counties and related agencies to undertake a groundwater study in the Quinte Region. The Study Area encompasses: Hastings County, Municipality of Prince Edward County, Municipality of Stone Mills in Lennox and Addington County, and the balance of the Quinte watershed. Specific emphasis was placed on the study partner municipalities of Hastings Highlands, Carlow/Mayo, Bancroft, Madoc, Tweed, City of Belleville, Tyendinaga, Prince Edward County and Stone Mills.

Study Objectives

The principal objective of this study was to develop an understanding of the groundwater resources in the Quinte Region. With this knowledge, management strategies are developed to protect groundwater resources, in order to maintain a safe supply of potable water for current and future generations and to protect the water resource ecosystem. To fulfill this objective, several separate but related work tasks were performed, including:

- i) Characterizing the regional groundwater flow systems, including areas of significant groundwater recharge and discharge;
- ii) Assessing the water resource capabilities of the regional aquifers;
- iii) Mapping areas vulnerable to groundwater contamination;
- iv) Compiling data relating to the existing use of the groundwater resource;
- v) Identifying major potential sources of groundwater contamination; and
- vi) Developing recommendations for groundwater management and protection strategies that can be implemented.

Data generated and compiled during this study were placed into a Geographical Information System (GIS) to facilitate future manipulation and presentation of data.

Study Approach

The study was completed in several stages:

PART 1: Understanding and Assessment of the Regional Groundwater Resource

PART 2: Assessment of the Existing Use of Groundwater

PART 3: Evaluation of Potential Contaminant Sources

PART 4: Evaluation of Groundwater Management and Protection Measures.

The results of the first three steps were used as input into the evaluation of future groundwater management and protection measures.

In addition to the above, separate capture zone and well head protection area studies were performed for the municipal water supply systems in Centre Hastings (Madoc system), Municipality of Tweed (Tweed system) and Prince Edward County (Peats Point subdivision system). The results of these studies are presented in separate reports.

Overall management of the Study was provided by Quinte Conservation. Direction for the study was provided by a Screening Committee (consisting of municipal representatives from the Study Area, Ontario Ministry of the Environment, Ontario Ministry of Agriculture and Food, local Health Units and Conservation Authorities) and a Technical Advisory Committee (made up of political, technical and municipal staff representatives and Quinte Conservation staff). The purpose of the Technical Advisory Committee was to provide technical input and direction to the Steering Committee and the consultants during the Study.

Summary of Findings

Aquifers

The predominant aquifer in the Study Area is fractured bedrock. Precambrian rock is the main aquifer in Hastings Highlands, Carlow/Mayo, Bancroft, Madoc, Tweed, and the northern portion of Stone Mills. Limestone is the main aquifer in Prince Edward County, Belleville, Tyendinga, and the southern portions of Tweed and Stone Mills. Groundwater flow is through vertical and horizontal fractures within these rocks. In general, the top 10 to 30 m of the bedrock is heavily fractured and is, therefore, very susceptible to contamination.

Overburden sand and gravel aquifers are present in some localized areas but are seldom used because of their limited extent and thickness. The majority of overburden aquifers that are used to supply water occur as drumlins in the former Thurlow Township, and as glacial outwash deposits in Hastings Highlands, Carlow/Mayo and Bancroft. Sand and gravel deposits in the Picton to West Lake area in Prince Edward County are also used locally as an aquifer.

Groundwater Flow

The direction of regional groundwater flow mimics surface water drainage patterns. In the Moira and Napanee watersheds, the regional groundwater flow is directed south to southwest. In Prince Edward County, regional groundwater flow is outwards from the plateau areas and directed to the shorelines. Beyond the Quinte watershed, in the northern municipalities of Hastings County, regional groundwater flow directions are to the northeast. Local-scale groundwater flow directions at the individual lot and concession level often deviate from deeper groundwater flow directions because of the effects of local topography.

Groundwater Recharge and Surface Water Interaction

The entire Study Area can be considered a groundwater recharge area because of the predominance of fractures within the top portions of the bedrock aquifer. Precipitation that falls on the land will rapidly infiltrate these fractures and percolate to the aquifer below.

On a regional scale, some areas provide deeper aquifer recharge than others. In general, areas of deep regional recharge correspond with areas that are locally elevated, such as hills and bedrock plateaus. Groundwater discharge areas occur in lowlying regions such as ravines and river valleys. Some of the surface water features identified as potentially having a significant baseflow component include portions of the Salmon River, Napanee River, Moira River, York River, and Little Mississippi River. Many of the lakes and marshes in the northern municipalities also likely have a significant discharge component. Lakes and marshes on bedrock plateaus (e.g., Lake On the Mountain, Roblin Lake) in Prince Edward County may act as local aquifer recharge areas.

Aquifer Vulnerability

The majority of the Study Area has been mapped as highly vulnerable. Isolated occurrences of clay are present in some localities, but rarely attain thicknesses that would allow for significant protection of the underlying bedrock aquifer. The high vulnerability of the aquifer makes the entire Study Area susceptible to contamination. A few very small areas were identified as moderately vulnerable in the municipalities of Tweed, Madoc, Hastings Highlands and Carlow Mayo. These wells intercepted clay, silt or till layers that were of sufficient thickness to be deemed as providing some aquifer protection at the local scale.

Well Yields

Most wells provide sufficient volumes for residential use on private services (approximately 13 L/m or 3 gpm); however, the risk of drilling a low yielding well varies across the Study Area. Average pumping rates are generally higher in the southern municipalities in sedimentary aquifers (with the exception of Prince Edward County) than in the northern municipalities where the aquifer is Precambrian rock. Poor yielding wells (<1 gpm) are most common in Hastings Highland, Carlow/Mayo, Bancroft and Prince Edward County. The probability of drilling a well with an acceptable yield depends upon the amount of fractures intercepted by the well. Considering that these fracture patterns are irregular, it is difficult to predict an area of good water quantity.

Natural Water Quality

The natural water quality is generally good. Sulphur problems are restricted mainly to the limestone aquifer, and are greatest in areas that receive water from the shaley Verulam Formation. Areas prone to sulphur water problems include Prince Edward County, Tyendinga and Belleville. The risk of encountering salty water increases with well depth beyond 30 m. The least water quality problems are reported in the

municipalities that pump primarily from the Precambrian rock aquifer, such as Hastings Highlands, Bancroft, Carlow/Mayo, Madoc and the northern portions of Tweed and Stone Mills.

Groundwater Use

Within the Study Area, groundwater is a major source of water for domestic, commercial, and agricultural activities. The estimated groundwater use over the nine study partner municipalities participating in the Regional Study is approximately 5,400,000 m³/year. The largest groundwater use is for potable water supply from individual private wells.

Approximately 45,800 people (46% of the Study Area's population) rely on groundwater for their potable water supply. Groundwater users, by percentage of total population, are:

Stone Mills (100%)	Carlow/Mayo (100%)
Tyendinaga (100%)	Prince Edward County (59%)
Tweed (100%)	Town of Bancroft (38%)
Madoc (100%)	Belleville (13%)
Hastings Highlands (100%)	

There is no indication of regional depletion of the aquifers as a result of over pumping. Localized areas of aquifer mining or interference caused by over withdrawal likely occur; however, these situations are localized and do not reflect widespread problems. Since the bedrock aquifer is sensitive to precipitation events, water levels are prone to drop during periods of drought.

Contaminant Inventory

An inventory of known and potential contamination sources was developed. Where possible, geographic coordinates were assigned to each known or potential source. A detailed methodology was developed and documented when conducting this inventory, such that the procedure can be repeated when new or more accurate data become available. Land uses identified as the highest potential concern were abandoned landfills and auto junkyards.

The risk of contamination from agricultural land uses was assessed. While there were no reported incidences of large-scale regional impacts to groundwater from agricultural activities, the potential does exist, considering the high vulnerability of the aquifer. Potential contaminants include nutrients, fecal bacteria and pesticides.

Groundwater Resource Management Strategy

Groundwater management and protection in the Quinte Area is the responsibility of several levels of government, public organizations and the general public. The groundwater resource management measures developed for the Study Area address two areas of consideration:

- 1) Land uses and activities that could affect groundwater resources; and,
- 2) Specific groundwater resource features such as wellhead protection areas, water recharge area and vulnerable aquifers.

The strategy was developed based on the following “first principles”:

- Utilize planning tools for smart growth
- Adopt a watershed approach with Conservation Authority leadership
- Improve enforcement of existing rules
- Coordinate activities among government and agencies
- Encourage a “living strategy” with continuous improvement
- Build upon and expand non-regulatory programs.

The Study evaluated different land uses and potential protection measures, including the Province’s current role in the regulation of each use or activity, and municipal regulatory options. These measures are summarized in a detailed summary table found at the end of **Section 7** of this report. It is recognized that the roles and responsibilities of stakeholders in groundwater protection are proposed to change in the near future as part of the Provincial government’s watershed-based source protection initiative. The planning strategies provided in this report can be used as a source of information from which stakeholders can draw upon when developing their own source water protection plans.

**QUINTE REGIONAL
GROUNDWATER STUDY
Final Report**

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Section F-F'	Rednersville: Section along County Road 23, Prince Edward County

1. INTRODUCTION

1.1 Background

The Ontario Ministry of the Environment has teamed up with local municipalities, Counties and related agencies to undertake a groundwater study in the Quinte area. The study covers a region of approximately 5,300 km², and includes the municipalities of Prince Edward County, City of Belleville, Stone Mills Township, Centre Hastings, Tweed, Tyendinaga, Hastings Highlands, Town of Bancroft, Township of Madoc and Carlow/Mayo Township. The Study Area is shown in **Map 1.1**.

The goal of the Groundwater Study is to map the location of regional groundwater systems, assess their susceptibility to contamination, and to determine the quantity and quality of the groundwater within. The study provides recommendations for an updated groundwater management and protection policy to be considered for implementation by municipal planning staff within the Study Area. The data will also be input into a larger provincial effort to map groundwater conditions across Ontario.

One of the main functions of the study is to bring together the scattered pieces of groundwater information relevant to the Study Area. Several groups, including municipalities, Health Units, Conservation Authorities and provincial agencies, each have portions of the information that, when compiled and interpreted, provide the groundwater “big picture”. By investigating and sharing groundwater knowledge, stakeholders will be in a better position to understand the groundwater resources and their use, and to protect public health and the natural environment.

The study was performed in several stages, including: a Groundwater Resource Assessment, a Groundwater Use Assessment, a Groundwater Contamination Assessment and a Groundwater Management Strategy. The study involved the completion of land use surveys, review of geology mapping, review of databases on known and potentially contaminated sites, review of water well records, inventory of communal groundwater supply systems, identification of aquifer recharge areas, and mapping of areas where the aquifer is most susceptible to contamination.

In addition to the regional study, separate Well Head Protection Area (WHPA) studies were undertaken for the municipal water supply systems in the communities of Tweed and Madoc, and the Peats Point Subdivision in Prince Edward County. Results of these studies are presented as separate reports.

1.2 Study Partners

The study was financed in large measure (85%) by the Ontario Ministry of the Environment through its Operation Clean Water Program. It is part of a provincial effort to better understand the Province's groundwater resources. The remaining 15% was provided by the following partners:

- County of Prince Edward
- City of Belleville
- Stone Mills Township
- Municipality of Tweed
- Tyendinaga Township
- Township of Hastings Highlands
- Town of Bancroft
- Township of Madoc
- Township of Carlow/Mayo.

1.3 Study Goals

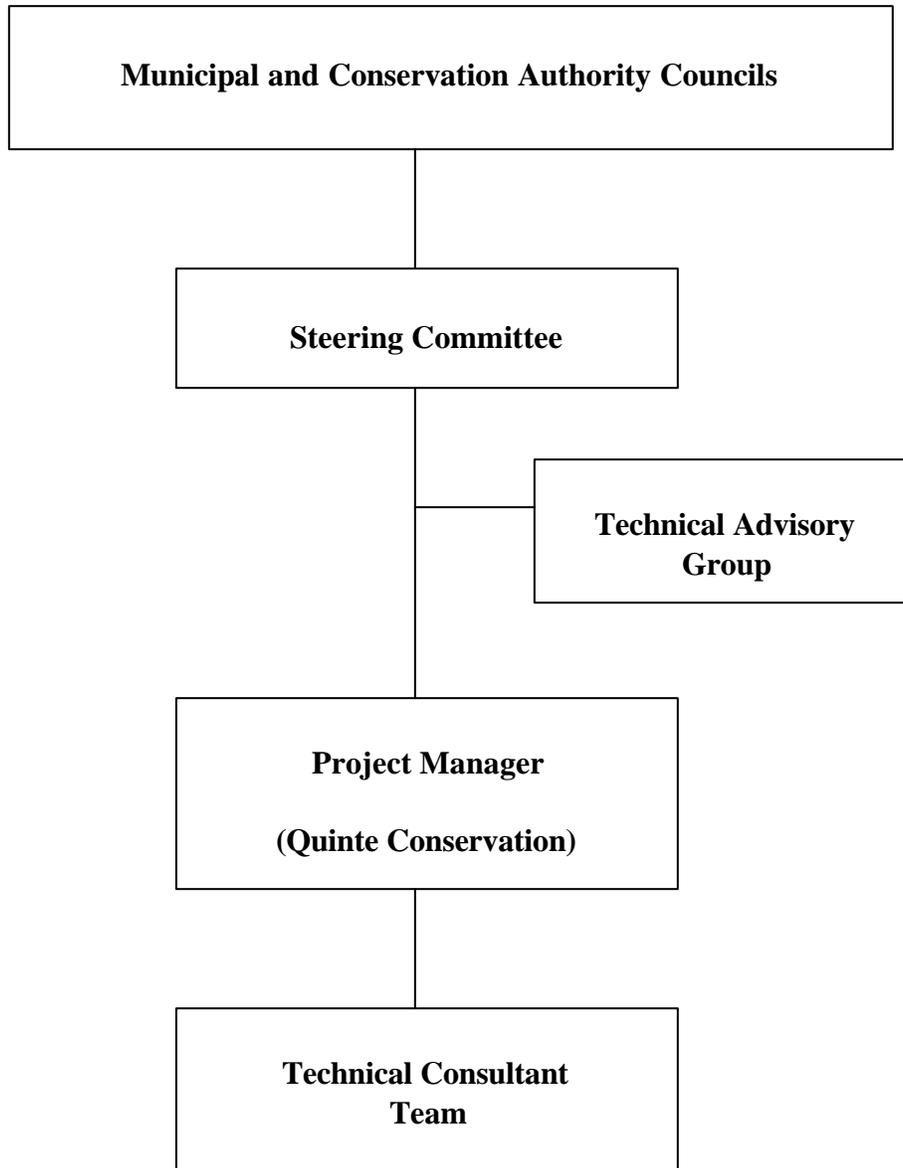
The principal goals of the study are, at a regional scale:

- 1) to map the location of significant groundwater aquifers and groundwater recharge/discharge areas, and to understand the groundwater flow system and quality conditions within such systems;
- 2) to inventory the major groundwater users within the Study Area and to assess whether aquifers, on a regional scale, can be expected to meet the groundwater demand;
- 3) to map areas where the aquifers are susceptible to contamination;

- 4) to identify known and potential contaminant sources that could possibly affect the quality of groundwater;
- 5) to inventory existing municipal, provincial and federal policies, guidelines and regulations that protect groundwater, and to identify various groundwater management strategies that the participating municipalities and Conservation Authorities can implement to enhance management and protection of groundwater resources within the Study Area; and
- 6) to develop a database and Geographic Information System (GIS) that can be used in the future by municipalities and Conservation Authorities to maintain data on the groundwater resources within the Study Area and to aid in future analysis, interpretation and management of these resources.

1.4 Project Organization

The organizational structure of the project is presented in the figure below.



Quinte Conservation (QC), on behalf of the Municipal Councils, administered the study. Reporting to the Councils was a Steering Committee comprised of members of the participating municipalities and Conservation Authorities that controlled the overall direction of the study and program objectives. A Technical Advisory Group, made up of individuals specialized in technical disciplines, was appointed to provide input to the Steering Committee on technical issues relating to the methodologies of the Consultant Team.

1.5 Acknowledgements

The successful completion of this study was the result of the invaluable contribution of many study partners including the Project Manager, the Steering Committee, and the Technical Advisory Group. These individuals provided guidance and advice throughout the study.

The members of the committees are listed below.

Project Manager

Bryon Keene (Quinte Conservation)

Steering Committee Members

Keith Taylor (Quinte Conservation)

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Kay Manderville (City of Belleville)

Robert Gaffney (Township of Stone Mills)

Darlene Plumley (Township of Stone Mills)

Margaret Walsh (Township of Tyendinaga)

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Doug Parks (Centre Hastings)

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Technical Advisory Group

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Andrew Landy (Hastings and Prince Edward Counties Health Unit)
Elizabeth Murray (County of Prince Edward)
Bob Putzlocher (Ontario Ministry of the Environment)
Jean Rixen (County of Hastings)
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Brent Barnes (Planning Peer Review)

Agricultural Watershed Associates, Ottawa, Ontario
Dr. Richard Coote (Agricultural Assessment)

1.6 Report Organization

This report is organized in 10 sections:

- Section 1:** presents an overview of the study objectives;
- Section 2:** reviews the physiography and surface drainage of the Study Area;
- Section 3:** summarizes the bedrock and overburden geology;
- Section 4:** details the results of the hydrogeology assessment;
- Section 5:** presents the existing groundwater use assessment;
- Section 6:** provides a regional assessment of the historical and potential sources of contamination;
- Section 7:** outlines the results of the groundwater management and protection assessment;
- Section 8:** summarizes the main components of the study; and,
- Section 9:** summarizes the recommendations.

References are listed in **Section 10**. A Glossary of Technical Terms used in the report is presented following the References.

Maps and Figures

There are two types of illustrations used in the report. Figures are included in the text, following the page where they are first referenced. The figures are letter size (i.e., 8 ½” by 11” paper) and are generally used to illustrate concepts or ideas discussed in the report. Maps are bound separately in a Map Booklet. The maps are a major part of the report, and

present ideas, themes and analyses that are central to the evaluation of the groundwater resource. The maps are ledger size (i.e., 11” by 17” paper). Both figures and maps are numbered similarly, first by the Section number of the report that discusses the map or figure, and then consecutively for that section. For example, there is both a **Figure 2.1** (found in the text) and a **Map 2.1** (bound separately).

Tables

Tables are numbered by Section number (e.g., **Table 5.1** etc.) and are found within the text.

Appendices

Appendices contain data tables and other detailed material and information that are referred to in the text of the report. The appendices are listed below:

Appendix A: summarizes the Public Consultation Materials

Appendix B: contains detailed Hydrogeological Data

Appendix C: contains detailed Groundwater Use Information

Appendix D: contains detailed Contaminant Inventory Information

Appendix E: presents the Agricultural Assessment Report

Appendix F: presents the detailed Groundwater Protection and Management Report.

2. OVERVIEW OF STUDY AREA

This section provides an overview of the landscape of the Study Area and summarizes the topography and drainage features.

2.1 Physiography and Topography

Physiography refers to the descriptions of landforms that commonly define the landscape of an area. As a result of the varied geological processes that have influenced the development of the Quinte region, a total of 7 diverse physiographic regions have been identified. The general locations of these regions are shown on **Map 2.1**, and their main features are summarized on **Table 2.1** below.

Table 2.1: Physiographic Regions

Region	Characteristics
Algonquin Highlands	Bare rock, rugged topography
Georgian Bay Fringe	Thin soils, with exposed rock outcrop
Dummer Moraines	Low-lying
Peterborough Drumlin Field	Hilly topography with large relief
Napanee Plain	Flat lying, shallow bedrock
Prince Edward Peninsula	Flat lying, shallow bedrock
Iroquois Plain	Clay plains, drumlins

Source: Chapman and Putnam, 1984

Algonquin Highlands

The Algonquin Highlands region covers the largest portion of the Study Area, and encompasses the Townships of Hastings Highlands, Carlow/Mayo, and the Town of Bancroft.

This region is characterized by rugged topography formed by outcrops of Precambrian granitic and metamorphic bedrock. Many of these outcrops extend 20 m to 60 m above the surrounding area. Soils are generally shallow and stony. An exception is the presence of thick (up to 70 m) sand, gravel and clay in the deep bedrock valleys, as is commonly found in the Bancroft area. The topographic elevation ranges from over 450 m above sea level (masl) near Baptiste Lake in Hastings Highlands to approximately 300 masl in the Townships of

Tudor and Cashel. The irregular topography has resulted in the development of numerous irregularly shaped lakes and rivers that have formed in depressions in the Precambrian bedrock surface. Some of the larger lakes include Kamaniskeg Lake, Papineau Lake, Baptiste Lake and Limerick Lake. Some of the larger communities that exist within this physiographic region include Bancroft, Maynooth and Boulter.

Georgian Bay Fringe

Fringing the Algonquin Highlands to the south is the Georgian Bay Fringe. Very shallow soil and bare rock knolls and ridges characterize this area. The land surface is less rugged than the Algonquin Highlands area to the north but soils remain stony. The Georgian Bay Fringe passes through the centre of Hastings County and incorporates much of the northern half of the Municipality of Tweed, Madoc Township, and the Municipality of Marmora and Lake to the west. The region also extends into the northern third of Stone Mills Township. Land elevation varies from 300 masl in parts of the Township of Tudor and Cashel to near 200 masl near the village of Madoc.

Dummer Moraines

The Dummer Moraines border the contact between the Canadian Shield and the sedimentary limestone rocks, and are present within the Township of Madoc, Centre Hastings, former Hungerford Township (Tweed) and the northern portion of Stone Mills Township. The topography is characterized by generally low relief, undulatory knolls that have been deposited upon southward sloping limestone located at the edge of the Precambrian Shield. The soil texture is rough and stony and the ground surface is littered with blocks of limestone and large Precambrian rock boulders. Along the north side of the region is an escarpment 10 to 25 m in height that forms the northern edge of the sedimentary rocks as they overlay the Precambrian Shield. North of this contact are several flat lying areas (outliers) of sedimentary rock that lie within the Precambrian Shield. Notable communities within this area include Marmora, Madoc and Tweed. Several tributaries of the Moira and Trent Rivers have cut deep valleys through this region as they migrate south to their outlets along the Bay of Quinte. Where these rivers have become plugged with glacial sediment, long narrow lakes or swamps have formed (e.g., Moira and Stoco Lake).

Peterborough Drumlin Field

The Peterborough Drumlin Field encompasses the Municipality of Centre Hastings and the northern portion of former Thurlow Township (City of Belleville). This area is characterized by rolling till plains of elevated topography reaching elevations up to 150 masl. Many well-formed glacial drumlins exist, as can be seen along Highway No. 62, and often extend over 30 to 50 m above their base. In general, drumlin frequency and size is greatest in the south near the southern and eastern boundaries of the Municipality of Centre Hastings, as opposed to the north where drift is thin. Connected with the drumlin field are many eskers, such as those extending from Marlbank to Foxboro, Tweed to Foxboro, and north of Moira in the Municipality of Centre Hastings.

Some of the larger communities within the drumlin field include Foxboro, Halloway and Phillipston.

Napanee Plain

The Napanee Plain is a flat to slightly undulating area of very thin stony overburden, overlying shallow limestone bedrock. The plain encompasses the southern portion of Tyendinaga Township, the City of Belleville and the southern portion of Stone Mills Township. Land elevation ranges from 75 to 100 masl. Traversing through this plain are the Salmon and Napanee Rivers, which have locally carved deep incised valleys up to 15 to 30 m in depth. Small, isolated drumlins are present in some localities. Shallow clay deposits appear in some of the bedrock depressions and near the Bay of Quinte shores. The larger communities within this area include Belleville, Shannonville, Marysville, and Newburgh. The Napanee Plain extends southward across the Bay of Quinte to become the physiographic region known as the Prince Edward Peninsula.

Prince Edward Peninsula

The Prince Edward Peninsula is the southerly extension of the Napanee Plain into Lake Ontario. The Municipality of Prince Edward County encompasses the entire area. This region, which is separated from the mainland by the Bay of Quinte, is characterized by low relief (typically between 75 and 100 masl). Soils are generally less than (<) 1 m deep.

Deeper deposits of clay exist along low-lying areas on the northern shores and in between West Lake and Picton. The region has an irregular shoreline as a result of the widespread bedrock faulting and later inundation of low-lying areas by Lake Ontario. The highest point is 150 masl on an escarpment near Picton that overlooks the hamlet of Glenora and extends eastward along Adolphus Reach and northward along Long Reach. Another escarpment is present in the northern portion of the County extending from Carrying Place to the west, past Mountain View and then east towards Northport. The larger communities in this region include Rossmore, Picton, Wellington, Bloomfield, Carrying Place and Consecon.

Iroquois Plain (Trent Embayment)

Immediately to the west of the Study Area and beyond the Quinte watershed is the Iroquois Plain physiographic region. This area has been shaped by the inundation of glacial Lake Iroquois from the south. North of Trenton, and extending northward to former Rawdon Township is a complex area of sand plains, hills and clay flats. Elevated areas, in the form of drumlins, extend through the clay. Some of the large communities in this area include Trenton, Stirling, and Frankford.

2.2 Surface Water Drainage

Surface water drainage in the southern two-thirds of the Study Area falls within the larger Quinte watershed, comprised of the Napanee, Moira and Prince Edward County watersheds. North of the Quinte watershed, but encompassing the Town of Bancroft, Municipality of Hastings Highlands and Carlow/Mayo Township are unorganized watersheds that are currently managed under the Ministry of Natural Resources. A general description of each of these drainage systems is presented below.

Napanee Watershed

The Napanee watershed comprises the eastern portion of the larger Quinte watershed, and drains an area of 1,950 km². The watershed crosses portions of the municipalities of Tyendinaga, Greater Napanee, Stone Mills, Addington Highlands, and North Frontenac. The main systems that comprise this watershed are the Napanee River and the Salmon River,

which drain into the Bay of Quinte to the south. Smaller creeks, such as Marysville Creek and Selby Creek, drain the area between the Salmon and Napanee Rivers.

The Salmon River has its headwaters in the Precambrian Shield region in North Frontenac and Addington Highlands Townships in the Kennebec Lake area. From this point, the headwaters discharge into the main Salmon River system, which follows southwestward down a rather consistent path along the Salmon River bedrock fault, where it discharges at the Bay of Quinte. The system contains many lakes including Kennebec Lake, Big Clear Lake, Buck Lake, Bull Lake, Horsehoe Lake and Sheffield Lake. The southern portion of the system, which contains fewer lakes and marshes than the northern portion, follows a well entrenched valley in the limestone plain. The depth of the valley is over 30 m in some areas.

The Napanee River flows in a well delineated pre-glacial valley, with a direction parallel to that of the Salmon River. The valley is up to 50 m deep in some places. The headwaters of this system are the numerous lakes and swamps within North and Central Frontenac Townships. The river then flows south across the southern portion of the Study Area in Stone Mills Township and discharges into the Bay of Quinte west of Napanee. Two of the larger lakes are Varty Lake and Camden Lake, which have formed in localized depressions in the bedrock in Stone Mills Township.

Moira Watershed

The Moira River watershed forms the largest watershed in the Study Area and drains approximately 2,700 km². The watershed, which ends across portions of Hastings County and Lennox and Addington County, includes all or a portion of the partner municipalities of this study including the Municipality of Tweed, Township of Madoc and Municipality of Centre Hastings.

The majority of flow to the Moira watershed originates from three main branches that have their headwaters in the marshy and lake-filled Precambrian Shield region in Tweed, Madoc and Addington Highlands Townships. These branches are the Upper Moira, the Black and the Skootamatta. These systems converge near the hamlet of Actinolite and flow south into Stoco Lake by Tweed. A fourth branch, Clare River, empties directly into Stoco Lake. From Stoco Lake to its discharge point in Belleville, in the Moira River flows over limestone

within a well-marked bedrock valley. At Plainfield, the river merges with Parks Creek and flows west to Foxboro along a broader valley. At Foxboro, the river meanders south to Belleville across limestone plains.

Prince Edward County Watershed

The Prince Edward County watershed does not have a well-organized drainage network. The pathways of many streams are controlled by bedrock depressions shaped by bedrock faults. The County is surrounded by water, resulting in drainage systems that are generally short and outletting to the nearest shoreline. Most of the flow is during periods of heavy precipitation or in the spring months during winter thaw. Marshlands are predominant around low-lying areas adjacent to Lake Ontario and connecting water bodies.

The main streams and their drainage areas are: Consecon (186 km²), Sawguin (84 km²), Black (72 km²), Hubbs (46 km²), Bloomfield (55 km²), Demorestville (40 km²), Hillier (22 km²), Lane (16 km²), Waring (13 km²), Waupoos (15 km²) and Cressy (4 km²). The headwaters of these streams are generally along the west to east oriented bedrock plateaus. Low-lying areas between the bedrock highs are prone to the development of marshland belts (Northport to Carrying Place; Big Swamp - Little Swamp-Consecon Lake; and Picton to West Lake).

In addition to the development of water bodies in low-lying areas, several notable surface water features are present in highland areas. These features include Roblin Lake near Ameliasburg, Fish Lake near Demorestville, and Lake on the Mountain near Glenora. These water bodies have formed in topographic depressions on the top of escarpments, and their presence is attributed to the low permeability of the underlying limestone rock.

Unorganized Watersheds in Northern Hastings County

The Study partner municipalities of Hastings Highlands, Carlow/Mayo and the Town of Bancroft are north of an organized watershed area. Drainage in northern Hastings County is controlled by the irregular bedrock topography of the Algonquin Highlands, resulting in irregular shaped lakes and streams, and many areas of poor drainage. Surface water features in this area generally drain to watersheds to the north and east. Significant watersheds

include the Little Mississippi River and York River that discharge into the Madawaska River to the east. Some of the larger lakes include Baptiste Lake, Papineau Lake, and Kamaniskeg Lake.

3. GEOLOGICAL ASSESSMENT

3.1 Background

The geological assessment of the Study Area is the first stage in understanding the hydrogeology of the region and the physical characteristics of the aquifers and protective aquitards. In the Quinte area, the hydrogeology is predominately influenced by the shallow bedrock, in that most wells pump from either fractured Precambrian rock or fractured limestone. As a result, most of the geological assessment focused on the bedrock. Nevertheless, significant overburden aquifers exist in some localized areas where glacial landforms have produced sufficient thickness of sand and gravel deposits to provide a source of potable water. As such, a summary of the overburden geology is made. The information discussed in this chapter forms the basis of the hydrogeology analysis in **Section 4**.

3.2 Methodology

3.2.1 Approach

Geology was assessed through perusal of existing government reports, maps and provincial water well records. To enable the assessment of regional geological conditions, a composite overburden and bedrock geology map was created. For the overburden geology map, 1:50,000 scale finalized and preliminary maps were used where available, and augmented where necessary with smaller scale (1:125,000 and 1:250,000) mapping. The units of the individual maps were combined based on their common lithology and depositional history. The composite bedrock map was created by merging 1:50,000 scale Paleozoic geology maps with 1:1,000,000 scale Precambrian bedrock mapping. A series of geological cross-sections were used to illustrate the stratigraphy and structure of the overburden and bedrock aquifers in the Study Area.

3.2.2 Data Sources and Limitations

A variety of data sources were used to assess the geology and hydrogeology of the Study Area. The key data sources, their application and limitations are presented below.

Government Geology Reports and Maps

Government geology and hydrogeology maps and reports were used to develop the hydrogeological regional model. The Ontario Geological Survey and the Geological Survey of Canada authored the majority of the reports and maps. This information was used to:

- understand the regional geology and classification of bedrock and overburden materials in terms of porosity and permeability;
- map the lateral and vertical extent of regional aquitards and aquifers; and,
- develop harmonized bedrock and overburden geological maps.

A significant goal of the study was to develop a regional harmonized overburden and geological map based on a compilation of Ontario Geological Survey and Geological Survey of Canada government publications. Because of the variety in scale, age and interpretations shown on these maps, lithological descriptions were grouped into common categories.

The limitation of this data set is primarily in terms of scale. Most of the reports and maps were regional in nature and were provided at the 1:50,000 scale. Notable exceptions were portions of Lennox & Addington and Frontenac Counties (1:125,000 scale), and the northern portion of Hastings County (1:250,000 scale). As a result, mapping accuracy decreases with a smaller scale. Furthermore, the different age and mapping/interpretation styles of the authors resulted in some inconsistencies between maps and adjoining map areas, even ones produced at the same scale.

Ministry of the Environment Water Well Information Systems (WWIS)

The Ministry of Environment (MOE) Water Well Information System (WWIS) (MOE, 2002) provided data on subsurface geology, aquifer properties and groundwater use as recorded in water well records. These records were provided by Earthfx Limited of Toronto, Ontario on behalf of the MOE, and covered the period between 1945 and 2001. Prior to delivery, the well records were modified using the Sharpe GSC materials protocol (Sharpe et al., 1998), which attempts to improve the usefulness of the original well record by simplifying the number of lithological categories reported.

A total of 38,000 water well records were provided. Of this total, 19,600 wells were geo-referenced based on Universal Transverse Mercator-North American Datum 1983 coordinates. Generally, geo-referenced wells provide better quality data in that the accuracy of the well location is often between 30 and 300 m. The accuracy of non-geo-referenced wells is deemed to be typically 600 m.

The limitations of the well data are as follows:

Limitation	Potential Effect
Variable density of well records	Error in estimating aquifer and hydrogeological properties in areas where well density is sparse. This is most significant in the northern portions of the Study Area. Maps that are most affected are potentiometric surface and vertical gradient.
Error in geological description	Error in geological profile and in identifying thickness and extent of aquitards and aquifers.
Error in well location and well elevation	Incorrect geological and hydrogeological properties may be assigned to an area. Errors in elevation will affect estimation of the water table elevations, and groundwater flow directions and gradients.
Not all wells represented	Overburden wells and shallow bedrock wells created by excavation or sandpoint will be under-represented.

To reduce error in the MOE water well records, the data were processed prior to interpretation to remove erroneous and suspicious entries, where practical. The process to remove these questionable data points is based on protocols established by the MOE and includes:

- limit analysis to wells that are located with 300 m accuracy. Exceptions were the use of wells in the northern portion of the Study Area where well data were sparse, and conformity to the rule would have resulted in inadequate information on which to formulate an interpretation;
- adjust the well record's top of ground elevation to Digital Elevation Model (DEM); and,

- apply the Sharpe GSC materials protocol to harmonize the geological description.

Government Geographic Information System (GIS) database

The Ministry of Natural Resources (MNR) and the Ministry of Northern Development and Mines (MNDM) provided digital base mapping. The Conservation Authorities and municipalities provided additional data layers. Mapping included roads, communities, lots/concessions, and water bodies. The majority of the mapping was provided at a scale of 1:50,000, which generally has a spatial accuracy of 25 m. The source and limitations of this data were provided by the original authors of the information and transferred to the study in the form of metadata.

3.3 Bedrock Geology

The bedrock comprises both Precambrian igneous and metamorphic rock and Paleozoic sedimentary rock, and varies in character across the Study Area. In general, Precambrian bedrock crops out over the northern half of the Study Area, and is the dominant form of bedrock exposed north of a line drawn between the communities of Marmora, Madoc, Tweed and Enterprise. Paleozoic rocks predominate south of this line, and are the dominant exposed bedrock in Centre Hastings, Belleville, Tyendinaga, Prince Edward County and the southern portion of Stone Mills Township. In these southern areas, Precambrian rock protrudes through the Paleozoic limestones in localized areas such as Ameliasburg Ward (near Centre), along the north side of the Salmon River (near Shannonville) and as inliers along the northern edge of the limestone belt in Centre Hastings, Tweed and Stone Mills. A map of the regional bedrock geology, showing the major rock types and significant regional faults, is shown as **Map 3.1**. A generalized regional cross-section through the Study Area is shown as **Section A-A'** in the back of the **Map Booklet**.

Descriptions of the type and distribution of the different bedrock types are presented in the following sections.

3.3.1 Precambrian Bedrock

Precambrian aged rocks of igneous and metamorphic origin underlie the entire Study Area and form a region commonly known as the Precambrian Shield. This shield forms the core of the North American continent and is composed of a series of accreted crustal material that, over time, merged into the North American continent between 0.9 and 1.6 billion years ago. The gradual accretion or “adding on” of material to the sides of the continent caused a thickening and lateral extension of the Precambrian Shield. Because of the complexity of the rock types within the Canadian Shield, geologists have subdivided the region into “belts”, with each belt having a common evolutionary history. Belts are further subdivided into “terranes” based on common rock types and age of development.

Brief descriptions of the Canadian Shield belts and terranes are provided in the following section. Each description contains the rock types, age, and notable features found in each terrane. **Map 3.1** shows the location of the terranes and belts described below.

Central Gneiss Belt

The Central Gneiss Belt is a north-east/south-west trending belt of gneissic rocks, and represents some of the oldest rocks (1.4 to 1.8 billion years) in the Study Area. The belt is exposed along the northern margin of Hastings Highlands (Units 37, 38 and 40). Within this small area, the rock type is comprised of Proterozoic age felsic gneisses. The gneisses are primarily igneous in origin, but have undergone metamorphosis as a result of mountain building during the Grenville Orogeny. There are also some isolated occurrences of mafic gneisses that occupy a small percentage of the area. The Central Gneiss Belt is bounded to the south-east by a distinctive band of tectonite (Unit 48), a rock type that has been heavily deformed by tectonic forces. This tectonite unit represents the border zone between the gneiss belt and the metasedimentary belt to the south. There are several major faults trending north-west/south-east in the north part of the gneiss belt. These faults are part of the Ottawa-Bonnechere Graben system, along the Ottawa River.

Central Metasedimentary Belt

The Central Metasedimentary Belt is located south of the Gneiss Belt and is exposed at surface south to the Marmora-Madoc-Tweed-Enterprise area, where it is covered by sedimentary rock. This portion of the Grenville Province contains five terranes and a variety of rock types. The terranes present from east to west are Bancroft, Elzevir, Mazinaw, Sharbot Lake, and Frontenac. The following paragraphs discuss the geology of these terranes.

Bancroft Terrane

The Bancroft Terrane is located just south of the Gneiss Belt and is exposed at surface in the southern portions of the municipalities of Hastings Highlands, Bancroft and Carlow/Mayo. The Bancroft Terrane is composed of highly metamorphosed, continental shelf sediments that were deposited at the edge of the ancient continental mass to the north. These sediments were subsequently intruded by volcanic activity (alkalic plutons), and metamorphosed by the Grenville mountain building event. The terrane now shows an abundance of marble, some clastic metasediments, gneiss, and a wide range of intermediate to felsic plutonic rocks.

Elzevir Terrane

The Elzevir Terrane is located south of the Bancroft Terrane and is exposed over most of central Hastings County, from Bancroft to the northern fringe of the sedimentary belt line demarcated by a line between Marmora-Madoc-Tweed-Enterprise. This terrane contains a variety of rock types that are different from those associated with the Bancroft Terrane. The primary difference is the greater percentage of felsic plutonic rocks such as granite and tonalite. Two distinct groups of northeast trending, supracrustal rocks, the Mazinaw Group and the Flinton Group, appear between the felsic plutons. The Mazinaw Group consists of mafic metavolcanic and meta-volcanoclastic rocks that appear in long thin bands. There are fewer occurrences of mature metacarbonates (marble, dolostone) and a greater percentage of clastic metasedimentary rocks. The Flinton Group has fewer carbonaceous metasediments present and contains less mature metaconglomerates, metapelites, and metamorphosed quartz arenites (sandstones).

Sharbot Lake Terrane

The Sharbot Lake Terrane is a wedge-shaped terrane that is bounded to the north by the Elzevir Terrane and to the south by Paleozoic cover rocks. This terrane is exposed in the Study Area in Stone Mills and Central Frontenac townships. Calcitic and dolomitic marbles dominate the terrane. The metasedimentary rocks are intruded by a variety of meta-igneous rocks ranging in composition from ultramafic to felsic. Plutonic rocks such as gabbros, granodiorites and granites are present. Deep crustal plutonic gabbros are exposed by faulting and uplift. There are also limited metavolcanic basalts and volcanoclastic rocks present in this terrane. The southern and northern boundaries of the terrane are marked by southwest to northeast trending faults.

Frontenac Terrane

There is only a small portion of the Frontenac Terrane within the Study Area. It is exposed along the far eastern extremity of the Quinte watershed in Central and South Frontenac townships. There are several rock types in this terrane including calcitic/dolomitic marbles, quartz arenites, and metamorphosed felsic plutonic rocks. Metavolcanic diorite-gabbros are also found along the boundary with the Sharbot Lake Terrane. Major faults are congruent with the boundaries of both the Sharbot Lake Terrane and the Paleozoic sedimentary rocks to the east.

3.3.2 Paleozoic Bedrock

Overlying the igneous and metamorphic rocks of the Precambrian Shield are sedimentary rocks of Paleozoic age. Deposition of these sediments began approximately 500 million years ago when an ocean inundated the eastern portion of the ancestral North American continent known as “Laurentia”. Prior to this event, the land mass consisted primarily of exposed Precambrian igneous and metamorphic rocks. During the development of marine conditions, erosion of the Precambrian landmass resulted in the deposition of sands and gravels along its continental shores. These deposits are found mainly east of the Study Area in the St. Lawrence-Ottawa River Valley. In the Study Area, quieter or deeper water environments prevailed, resulting in the deposition of mainly carbonate rich sediments. The geological record shows that the depositional environment along the continental shelf of

Laurentia fluctuated in the Paleozoic period, resulting in the alternating deposition of limestones and shales, and to the east, sandstones.

Lithology and Distribution

The distribution of Paleozoic bedrock is shown on **Map 3.1** (Units 1 through 6). A generalized regional north-south cross-section through the Study Area is shown as **Section A-A'** in the **Map Booklet**. These rocks cover the area south of a line drawn between Marmora, Madoc, Tweed and Enterprise, and are the dominant bedrock type in the municipalities of Centre Hastings, Belleville, Tyendinaga, Prince Edward County, and southern portions of Tweed and Stone Mills.

There are two groups of Paleozoic rocks in the Study Area, the Simcoe and Basal Groups (these groups are combined and called the Ottawa Group in Eastern Ontario). Each group contains a number of rock formations with similar lithologies and characteristics. Descriptions of each group and their component formations are presented in **Table 3.1**. A discussion of the main rock types, from oldest (Basal Group) to youngest (Simcoe Group), is presented in the following paragraphs.

Table 3.1: Bedrock Formations

Formation	Member **	Map Unit *	Age	Thickness	Lithology
SIMCOE GROUP					
Lindsay	Upper	6b	Upper Ordovician	0 to 90 m (usually <30m)	limestone and shale
	Lower	6a	Upper Ordovician		nodular limestone with shale interbeds
Verulam Formation		5	Middle Ordovician	0 to 70 m	interbedded limestone and shale
Bobcaygeon	Upper	1c, 4b	Middle Ordovician	0 to 60 m	limestone with shaly partings
	Lower	1c, 4a	Middle Ordovician		limestone and calcarenite
Gull River Formation	Upper	1b, 3, 3c	Middle Ordovician	0 to 30 m	dolomitic limestone and weathered limestone
	Middle	1b, 3, 3b	Middle Ordovician		shaly laminated limestone and massive bedded

	Lower	1b, 3, 3a	Middle Ordovician		crystalline limestone
BASAL GROUP					
Shadow Lake Formation		1a,2	Middle Ordovician	0 to 20 m	dolostone with interbeds of sandstone and shaly partings
PRECAMBRIAN					
		37 to 48	Precambrian	Basement rock	igneous and metamorphic rocks

* Formation shown as map units displayed on original source mapping

** Member is a subgroup of a Formation

Shadow Lake Formation

The Shadow Lake Formation consists of red and green arkosic sandstones, siltstones and shales with clasts of granite, quartz and feldspar. This formation was deposited on top of the Precambrian rock in a nearshore environment. The formation is rarely exposed in the Study Area, but does crop out near the northern fringe of the sedimentary/Precambrian rock boundary. Surface exposure is present north of Madoc Village and southeast of Tweed. Natural gas wells drilled in Prince Edward County indicate that the formation extends beneath the southern half of the Study Area and attains a thickness of 15 m at Cherry Valley (Prince Edward County) at a depth of 250 m below ground surface. In Tyendinaga Township it is found closer to surface, at a depth of 80 m with a thickness of 20 m.

Gull River Formation

The Gull River Formation is extremely complex and contains several different sedimentary sequences. It is divided into lower, middle and upper members. The lower member consists of mottled crystalline dolomitic limestone. The middle member consists of shaly laminated limestone at its base, changing to massive bedded limestone at higher intervals. The upper member is composed of massive beds of semi-crystalline limestone. In the Study Area, the Gull River Formation is generally massive, medium grey to dark brown and weathers to light grey. Massive rock beds from the Gull River Formation have been used extensively in Eastern Ontario as a building material.

The formation is exposed at surface in the northeast portion of Tyendinaga Township, former Hungerford Township (now Tweed) and the west and south parts of Stone Mills Township.

The Gull River Formation is also exposed along the Salmon River and north of Foxboro. Natural gas exploratory wells indicate a formation thickness of 20 m in Tyendinaga Township, and 30 m near Cherry Valley (Prince Edward County) at a depth of 220 m.

Bobcaygeon Formation

The Bobcaygeon Formation is a Middle Ordovician limestone sequence that contains some shale. This formation lies conformably on the Gull River Formation. The formation is divisible into two members. The lower member consists of pale to dark brown and grey crystalline limestone interbedded with calcarenite, weathering to pale grey, buff or brown. The upper member consists of interbedded crystalline limestone, with shale content increasing upwards.

This formation appears as the surface bedrock unit over much of Centre Hastings and the central portions of Tyendinaga Township. It is exposed along and south of the Salmon River valley. Deep boreholes located in Tyendinaga Township and Prince Edward County reveal an increasing thickness to the south, where the Gull River Formation reaches thickness of 50 m in Ameliasburgh Ward and 60 m near Cherry Valley. In the southern portions of Prince Edward County, the top of the Gull River Formation is found at depths of 160 m below ground surface.

Verulam Formation

The Verulam Formation makes up a large proportion of the exposed Paleozoic bedrock in the Study Area. It is exposed over most of Belleville and the northern portion of Prince Edward County, and in the southern portion of Tyendinaga Township.

The Verulam Formation is a Middle Ordovician age sequence consisting of 3 to 15 cm thick grey bioclastic and fossiliferous limestone beds positioned between beds of shale. This formation conformably overlies the Bobcaygeon Formation. The limestone is crystalline, contains fossils, and is light to dark brown-grey on fresh surfaces with weathered surfaces appearing blueish brown. The shale interbeds are found up to 15 cm thick and are dark grey in colour. The thickness of the unit varies from not being present north of Crookston (Centre Hastings) and County Road No. 6 in Tyendinaga, to 70 m thick near Cherry Valley (Prince

Edward County). This formation underlies all of Prince Edward County. It is exposed at surface below the Carrying Place-Ameliasburgh-Demorestville escarpment, and in North Marysburgh Ward to being found 40 m below surface in Athol Ward.

Lindsay Formation

The Lindsay Formation is the youngest sedimentary unit in the Study Area and overlies most of the southern two-thirds of Prince Edward County. In the Study Area, it is not found north of the Bay of Quinte. The formation has been divided into two members; the lower member contains nodular limestone with shale partings and the upper member consists of nodular limestone and shale. The lithology of the formation is predominantly limestone with some shale interbeds. Burrows and feeding tracks are common sedimentary features within the finely to coarsely crystalline fossiliferous limestone. The limestone is grey-brown on fresh surfaces with weathered surfaces appearing blue-grey. The calcareous shale interbeds are up to 5 cm thick and are dark grey. The formation has a thickness of 20 to 30 m where exposed; however, natural gas exploratory wells near Cherry Valley intercepted 90 m of Lindsay Formation, suggesting that the formation was once much thicker and that a considerable portion has eroded away.

3.3.3 Bedrock Structure and Tectonic History

This section provides a summary of the geological processes that have shaped the current configuration of the bedrock. Since their deposition, the rocks have undergone faulting, erosion and uplift. The reader is referred to **Map 3.1** and geological **Cross-Section A-A'**, in the **Map Booklet**, when reading the following sections.

Tectonic History

The tectonic history of the region greatly controlled the distribution of rock types in the Study Area. The Paleozoic rocks were initially deposited as sediments into a foreland basin (shallow sea) centred in New York State and extending 1400 km south to the present day State of Alabama. The basin was formed as a result of mountain building activity (Appalachian Mountains) to the east that downwardly flexed the earth crust on the west side of the mountain belt. The lowering of the elevation of the earth's crust allowed marine

conditions to invade, developing a shallow carbonate shelf. The deposited carbonate sediments, which would later become rock, were thickest in the south towards the centre of the basin, and pinched out to the north, where the ocean water lapped onto the ancient Precambrian rock continent. As a result, the sedimentary rocks become thicker toward the south (Prince Edward County) and pinch out in the north (around Marmora-Madoc-Tweed-Enterprise). The thickest deposit of Paleozoic rock in the Study Area is 300 m, which was encountered at a borehole at Salmon Point in Prince Edward County (Athol Ward).

The rocks are essentially flat lying, with a slight dip to the south (basinwards) at approximately 3 m per km. Higher dips are present in localized areas where the Precambrian rock is exposed, such as is found at the granite surface exposures near Ameliasburgh, Shannonville and Foxboro. These localized Precambrian protrusions would have once been islands surrounded by the Paleozoic seas.

Faults and Fractures

The Study Area has undergone alternating periods of crustal extension and shortening since the Precambrian era, resulting in the development of faults and fractures. Some of these faults have not been active since their original formation in Precambrian times, while others have been reactivated from time to time. The stresses and strains on the bedrock have resulted in the development of extensive fracturing or jointing networks in the rock. The extent and spacing of the fractures depend upon the nature of the rock material. In general, vertical fracturing is more common in Precambrian rock than in limestone; however, horizontal fracturing along bedding planes is more prevalent in sedimentary rock. These fracture patterns often exert a strong influence on other geological processes. For example, chemical weathering tends to be concentrated along joints. This weathering can cause large voids in the bedrock, such as is found in the “Moirs Caves” area near Latta and south of Parks Creek in Tyendinaga Township. Moreover, a system of joints can influence the direction of stream courses. Surface exposures of the limestone bedrock in the southern portions of the Study Area often reveal considerable joint patterns.

The major faults that cross the Study Area are shown in **Map 3.1**. The faults in the southern part of the Study Area are attributed to the formation of the Atlantic Ocean 170 million years ago during Jurassic time. Many of these faults may follow along older faults that occurred

during Paleozoic or Precambrian times. Some of the more significant faults in the Study Area are described below.

Salmon River Fault

The southern reaches of the Salmon River follow the course of a normal fault, where the west side has been displaced downwards by approximately 30 m. This fault extends from the Kaladar area, across the Bay of Quinte to Massassauga Point and onto Huycks Point in Hillier Ward (Prince Edward County). Some suggest that this faulting is related to the exposed Precambrian rock that is observed at Shannonville and Ameliasburgh. Other studies (WESA, 1985) have suggested that the fault acts as a preferential pathway for the movement of older saline and sulphur bearing groundwater, resulting in natural water quality problems in the area.

Picton Fault

A second large normal fault trends from Deseronto south towards Picton, along Long Reach, and then separates into at least two faults as it crosses Athol Ward (Prince Edward County). At Picton, land west of the fault has been downthrown by approximately 30 m, resulting in the younger Lindsay Formation being exposed west of the fault and the older Verulam Formation outcropping east of the fault. The Picton fault is likely related to the fault that extends along the Napanee River and onto Sharbot Lake in Central Frontenac Township.

Other Faults

Two main faults are shown on **Map 3.1** in the municipalities of Hastings Highlands, Carlow/Mayo and Bancroft. These faults trend northwest-southeast, sub-parallel to the Ottawa River, and are believed to be associated with the Ottawa-Bonnechere horst and graben complex that developed during the formation of the Ottawa River.

Bedrock Topography

Several geological processes shaped the topography of the bedrock, the most important being glacial erosion and abrasion caused by the movement of ice sheets over the area during the

last glaciation. The resulting depressions, valleys and highlands that formed on the bedrock controlled the deposition of the overlying overburden. Depressions in the bedrock surface formed in areas where the rock was most susceptible to erosion, such as along faults and joints, or in areas where the softer Paleozoic sedimentary rocks were exposed.

Bedrock topography is shown on **Map 3.2**. Because of the shallow overburden conditions of the Study Area, bedrock topography is similar to topographic elevations (**Map 2.2**). The map shows that the highest bedrock surface elevations (>500 masl) are in the municipality of Hastings Highlands. The bedrock surface elevation decreases southward, reaching its lowest point of 75.6 masl along the shores of Lake Ontario.

3.4 Overburden Geology

This section presents an overview of the surficial geology of the Study Area and its depositional history. The landforms have been largely shaped by glacial activities that occurred approximately 10,000 to 20,000 years ago. These events removed pre-existing material, smoothed bedrock surfaces, and created features such as moraines, eskers and drumlins. Melt waters produced during the retreat of the glacier formed large postglacial lakes and rivers that redeposited sands and gravels in ancient spillways and low-lying areas.

A generalized overburden map of the Study Area is presented as **Map 3.3**. Overburden units shown on this map are described in **Table 3.2**. Geological cross-sections have been created through selected portions of the Study Area to illustrate some of the glacial features that are common to the region. These sections are shown at the rear of the **Map Booklet**.

Table 3.2: Surficial Geology

Overburden Type	Description	Means of Deposition	Associated Landform(s)	Map Units on Map 3.3
Eolian	Sand	Wind deposited	Dunes	Unit 14
Organic Deposits	Muck and other organic rich soils, peat	Mostly accumulated in place by partial decomposition of vegetation; recent deposits	Lowlands, wetlands and poorly drained areas	Unit 13
Alluvium	Mainly silty or	Recent detrital material	Riverbeds and terraces	Units 10, 12

Overburden Type	Description	Means of Deposition	Associated Landform(s)	Map Units on Map 3.3
	sandy, organic rich material	transported and deposited by rivers/creeks		
Glaciolacustrine	Includes clay, silty clay, silt, sand, gravel	Sediments placed during the development of pro-glacial lakes	Varved clays, beaches and nearshore sediments	Units 7, 8 and 9
Glaciofluvial Outwash and Deltaic Sands	Includes gravel and coarser material, some sand and minor amounts of till	Deposited and/or sorted during and immediately after last glaciation; by glacial meltwater and/or post-glacial river environments	Undulating topography and ridges formed by relic beaches, kames and deltas. Often deposited in bedrock depressions and valleys	Unit 3
Glaciofluvial Ice contact Gravel and Sand	Includes gravel and coarser material, some sand and minor amounts of till	Deposited and/or sorted during and immediately after last glaciation; by glacial meltwater and/or Champlain Sea wave action; (Glaciofluvial; marine)	Undulating topography and ridges formed by relic beaches, spits, bars, eskers etc. Found in Till Plains, Sand Plains, as well as over Precambrian rock	Unit 2
Till	Bouldery cobbly silty sand to sandy silt till. Provided the sediment from which the coarser deposits were formed	Deposits left by glaciers formed from the glacial action on bedrock	Ground moraine and some drumlins. Essentially a sheet of debris after the retreat of the glacial ice	Unit 1

3.4.1 Depositional History

Approximately 20,000 years ago, Ontario was in the midst of an ice age. An ice sheet, approximately 1 km thick, extended from northern Canada into the northern states near Ohio. In the Study Area, the ice sheet originated from the highland area north of Quebec. The progressive expansion of the ice sheet was in the form of glacier lobes that transcended south and westward following preglacial bedrock valleys. Lobes of the ice sheet advanced from Quebec and crossed the Ottawa River Valley and headed south to present day Lake Ontario. As the ice sheet advanced, the bedrock and pre-glacial sediments were scoured and the debris

was entrained within the glacier. Many of these eroded sediments were later redeposited during glacial retreat as discontinuous till sheets, eskers and drumlin features.

Approximately 10,000 years ago, the ice sheet began to regress. At this time, the St. Lawrence lowlands region was isostatically depressed below sea level. Melting of ice in the St. Lawrence valley to the east allowed marine water from the Atlantic Ocean to inundate the area. This ancient body of marine water, known as the Champlain Sea, covered a large portion of the area east of the Study Area and extended from New York State to north of the Ottawa River, and up the Ottawa Valley to Petawawa. Early drainage of the area was directed west through channels that lead to the Mississippi River as the St. Lawrence valley was blocked with ice.

At this time, the Dummer Moraines, which now cover a considerable portion of the central Study Area, were formed by a receding northern lobe of the ice sheet. In the northern portions of the Study Area in the municipalities of Hastings Highlands, Bancroft and Carlow/Mayo, meltwaters produced from the edge of the glacier formed huge rivers (spillways) that flowed along bedrock valleys, filling these areas with sand and gravel. Meltwaters also flowed beneath and within the glacier, resulting in the development of eskers. In Prince Edward County, meltwater flowing down the Napanee River deposited sands and gravels in the low lying area between Picton and West Lake. These sands were later reworked by westerly winds to form baymouth bars. Water from the melting glaciers also caused flooding along the borders of present day Lake Ontario. The results of this flooding are expressed as shallow clay and silt deposits surrounding the Bay of Quinte and in other lowland areas, such as in the West Lake to Picton area.

3.4.2 Geological Units

Descriptions of the overburden units that exist within the Study Area are presented in the sections below. **Map 3.3** shows the distribution of these materials. Cross-sections through areas with significant overburden accumulations are shown in the **Map Booklet**.

Till (Unit 1)

Till deposits are present in the municipalities of Belleville and Centre Hastings, northern portions of Tyendinaga, southern portions of Tweed and parts of Stone Mills, in the form of ground moraines, end moraines and drumlins. The till is characteristically stony and sandy. MOE water well records indicate that this till can attain thickness of up to 80 m in the former Thurlow Township.

A geological cross-section through the drumlin complex along Highway 62, north of Foxboro, is presented as **Section B-B'**. This section runs along Highway No. 62 between Foxboro and West Huntington (Centre Hastings). The section shows that sand, gravel and till have accumulated on the bedrock surface, reaching a localized thickness of 30 to 80 m. The section also shows depressions in the bedrock surface that have been infilled with sand and gravel deposits by an esker that runs along the base of the drumlins, approximately 2 km north of Foxboro.

Glaciofluvial Ice-contact Sand and Gravel Deposits (Unit 2)

Glaciofluvial ice-contact deposits, in the form of eskers, are present in several areas within the Study Area. Eskers were glacial rivers that formed either in tunnels within the glacial ice or at the glacier's base. Usually their sinuous path formed along pre-existing bedrock valleys and faults. The eskers often form ridges 5 to 15 m higher than the surrounding landscape. Some of the more prominent eskers in the Study Area are:

- Ridge Road Esker, Picton (Prince Edward County)
- Tweed -Thomasburg-Frankford (Tweed, Centre Hastings, Belleville, Quinte West)
- Tamworth-Marlbank-Plainfield (Stone Mills, Tweed, Belleville).

A geological cross-section through the esker at Thomasburg in the Municipality of Tweed is shown in **Section C-C'**. The section runs west to east through the village of Thomasburg. The section clearly shows the broad, 4 km wide postglacial Moira River valley. The esker is located on the west side of the valley and has formed a 35 m deep sand and gravel deposit.

Section D-D' shows the geological cross section through the esker located between Picton and the Sandbanks Provincial Park in Prince Edward County. The section is taken along the long axis of the esker and shows that it reaches thickness of 15 to 20 m.

Glacio-fluvial Outwash and Deltaic Sands (Unit 3)

Sands deposited in fluvial environments, either in the form of a glacial outwash plain or in a post-glacial deltaic environment, are presented as Unit 3. These areas are characterized by having near surface sand deposits that have a thickness ranging from 5 to 10 m in depth. Glaciofluvial sands have formed extensive deposits in the highland areas of the municipalities of Bancroft, Hastings Highlands and Carlow/Mayo, attaining thicknesses of up to 70 m. They were formed by glacial meltwater channels that formed at the edges of the receding glaciers, filling pre-existing bedrock valleys with sands and gravels.

Section E-E' shows a cross-section through a glaciofluvial deposit along Highway 62 north of Bancroft in Hastings Highlands Township. The section starts 3 km north of Bancroft and runs through the community of Birds Creek to Hybla Side Road. The section generally follows the York River, which follows the same channel of the glacial spillway. In this section, sand and gravel deposits up to 60 m deep are encountered within former bedrock valleys. Fine-grained clay and silt are encountered in some of the wells. This material was deposited during flooding of the areas by proglacial lakes that formed as a result of ponding of glacial meltwaters.

Glaciolacustrine Deposits (Units 7, 8, 9)

Occurrences of offshore clays (Unit 7), nearshore sand and silt (Unit 8) and beach gravel and sand (Unit 9) with a glaciolacustrine origin, exist in low-lying areas near Lake Ontario and at the mouths of the river valleys that empty into it. Glaciolacustrine deposits are also present away from Lake Ontario in areas near Tweed, Hastings Highlands, Carlow/Mayo and Bancroft, where large proglacial lakes were formed.

An example of a glaciolacustrine deposit is illustrated in **Section F-F'**, which runs south from Rednersville (Prince Edward County) along County Road 23 onto the escarpment near

Ameliasburgh. The section displays clays that have accumulated in the low-lying areas at the foot of the escarpment. The clays are thin, attaining thickness of usually <5 m.

Alluvium (Units 10 and 12)

Alluvium deposits are fine-grained sand, silt and clay that were deposited during relatively recent times (post-glaciation). They are found sporadically along most watercourses.

Organic Deposits (Unit 13)

Muck and other organic rich soils are widespread over much of the Study Area as a result of poor drainage and/or a shallow water table. The unit is manifested as marshes, bogs or fens, and often surrounds standing water. Large expanses of organic deposits are present in most of the municipalities. The thickness of the organic deposits is usually less than a few metres.

Eolian (Unit 14)

Eolian sand and silt are deposited by wind often in the form of dunes. Sand dunes are common in Prince Edward County along East Lake and West Lake.

3.4.3 Overburden Thickness

The thickness of the overburden in the Study Area is shown on **Map 3.4**. The map shows that the majority of the Study Area is covered by only a thin layer (<1.5 m thick) of overburden. The thickest accumulations are associated with sand and gravel filled bedrock valleys in Hastings Highlands; drumlins in Belleville and Centre Hastings; ground moraine (Dummer Moraines) in Tweed, Tyendinaga and Stone Mill; and, in the form of sand and gravel fill in bedrock valleys.

Table 3.3 is a summary of the areas of greatest overburden accumulation in each of the study partner municipalities.

**Table: 3.3
Areas of Significant Overburden Deposits**

Municipality	Description	Typical Thickness
Hastings Highlands	Highway 62, Maynooth, other infilled bedrock valleys	0 – 70 m
Bancroft	Highway 62, north of Bancroft, other infilled bedrock valleys	<20 m
Carlow/Mayo	Boulter Road, Hermon, Fort Stewart, McArthur Mills, other infilled bedrock valleys	0 – 70 m
Madoc	Till plain and eskers, Cty Rd 11, Cooper, Allen	<20 m
Centre Hastings	Dummer moraines and drumlin field, eskers, Cty Rd 8, Moira	<20 to 80 m
Tweed	Till plain (Dummer moraines), eskers, Thomasburgh to Tweed	<10 – 40 m
Belleville	Dummer moraines and drumlin field north of Moira River, eskers, NW former Thurlow Township	<20 to 80 m
Tyendinaga	Till plain, eskers, clay deposits near Shannonville	Mainly shallow rock
Stone Mills	Till plain in Erinsville-Tamworth, and Enterprise areas	Mainly shallow rock
Prince Edward County	Esker, Picton-West Lake	<20 m

4. HYDROGEOLOGY

4.1 Background

The Quinte Regional Groundwater Study has been undertaken to assess the nature and condition of the groundwater resources within this Study Area. Fundamental steps in this analysis are to map the location and characteristics of significant water bearing horizons (aquifers) and protective deposits (aquitards), identify significant groundwater recharge and discharge areas, and identify areas of high aquifer vulnerability.

4.2 Methodology

The hydrogeology assessment follows protocols outlined in the MOE Terms of Reference. For the purpose of brevity, details of the methodology are not repeated here, but are reprinted in **Schedule B.2, Appendix B**. A summary of the general approach and major limitations of the methodology follows.

Well Location and Construction

The MOE Water Well Information System (also referred to as well records) was used to map the location of all recorded wells. From this database, information on the well depth, construction, encountered geology and water levels was obtained. This data formed the basis of analysis for many of the key maps.

The database classified each well according to recorded location and elevation accuracy. In this study, there were approximately 38,000 wells, of which 19,600 were classed as having a positional accuracy of +/-300 m and an elevation accuracy of " 3 m. The remaining 18,400 wells have not been accurately positioned in the database, and instead have been assigned co-ordinates by the MOE that correspond with the centre of the geographic lot. On average, each lot is approximately 1.2 km long and 600 m wide, so the location of the well is considered accurate to +/- 600 m.

Most maps in this study were created using only the geo-referenced wells. An exception was the Vulnerability of Water Table Aquifer map, Driller Reported Well Water Quality map, and the Well Driller's Recommended Pumping Rate map, where non-geo-referenced data

was used. The lack of good quality geo-referenced well data had the greatest affect on maps developed for the municipalities of Hastings Highlands, Carlow/Mayo, Bancroft and Tweed, where the density of useable wells is low. For the southern municipalities, there is a higher density of geo-referenced wells to permit the creation of more accurate regional maps.

Both geo-referenced and non-geo-referenced well data were used for statistical analyses performed for each municipality, such as determining the number of wells in a given municipality or calculating the average well pumping rate. Since the quality of the maps is controlled in large measure by the density of useable well points, it is highly recommended that the MOE geo-reference the remaining 50% of the wells in the Study Area. Once this data becomes available, study maps should be updated with the new information.

Another significant limitation of this database is that it does not include wells that do not have a well record, such as sand points, dug wells or many shore wells. It is believed that the use of these “non-registered” wells is significant, especially in the rural areas. The implications of this situation include the risk of underestimating both the use of surface water from shore wells and the use of shallow bedrock/overburden aquifers.

Water Table and Potentiometric Surface Map

The horizontal direction of groundwater flow was estimated by constructing water table and potentiometric surface maps. These maps show water levels and/or pressures in the aquifer, and can be used to estimate groundwater flow directions. The water table map was calculated by contouring the elevation of measured water levels, as recorded by the well driller, for wells less than 15 m deep. Only data from geo-referenceable wells were used. These data were supplemented with elevation information for surface drainage features such as lakes, rivers and marshes. The potentiometric surface map was determined by contouring water level elevations of geo-referenceable bedrock wells that exceeded 30 m deep. For the potentiometric surface south of East Lake in Prince Edward County, non-geo-referenceable wells were used because of the scarcity of well data.

Creating a potentiometric surface map for the Study Area is difficult because the majority of the wells are constructed in bedrock and have shallow casings. Water levels in many bedrock wells will be influenced, not only by the potentiometric surface at depth, but also by

the hydraulic pressures in all the fractures that are intercepted along the length of the open hole. As a result, the measured static water level will be an “average” water level that is controlled by the permeability and length of exposure of each fracture zone in the well. In addition, springtime wells would likely have a higher recorded static level than wells constructed in the late summer months, and dry years may produce lower static elevations than in wet years. Notwithstanding the limitations, the map can be interpreted as generally representing regional scale groundwater flow conditions.

The accuracy of these maps depends upon the reliability of the water well records. Considering that there are inaccuracies in the water well locations, elevations and measured static water levels, these maps should be reviewed with caution and considered valid only at the regional scale. Furthermore, the accuracy of mapping will vary across the Study Area. As an example, maps created for the southern municipalities, where well density is high, will have a greater accuracy than maps created for the northern municipalities, where well density is low. In addition, local groundwater flow conditions will likely deviate from the predicted groundwater flow patterns shown on the maps. Nevertheless, the maps do show the general pattern of regional groundwater flow.

Well Yields and Well Productivity

Well pumping rate data were used to map areas that are prone to low, moderate or high groundwater yields. The data used compromised the recommended pumping rate values determined by the well driller at the time of well construction. This analysis was augmented with a review of well specific capacity. Specific capacity is a term used to represent the volume of water that can be pumped from a well for a unit drop in water level. For example, a well pumped at 40 L/minute, causing a drop in the water level in the well of 20 m, will have a specific capacity of 2 L/minute per 1 m drop in water level. The higher the specific capacity of a well, the more the well can be pumped for a unit drop in water level. Specific capacity of a well is controlled by many factors such as well construction, permeability of the aquifer, porosity and depth to the water table.

While this approach provides a regional assessment of where well yields are good or poor, considerable inaccuracies can be associated with these values. Both the pumping rates and specific capacity values are based on measurements taken by the driller at the time of well

construction. Not only does the accuracy depend upon the care taken by the well driller, it also depends upon natural conditions. The reported pumping rate will vary, depending on when the well was drilled and the time since the last rainfall event. In general, reported well yields will be greater for wells drilled in the wetter spring and fall seasons than those drilled in the summer or winter. Deeper wells may also be reported as having a higher pumping rate, mainly because the borehole intercepts more fractures. Overall, the values mapped should be used as a guide only, and do not necessarily reflect (or predict) actual conditions.

Groundwater Vertical Gradient Map

The direction of vertical groundwater movement has significance when it comes to the sensitivity of an area to contamination or the ability of an area to supply necessary base flow to a sensitive ecological environment (i.e., wetland, cold water stream etc). The ability of an area to transmit groundwater vertically is a function of the vertical water force or pressure (hydraulic gradient) and the aquifer permeability. Both of these factors must be considered when determining if an area is a recharge or discharge environment.

The MOE required that the direction of vertical groundwater gradient be mapped as part of this study. These areas were mapped by subtracting the water table elevation from the potentiometric surface elevation. Areas where the water table is higher than the potentiometric surface can be considered as having a downward groundwater flow gradient (potential recharge), whereas areas where the potentiometric surface is higher than the water table can be considered as having an upward vertical gradient (potential discharge). It is important to note that these maps only identify areas where there is a gradient (or force) pushing groundwater. Mapping does not indicate whether groundwater is actually moving. For example, in a downward gradient area, where the aquifer is not permeable (such as in an area of non-fractured bedrock or clay), there can be a downward force, but groundwater recharge is not occurring because the groundwater cannot move in the absence of permeability.

As a requirement of the MOE Terms of Reference, potential discharge areas were also identified. The approach was to map areas where the water table, prior to correction for topography, extends above the ground surface. This map has been interpreted to identify areas where the land elevation is below the average local water table. In essence, this map

highlights areas where the water table may be near surface and groundwater seepage faces may exist. For example, the sides of steep river valleys or escarpments will be highlighted by this map as being potential discharge zones.

Depth to Water Maps

Depth to water maps were created for each Partner municipality. The map was not produced at the regional scale. The maps were created by subtracting the land surface elevation from the estimated water table elevation. The maps can be used to help identify areas of groundwater recharge and discharge. Areas where the water table is near ground surface are more prone to be discharge areas, while areas where the water table is deep are often recharge areas. The depth to water map is expected to be a more realistic method to determine recharge and discharge areas than the groundwater vertical gradient map.

Water Quality

The Study Area is prone to natural water quality problems, especially sulphur, salt and hard water. Natural water quality, as reported by the well driller at the time of well construction, is used in this assessment to determine where water quality problems exist. The driller describes the water as being either fresh (good taste), sulphur, mineral (hard, iron, taste), or salty. This classification is based purely on taste and smell rather than a chemical analysis. As a result, water reported to be fresh can be impacted with contaminants. Furthermore, the taste of the water can change as the well is in use. For example, a well producing sulphur tasting water can become more fresh if the well is pumped a lot; however, the opposite can also occur.

Aquifer Vulnerability

Aquifer vulnerability refers to the susceptibility of the aquifer to contamination from either a land use practice or a chemical spill. In this study, aquifer vulnerability was assessed following the MOE Intrinsic Susceptibility Index (ISI) mapping approach. This approach is based on mapping areas that are susceptible to surface contamination as opposed to buried contaminants. The approach has the following components:

- Water well records are used to derive the “Intrinsic Susceptibility Index” for each well, based on information on soil or rock types encountered, thickness and depth to the water table.
- A “K” factor is assigned for each type of soil or rock indicated in the well record. The K factor varies inversely with the permeability of the soil or rock. For instance, sand has a K factor of 2 and clay has a K factor of 6. The intrinsic susceptibility index for that layer is the K factor multiplied by the thickness of the layer.
- The “first” aquifer is identified as any consecutive grouping of aquifer type layers (e.g., sand, gravel, limestone) that is at least 2 m thick and is at least partially saturated (i.e., the water table is above the bottom of the grouping). A consecutive grouping includes non-aquifer (e.g., clay) layers of less than 1 m thickness.
- Aquifers are further classified as “confined” (where the water table elevation is at least 4 m above the top of the aquifer layer) or “unconfined” (where the water table elevation is less than 4 m above the top of the aquifer).
- The Intrinsic Susceptibility Index for a well is the sum of each layer’s ISI above the top of the confined aquifer, and to either the top of the first aquifer or the water table (whichever is lower) for an unconfined aquifer.

Once an ISI value is determined for each well, the well is given an index depending upon the ISI value:

Low Vulnerability:	ISI values 80	Index 3
Moderate Vulnerability:	ISI values 30-80	Index 2
High Vulnerability:	ISI values <30	Index 1

A computer program is used to contour the map, based on the well index values. For the Study Area, the approach was modified so that any area mapped as either bare rock or shallow soils (less than 1.5 m of material) was classed automatically as highly vulnerable.

The limitation of this approach is that it is purely empirical and does not take into account the vertical direction of groundwater flow. It is also highly dependent upon the accuracy of the well driller's description of the geological material encountered when drilling, which is often poor. As a result, the mapping results should be considered as a screening level assessment, and are not suitable for site-specific analysis.

4.3 Overview of Groundwater Flow Principles

This section reviews some of the basic concepts of groundwater flow and is written to provide the reader with an understanding of the more common terminology used in this report. A glossary of additional technical terms is provided at the end of **Section 10**.

Groundwater Flow and the Hydrologic Cycle

The continuous circulation of water between ocean, atmosphere and land is called the hydrologic cycle (**Figure 4.1**). Precipitation falls onto the watersheds in the form of rain or snowfall. A portion of this precipitation runs directly to surface water tributaries as overland flow, while some is returned to the atmosphere via the process of evapotranspiration (combination of evaporation and plant transpiration). The remaining precipitation infiltrates into the ground and becomes groundwater. The rate at which precipitation soaks into the ground (recharge) is controlled by the permeability and porosity of the shallow soil layers and water table depth.

Once in the ground, the direction and rate of groundwater flow is controlled by the permeability (referred to as hydraulic conductivity) and porosity (amount of pores or spaces) of the soil or rock material, and by the water pressure (referred to as the hydraulic head or gradient). Groundwater generally moves faster in permeable materials such as sand, gravel, sandstones and fractured rock, and slower in less permeable deposits such as clay or shale. The hydraulic conductivity of natural solid deposits is governed by the particle size of the soil and its gradation, whereas the hydraulic conductivity of weathered clay and bedrock is governed by the size, frequency and connection of discontinuities such as joints, bedding planes and fractures (also known as secondary permeability).

Aquifers and Aquitards

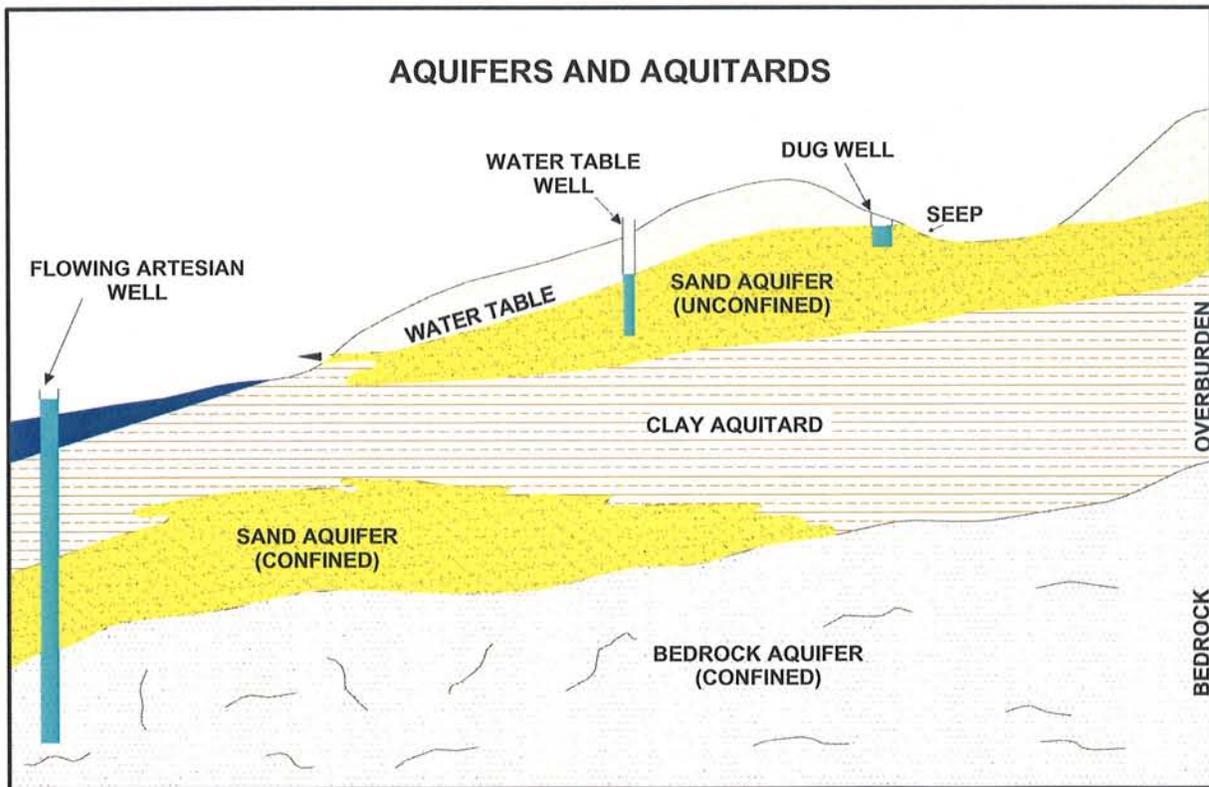
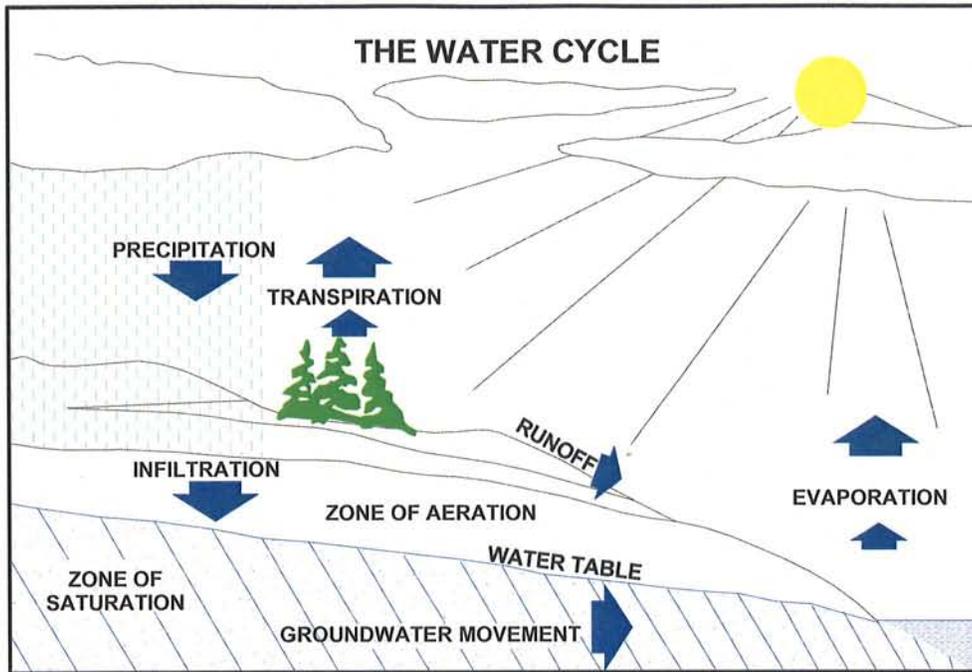
Hydrogeological units or formations that supply adequate quantities of water for use when tapped by a well are referred to as aquifers. Typical geological units that can be good aquifers include sandstones, fractured dolostone and limestone bedrock as well as coarse-grained unconsolidated deposits such as sands and gravels.

Geological units that are almost impermeable or have low permeability are referred to as aquitards. While aquitards are not suitable for groundwater supply, they can protect underlying and/or adjacent aquifers from contamination, as they restrict migration of potential contaminants. Materials that often act as aquitards include shale, unfractured rock, clays and certain fine-grained glacial tills.

Figure 4.1 illustrates the relationship between aquifers, aquitards and groundwater supply wells.

Confined and Unconfined Aquifers

Aquifers are defined as either being confined or unconfined. A confined aquifer is bounded or confined between two low permeability units (aquitards). An aquifer is unconfined if its upper surface is defined by the water table. In the Study Area, the shallow surficial sand or sand and gravel aquifers are unconfined. Where the bedrock is exposed at surface, the bedrock aquifer may be either confined or unconfined, depending on whether the interconnected fractures extend to surface. That is, if fractures do not extend to the surface, the bedrock aquifer is confined. In the Study Area, most of the fractures are vertical and extend to surface. As a result, the bedrock aquifer, at least in the top horizons that are targeted by wells, can be considered as unconfined. Deeper wells that intercept deeper fractures may be semi-confined or confined. In addition, where the bedrock is buried by a significant thickness of clay or till, the bedrock is confined. From a groundwater management perspective, confined aquifers are usually better protected from potential sources of contamination than are unconfined overburden aquifers.



**LAMBTON COUNTY
GROUNDWATER STUDY**

GROUNDWATER PRINCIPLES

Water Tables and Potentiometric Surfaces

In unconfined aquifers, the top saturated portion of the aquifer is defined by the water table. The slope of the water table over an area defines the direction of groundwater flow. Groundwater flows from areas of higher water table elevation to areas of lower elevation. Often the elevation of the water table surface is a subdued reflection of the topography. For confined aquifers, where the water table is located above the aquifer, the direction of groundwater flow is controlled by the slope or gradient in the potentiometric surface of the aquifer unit. The potentiometric surface is the imaginary surface developed by plotting and contouring the water levels or hydraulic heads (pressure) in all wells that tap into the confined aquifer. Hydraulic heads are determined by measuring the standing (or static) water level in wells completed in the confined aquifer. Groundwater flow in the confined aquifers travels from areas of relatively high hydraulic head to areas of relatively low head.

Groundwater Recharge and Discharge

The terms recharge and discharge are often used to describe the direction of vertical groundwater flow near the ground surface. Where the net direction of groundwater flow is downward, the area is under recharge conditions, while areas where the net direction of groundwater flow is upward are referred to as groundwater discharge zones. Identification of recharge and discharge areas within a watershed is important from a planning perspective, since contamination of recharge areas can have a wider impact on the aquifer(s). Groundwater flowing downwards can introduce contaminants from the surface into potable aquifers.

Both large scale (regional) and small scale (local) recharge and discharge zones can occur. The number and size of recharge/discharge zones depend on the watershed topography. An illustration on how topography controls the development of recharge and discharge zones is provided in the cross-sections of **Figure 4.2**. The top figure shows a situation where the topography is relatively flat, similar to conditions in Tyendinaga Township and Prince Edward County. In this situation, groundwater flow is uniform, causing the development of a large recharge area in the uplands and a small discharge area in the lowlands. The discharge area could be analogous to the Bay of Quinte or Lake Ontario. In many cases, the area of recharge is far greater than the area of discharge. Discharge areas commonly only

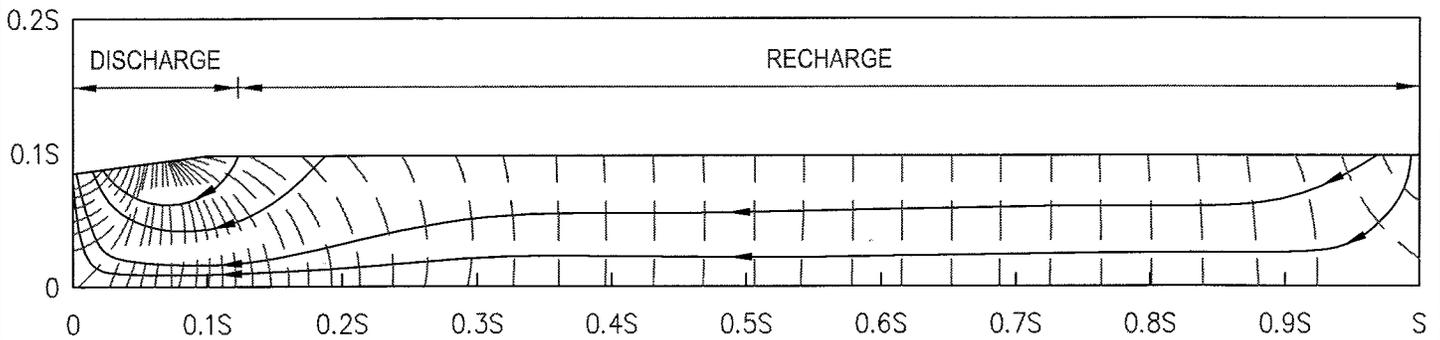
make up 5 to 30 percent of the watershed area (Freeze and Cherry, 1979). The bottom figure shows the effects that irregular topography has on groundwater flow, and is analogous to what occurs in Hastings Highlands, Carlow/Mayo and Bancroft areas. The irregular topography creates numerous local scale recharge and discharge zones in the upland areas, while a deeper regional groundwater flow system is maintained at depth. The development of local scale recharge/discharge zones can produce numerous isolated wetlands and lakes, as is observed in the highland areas of the Study Area.

Groundwater Chemistry

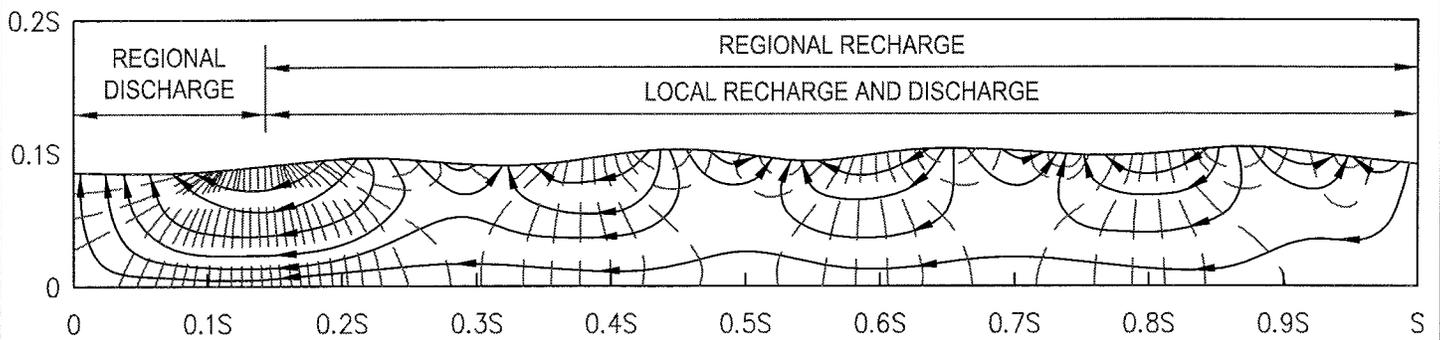
Groundwater geochemistry is a product of the original quality of the recharge water and geochemical processes that occur in the subsurface (e.g., redox reactions, dissolution/precipitation reactions, ion exchange, adsorption and diffusion). Generally, the most dominant geochemical processes that affect the quality of groundwater within fractured rock aquifers are dissolution and precipitation reactions and possibly redox reactions. Other processes (particularly ion exchange and adsorption) are generally more active in unconsolidated soil deposits with significant organic carbon content and/or clay mineral content. Contamination of groundwater by human activities (anthropogenic impacts) can also lead to geochemical reactions that affect groundwater quality.

Aquifer lithology and the residence time of the groundwater as it migrates through the aquifer can impart a significant influence on groundwater geochemistry. The Chebotarev sequence (Freeze and Cherry, 1979) indicates that, as groundwater enters the subsurface, it is similar to the chemical composition of rainfall and, with time, it evolves towards the composition of seawater. Shallow groundwater that has recently entered the subsurface is dominated by bicarbonate (as the major anion) and is low in total dissolved solids (TDS). Intermediate depth groundwater that has had increased time in the subsurface will have a higher TDS concentration and sulphate is normally the dominant anion. Deep groundwater, with sluggish groundwater flow or long residence times in the subsurface, will have high concentrations of TDS and chloride.

The evolution of groundwater geochemistry, according to the Chebotarev sequence, is dependant on the availability of minerals containing sulphate and chloride as well as groundwater residence time. Longer groundwater residence times allow for increased



a) LEVEL TOPOGRAPHY



b) UNEVEN TOPOGRAPHY

LEGEND

- GROUND WATER FLOW
- EQUIPOTENTIAL LINES

AFTER FREEZE AND WITHERSPOON, 1967



TITLE

**EFFECT OF TOPOGRAPHY ON REGIONAL
GROUNDWATER FLOW PATTERNS**

PROJECT

QUINTE REGIONAL GROUNDWATER STUDY

FIGURE 4.2

dissolution of soluble minerals; therefore, poorer quality groundwater (high in TDS) is often associated with discharge zones of deeper groundwater and areas of stagnant groundwater (e.g. within bedrock zones bounded by tight faults). Poorer groundwater quality is also occasionally associated with confined aquifers (e.g., overlying clay aquitard) due to limited aquifer recharge by precipitation.

Based on aquifer lithology, groundwater geochemistry in the regional aquifer can be predicted. The following summary of the effects of lithology on groundwater geochemistry is modified from Mazor (1991):

- | | |
|-----------|--|
| Sandstone | <ul style="list-style-type: none">• Low TDS (300-500 mg/L)• Bicarbonate is the major anion; sodium, calcium and magnesium in similar concentrations• Good taste |
| Limestone | <ul style="list-style-type: none">• Moderate TDS (500-800 mg/L)• Bicarbonate is the major anion; calcium is the dominant cation• Good taste |
| Dolostone | <ul style="list-style-type: none">• Moderate TDS (500-800 mg/L)• Bicarbonate is the major anion; calcium and magnesium are dominant cations• Good taste |
| Shale | <ul style="list-style-type: none">• High TDS (900-2,000 mg/L)• Chloride is often the dominant anion followed by sulphate; sodium is the dominant cation• Poor taste to non-potable |
| Granite | <ul style="list-style-type: none">• Moderate TDS (500-800 mg/L)• Bicarbonate is the major anion; sodium and calcium are dominant cations• Very good taste. |

4.4 Regional Summary

This section presents the results of the hydrogeological analysis of the Study Area at the regional level. Specific results of the assessment, as they apply to each of the study partner municipalities, are presented in **Section 4.5**.

4.4.1 Hydrogeological Setting

Aquifer and Groundwater Flow

The hydrogeological setting of the Study Area is shown schematically in **Figure 4.3**. This figure illustrates the major aquifers and aquitards along a hypothetical north-south cross section running through the central portion of the Study Area.

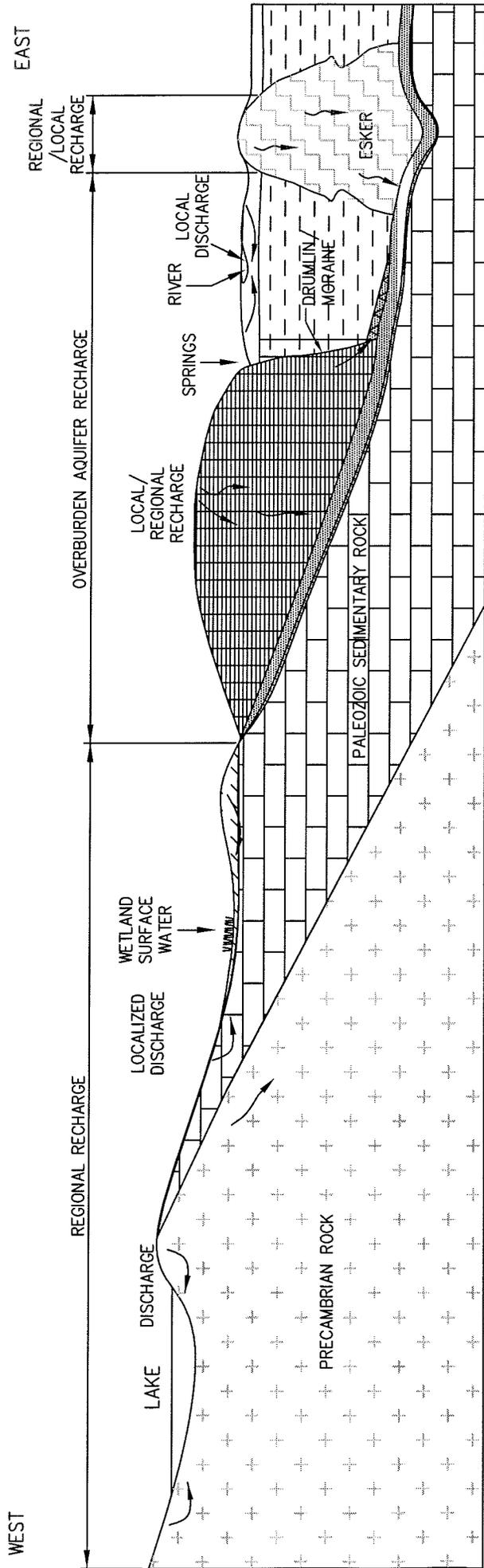
Two main groundwater flow systems are evident and include:

- Bedrock Flow System; and,
- Overburden Flow System.

The bedrock flow system underlies the entire area and can be divided along its lithological boundaries as comprising Precambrian and sedimentary rock aquifers. Groundwater flow is through fractures that have formed through these rocks. Recharge to the bedrock aquifer occurs in areas where the bedrock is either exposed or covered by thin layers of permeable sands and gravels or glacial till, allowing precipitation to infiltrate into the subsurface. Over the majority of the Study Area, the top 10 to 30 m of the bedrock is considered to be regionally unconfined as a result of fracturing near the surface. Locally, the bedrock aquifer can be confined in areas where the overlying rock is not as heavily fractured.

The overburden flow system is characterized by isolated occurrences of sand and gravel aquifers that are present mainly in the form of eskers, glaciofluvial outwash deposits, drumlins, till moraines or glacial beach deposits. With the exception of some of the glacial outwash sand and gravel aquifer in the north part of Hastings County, the overburden aquifers are hydraulically connected to the bedrock aquifer. In areas where the overburden is

TYPES OF AQUIFERS IN STUDY AREA



NOT TO SCALE, DIAGRAM FOR ILLUSTRATION PURPOSES ONLY

OVERBURDEN AQUIFERS

- SHALLOW SURFICIAL SAND - UNCONFINED AQUIFER
- GLACIOFLUVIAL SAND AND GRAVEL - MAINLY UNCONFINED AQUIFER
- BASAL SAND AND GRAVEL - CONFINED AQUIFER
- WETLAND/SURFACE WATER

BEDROCK AQUIFERS

- PALEOZOIC - REGIONALLY UNCONFINED
- LOCALLY UNCONFINED/CONFINED PRECAMBRIAN
- MAINLY UNCONFINED

OVERBURDEN/BEDROCK CONTACT AQUIFER

- CONTACT AQUIFER

AQUITARDS

- CLAY AND SILT
- TILL (where silty. Can be Aquifer where Sandy)

NOTE:

RELATIVE THICKNESS OF OVERBURDEN HAS BEEN EXAGGERATED

FIGURE 4.3

QUINTE REGIONAL GROUNDWATER STUDY

thick enough to hold water, it can be used as an aquifer. The deposits can also act as “sponges”, trapping precipitation and allowing it to infiltrate into the bedrock aquifer. As a result, these overburden aquifers can be considered recharge zones.

Groundwater flow patterns are driven by topography, in that groundwater flow, in general, moves from highland areas to lowlands, closely mimicking surface water drainage patterns. As described in **Section 4.2** and illustrated in **Figure 4.2**, the complexity of the groundwater flow pattern depends largely on irregularities in surface topography. In the Study Area, the northern portion of Hastings County (and the Quinte watershed) has an irregular land surface typical of Canadian Shield topography. This area, which is characterized by lakes, wetlands and rivers interspersed between outcrops of rock, will cause the groundwater flow to be irregular, with flow directions changing dramatically, depending upon proximity to the nearest surface water feature. At depth, the flow system will become more uniform and will be oriented similar to regional flow conditions, which are southward towards Lake Ontario. In the southern portion of the Study Area (south of Madoc), the land elevation is flatter, causing local groundwater flow patterns to be less irregular and more typical of regional flow directions.

Most of the Study Area has been heavily faulted. The effect of these faults is three-fold: a) they cause different types of bedrock aquifers to be juxtaposed beside each other, resulting in variations in water chemistries and aquifer properties over short distances; b) in many cases rivers or lakes form in the fault zones, forming local discharge areas that influence local groundwater flow conditions; and, c) faults may act as a preferential pathway for groundwater flow movement in areas where fracture zones are dense.

4.4.2 Bedrock Aquifers

Distribution

Bedrock aquifers are, by far, the most used aquifers in the Study Area and are tapped in all municipalities. The particular bedrock aquifer that is exploited depends mainly on economics, in that domestic water wells seldom extend beyond 30 to 40 metres. As a result, the aquifer that is exploited depends mostly on geographic location and the type of bedrock formation that is closest to the ground surface. **Map 3.1** shows the location of the various

bedrock aquifers. The location of wells that pump from the bedrock aquifer are shown in **Map 4.1**.

Aquifer Types and Characteristics

The main regional bedrock aquifers include the Precambrian aquifer and the sedimentary rock aquifers. A summary of the hydrogeological properties of these aquifers is presented in the following table and discussed below.

Table: 4.1
Summary of Bedrock Aquifer Properties

Material/ Formation	Lithology	Water Quality	Yields*
Upper Lindsay	Limestone/shale	Hard, sometimes sulphury	Poor
Lindsay	Limestone	Hard, sometimes sulphury	Poor
Verulam	Limestone/shale	Hard, often sulphury	Poor to Moderate
Bobcaygeon	Limestone	Hard	Poor to Moderate
Gull River	Dolostone/shale/ sandstone	Hard	Poor to Moderate
Shadow Lake	Sandstone/siltstone	Fresh, sometimes mineral	Very Good
Precambrian	Igneous/metamorphic	Fresh, sometimes mineral	Moderate

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

Precambrian Aquifer

The Precambrian aquifer includes all Precambrian igneous and metamorphic rocks and covers the northern half of the Study Area, including the municipalities of Hastings Highlands, Carlow/Mayo, Town of Bancroft, Madoc, and the northern portions of Tweed and Stone Mills.

Groundwater flow is through secondary porosity from fractures that have developed as a result of tectonic processes. Primary porosity, while present in Precambrian rocks, is less than 2 percent. The distribution and density of fractures commonly decrease with depth. Near the surface, stress releases cause bedrock “sheeting” that results in the development of

horizontal fractures parallel to the topographic surface. These shallow fractures can be of sufficient density to provide adequate sources of potable water supplies. Vertical fractures are also prevalent, often making the aquifer unconfined and sensitive to surface contamination. Estimates of bulk hydraulic conductivity of fractured igneous and metamorphic rocks range from 10^{-6} to 10^{-2} cm/s (Freeze and Cherry, 1979). Actual values for the Precambrian aquifer in the Study Area are typically toward the lower end of this range. In general, fracture zones in the Precambrian aquifer yield marginal to adequate quantities of water for individual wells.

The natural water quality of the Precambrian aquifer is usually very good. In granitic type rock, calcium and bicarbonate are the dominant dissolved elements, while total dissolved solids are low (often less than 300 ppm). Within the Study Area, water from granitic type aquifers is often of the highest quality. Groundwater from metamorphic rock aquifers often has higher total dissolved solids than water from igneous rock, but the concentrations are still relatively low (less than 500 ppm), giving the water a good quality. Water from metamorphic rocks is often harder than water from igneous rocks and may contain more metals such as iron and manganese.

Sedimentary Aquifers

Sedimentary aquifers underlie the majority of populated areas in the Study Area. Groundwater flow is through both horizontal fractures parallel to bedding planes as well as vertical joint fracture sets. The quantity of water produced by any given well depends upon how many fracture sets have been intercepted and the lateral extent of these fractures below ground. These fractures also make the aquifer vulnerable to surface contamination. Because of the seemingly random orientation and density of these fractures, there is a tremendous variation in well yields. Water quality is generally hard (300 to more than 600 ppm) and calcium and bicarbonate are the dominant ions. Areas of high sulphate, sodium and chloride concentrations are common and can leave the water unpotable. A summary of the characteristics of each sedimentary rock formation is as follows:

Shadow Lake Formation Aquifer

This formation consists of interbedded sandstone, siltstone and shale. The unit is relatively thin and is likely only tapped at the northern margins of the sedimentary rock belt that cuts through the municipalities of Central Hastings, Tweed and Stone Mills. Because of the sporadic location of this aquifer, it is difficult to accurately assess its qualities. It is often reported in the well records as sandstone immediately above the Precambrian rock. Water quality from this aquifer is expected to be good in quality and quantity, but may be hard and mineralized in some locations because of the potential for dissolved metals.

Gull River and Bobcaygeon Formation Aquifers

These formations provide yields that are marginally adequate to acceptable for domestic consumption (less than 10 to 13 L/min for a typical domestic use). The groundwater yield of these formations also typically decreases with depth. These formations are used as the potable water source over the northern portion of Tyendinaga, City of Belleville, southern portion of Tweed and the southern half of Stone Mills. They are generally too deep to be intercepted in Prince Edward County. The water quality is usually hard, and sulphur and salty water is common, but not as prevalent as is found in the Verulam or Lindsay Formations to the south.

Verulam Formation Aquifer

The Verulam Formation is the main bedrock aquifer for the area bordering the Bay of Quinte, underlying most of the City of Belleville, the northern portion of Prince Edward County, and the southern half of Tyendinaga. Well yields are poor to moderate depending upon the shale content, with higher yields produced in wells that intercept more shale bedding or fractures. The increased amount of shale also results in many wells having sulphur and salt problems. The aerial distribution of good wells and sulphur wells is generally unpredictable, with good wells being drilled near poor yielding or sulphur wells.

Lindsay Formation Aquifer

The Lindsay Formation aquifer (limestone and shale interbeds) is found only in Prince Edward County south of the Mountain View Escarpment. Flow within this aquifer is through horizontal fracturing along shale bedding planes and along vertical fracture sets caused by bedrock jointing. Well yield and quality varies tremendously with location and depends largely on whether the well intercepts a vertical fracture. It is not uncommon for a greater than 90 L/min (greater than 20 igpm) well to be located next to a dry well. Water quality is usually hard, and sulphur and salt problems are common, but less so than wells in the Verulam Formation.

4.4.3 Overburden Aquifers

Overburden aquifers exist throughout the Study Area where sand and gravel deposits exist below the water table at sufficient thickness to provide adequate well storage wells that pump from the overburden aquifer are shown in **Map 4.1**. The location of these aquifers are shown in **Map 3.3** and are plotted as the following deposits:

- Glaciofluvial Ice-Contact Deposits (Eskers and Kames);
- Glaciofluvial Outwash Deposits and Deltaic sands;
- Glaciolacustrine Nearshore Deposits (Beaches); and,
- Till (Drumlins or Moraines).

A summary of the hydrogeological properties of these aquifers is presented in the following table and discussed below.

Table: 4.2
Summary of Overburden Aquifer Properties

Material/Formation	Lithology	Water Quality	Yields*
Nearshore & Beach	Sand and silt	Fresh, mineral	Very Good
Eskers/Kames	Sand and gravel	Fresh, mineral	Very Good
Clay	Silt and clay	Sulphury	Poor
Till	Sand, silt, gravel	Fresh, mineral	Moderate

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

Areas where registered wells have been drilled through these deposits, and sufficient sand and gravel is present to potentially act as an aquifer, are shown in **Map 3.5**.

Glaciofluvial Ice-Contact Deposits (Eskers and Kames)

The glaciofluvial sand and gravel deposits that formed as eskers and kames are limited in extent and are important aquifers at the local scale only. They do provide storage capacity for infiltrating groundwater and, therefore, act as a sponge for water that is later infiltrated into the regional bedrock aquifer.

The hydraulic conductivity of these deposits has been estimated to range from 10^1 to 10^{-4} cm/s, depending upon gravel content, which generally decreases away from the centre of the ridges. These sand and gravel deposits are capable of producing large quantities of groundwater; however, they are susceptible to contamination from surface sources.

Significant aquifers of this type include: the Ridge Road esker in Picton; Tweed-Thomasburgh-Frankford esker; and, the Tamworth-Marlbank-Plainfield esker. Other eskers are present in the east portion of the Township of Madoc and in the west portion of the Township of Hastings Highlands.

Glaciofluvial Outwash Deposits and Deltaic Sands

The surficial sand aquifer consists of aerielly extensive shallow sands that formed in a deltaic, nearshore or alluvial environment. The aquifer is unconfined in most places and

attains thicknesses of usually between 3 and 10 m. In Hastings Highlands, where the sand filled preglacial bedrock valleys, the aquifer can be up to 70 m thick. The water table is usually within 2 to 5 m below ground surface.

Hydraulic conductivities range from 10^{-3} to 10^{-2} cm/s, but may be lower in areas of higher silt content. This aquifer is most prevalent in Hastings Highlands, Carlow/Mayo and Bancroft.

Glaciolacustrine Deposits (Beaches)

Shallow unconfined sand aquifers appear along the margins of Lake Ontario and the Bay of Quinte. These aquifers are shallow and unconfined. Because of the high permeability of these deposits, well yields can be high, but are often limited by the low available drawdown in this thin aquifer. Many dug wells and sand point wells produce water from this aquifer for individual use. Significant aquifers of this type exist in Prince Edward County near West Lake and along the base of escarpments. This type of aquifer is also found east of Tweed and north of Foxboro.

Till Aquifer

Till aquifers occur where sand and gravel are present in sufficient thickness below the water table. The best till aquifers occur at the drumlin field located in the northwestern corner of the City of Belleville (former Thurlow Township). In these areas, 10 to 50 m of saturated sand and gravel can be present. The hydraulic conductivities of these wells will depend upon clay and silt content; however, 10^{-2} to 10^{-4} cm/s is expected. These important features act as recharge zones for the underlying bedrock aquifer. Groundwater discharges in the form of springs at the base of these till aquifers and feeds surface creeks and wetlands.

Silt and Clay Aquitard

The Study Area does not contain any regionally significant aquitards. Locally, silt and clay deposits can provide moderate protection to some aquifers. Fine-grained deposits are present along some of the low-lying areas near the Bay of Quinte and Lake Ontario, such as Belleville, Shannonville, south of Rednersville, and West Lake. Clay is also present in some

locations in Hastings Highlands, Carlow/Mayo and Bancroft below the unconfined sand aquifer.

The hydraulic conductivity of the clay and silt likely ranges from 10^{-4} to 10^{-5} cm/s. Some dug wells produce water from this formation, but the water quality is often high in sulphur and organic carbon, leaving a strong smell and taste. This material is usually less than 3 m thick and is fractured. As a result, its ability to provide protection to the underlying aquifers is limited.

4.4.4 Groundwater Flow

This section presents the results of the regional groundwater flow assessment. Assessments specific to each study municipality are summarized in **Section 4.5**.

Water Table

The regional water table elevation map is shown as **Map 4.2**. Areas of high elevation are shown in red, while areas of low elevation are shown in blue. Water table elevations range from greater than 500 masl in Hastings Highland to ~75 masl along Lake Ontario. The water table elevations coincide with topography (**Map 2.2**) and show a regional trend of high water table elevations in the north, decreasing towards Lake Ontario to the south.

Based on the orientation of the water table contours, the direction of the large-scale regional groundwater flow can be interpreted. In the Moira and Napanee watersheds, the regional groundwater flow mimics surface drainage patterns and is directed south to southwest. In Prince Edward County, regional groundwater flow is outwards from the highland areas and directed to the shorelines. Beyond the Quinte watershed, in the northern municipalities of Hastings County, regional groundwater flow direction is expected to be northeast.

In contrast to the large-scale regional trends, local groundwater flow directions at the municipal level can be highly variable, especially in areas of rugged topography such as is found on the Precambrian shield. In the rugged areas of Hastings Highlands, Carlow/Mayo and Bancroft, groundwater flow will be directed from areas of localized high elevation to topographic depressions such as valleys and lakes. Over the Study Area, the irregularity in

the water table surface decreases to the south, as the topography becomes more subdued, resulting in an expected closer alignment between regional and local scale groundwater flow directions. Divergence between local and regional flow directions is observed around many of the southern drainage systems such as the Salmon, Napanee and Moira River valleys, where shallow groundwater flow is directed towards the rivers.

Potentiometric Surface

Map 4.3 illustrates the potentiometric surface, as determined from water well records. A review of the map shows that the potentiometric surface is highest (~ 490 masl) in the Hastings Highlands area and lowest near Lake Ontario (75 masl). Areas of high elevation are shown in red, while areas of low elevation are shown in blue. The map is similar to the water table map (**Map 4.2**), in that water level elevations are highest in the north and decrease to south. Regional flow directions are anticipated to be similar to the water table map, and will generally be directed to the southwest in the Quinte watershed, radiate outward from high land to Lake Ontario in Prince Edward County, and directed to the northeast in Hastings Highlands, Carlow/Mayo and Bancroft.

Similarities between the water table and potentiometric surface maps suggest that many of the wells used to plot the potentiometric surface are somewhat hydraulically connected to the water table. Since the potentiometric surface is created largely by bedrock wells that have open-hole construction from near surface (that is, both shallower and deeper zones in the bedrock contribute water to the well bore), similarities in the two maps are expected.

Recharge and Discharge Areas

Mapping of the vertical direction of groundwater flow can be used to identify surface water features or wetlands that are sensitive to groundwater input (discharge areas), or regions where the land use can potentially impact the groundwater quality and quantity (recharge areas).

The vertical direction of groundwater flow was estimated using three methods. The first method (shown in **Map 4.4**) involved identifying vertical groundwater flow directions based on water levels in wells. The second method (shown in **Map 4.5**) involved identifying areas

where the land surface falls below the average water table elevation in the area and the topography is steep, such as would be found on the side of river valleys. This map predicts areas where the water table may be near ground surface. The third method involves mapping the depth to the water table. All of these maps can be used to identify water bodies such as wetlands, streams and lakes that may have a significant base flow component.

While these maps do provide useful information on areas of potential groundwater recharge and discharge, they are, at best, an approximation of actual conditions. Considering the assumptions that have been used, the accuracy of the boundaries between potential recharge and discharge areas can be in the order of kilometres. The degree of accuracy also varies with location, with the map being considered more accurate in the south than the north. Also, the map shows the direction of the force (hydraulic gradient) that is pushing groundwater, but not necessarily the actual groundwater flow direction. The actual direction and significance of vertical groundwater flow will depend upon the permeability of the aquifer, which is not assessed in this study. As a result of these limitations, it is highly recommended that any future interpretation using these maps be performed with the input of a trained hydrogeologist.

Vertical Hydraulic Gradient Map

The location and extent of recharge and discharge areas, as determined by vertical hydraulic gradient, are presented in **Map 4.4**. The map was created by subtracting the water table elevation from the potentiometric surface elevation. Areas of a vertical downward hydraulic gradient (potential groundwater recharge) are shown in green, while areas of vertical upward hydraulic gradient (potential groundwater discharge) are shown in light orange. Yellow designates transitional areas where the direction of the vertical gradient is uncertain or weak. Transitional areas are defined where the difference in the water table and potentiometric surface is less than 5 m.

The vertical hydraulic gradient shows that, in general, the areas of potential recharge correspond with areas that are locally elevated. For example, bedrock outcrop areas in Hastings Highlands are identified as potential recharge zones, whereas the sand filled valleys are identified as potential discharge zones. Similarly, in Prince Edward County, the highland

areas near Picton and in Sophiasburgh Ward are indicated as potential recharge areas, while near the shorelines, transitional or potential discharge conditions prevail.

Map 4.4 shows that the distribution of recharge and discharge areas is somewhat sporadic across the Study Area; however, when compared with the outline of the quaternary subwatersheds (**Map 1.2**), there is a general correlation between the recharge areas and the headwaters of the subwatershed drainage basins. This complexity is attributed to the development of localized topographically controlled recharge and discharge groundwater flow systems similar to those illustrated in **Figure 4.2**.

The information contained in **Map 4.4** reflects uncertainty in the data, as revealed by anomalous results in some areas. As a general rule, the map is most prone to anomalous results in areas where no wells are present on the Potentiometric Surface Elevation Map (**Map 4.3**). As an example, the northern portions of Tweed are plotted as a potential recharge area; however, no wells are present in this area. This is likely a discharge or transitional area, as evident by the numerous lakes and wetlands. The map is considered most accurate in the municipalities of Prince Edward County, Belleville, Tyendinaga and Stone Mills where well data are more available.

Potential Groundwater Discharge Areas

The second method of mapping discharge conditions was to identify areas where the water table is expected to be near ground surface. This map (**Map 4.5**) was required in the MOE Terms of Reference; however, the results are largely inconclusive. Areas marked in red were determined by this method to indicate potential discharge areas. As a general observation, many of the potential discharge (red) areas occur in lowlands that are located near abrupt changes in elevation, such as near ravines or escarpments. For example, the land area at the foot of the Mountain View escarpment in Prince Edward County is identified as a potential discharge area. Similarly, the sand flats near the York River on Highway 62 just north of Bancroft also are indicated as a potential discharge area.

Depth to Water Maps

The third method of mapping recharge and discharge areas is based on estimating the depth to the water table. These maps were created at the municipal scale only. Areas where the water table is near ground surface are more prone to be discharge areas, while areas where the water table is deep are often recharge areas. The depth to water map is expected to be a more realistic method to determine recharge and discharge areas than the groundwater vertical gradient map, especially in the northern Study Partner municipalities where there are few wells. A discussion of these maps is presented in **Section 4.5**.

4.4.5 Water Supply

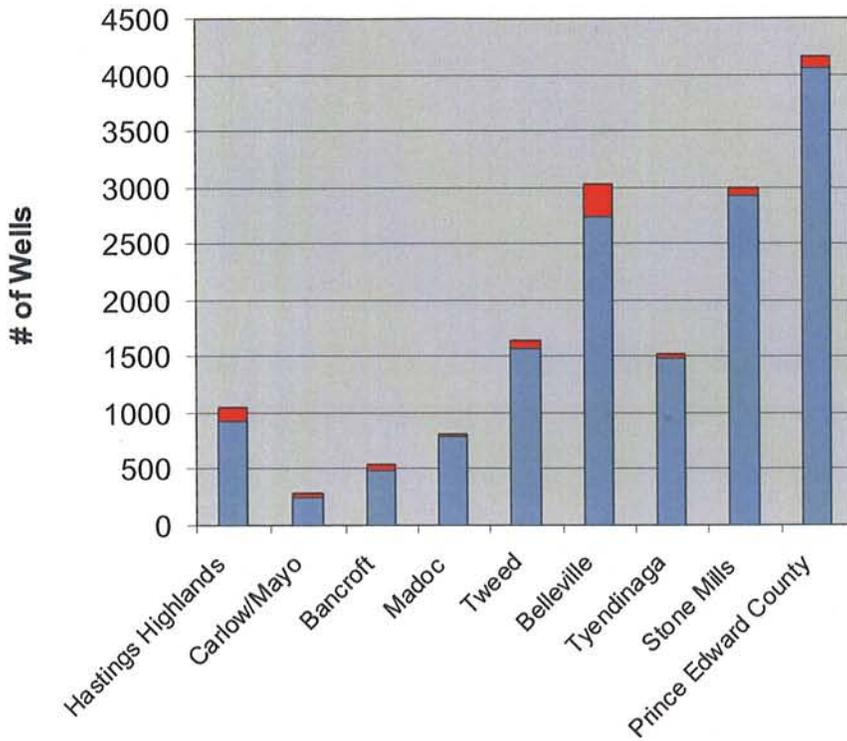
An assessment of the utilization of the major types of aquifers is presented in this section. Data on aquifer type, well construction, water quality and well yield were from well records.

Distribution of Types of Aquifers Pumped

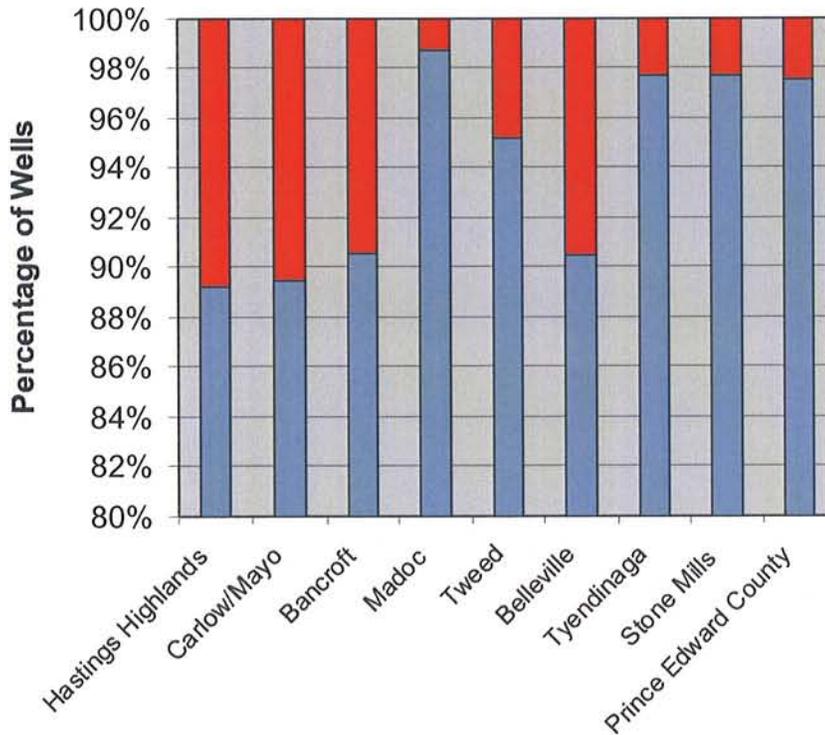
The distribution of overburden and bedrock wells is presented on **Map 4.1** and is summarized by municipality on **Figure 4.4**. Overall, greater than 95% of all wells in the Study Area tap the bedrock aquifer. The municipalities with the largest percentage of overburden wells (greater than 10%) are Hastings Highlands, Carlow/Mayo, Bancroft and Belleville. Madoc has the lowest percentage of overburden use (less than 2%). The municipality with the most registered groundwater wells is Prince Edward County (4,350), followed by Belleville (3,170) and Stone Mills (3,160).

Well Construction

All types of well construction methods have been used in the Study Area. The most common is drilling using either air rotary, mud-rotary or cable tool technology. Dug wells and sand point wells exist; however, their location and frequency of use is difficult to assess because well records are often not completed. Dug wells are most common at older homesteads, farms and cottage areas. Sand points are used in unconfined sand aquifer areas, where the water table is shallow and little gravel is present. Shore wells, which are constructed by either blasting or excavation, are common at residential/cottage waterfront properties. Dug,



■ Bedrock ■ Overburden



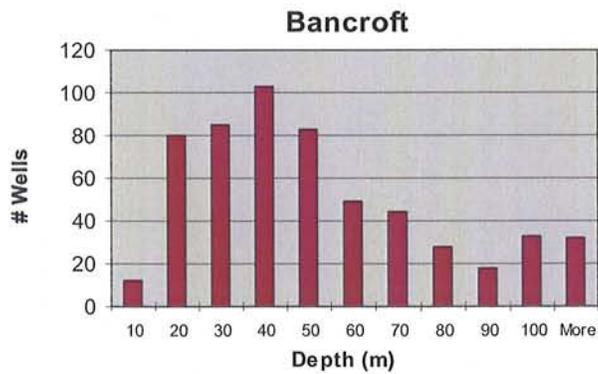
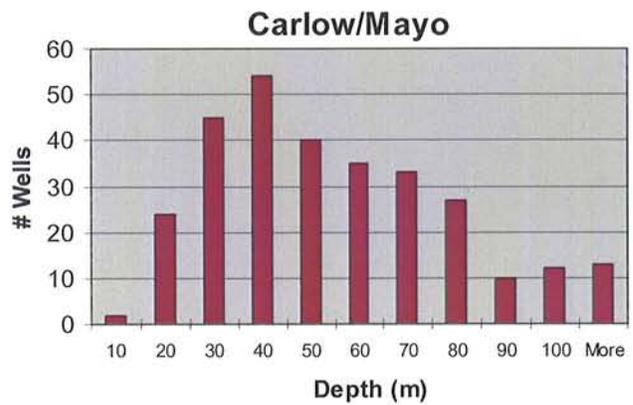
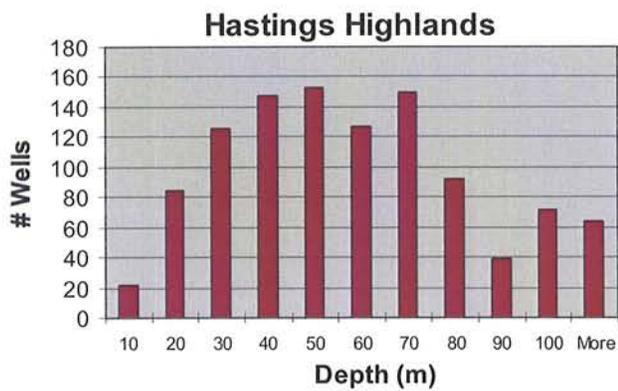
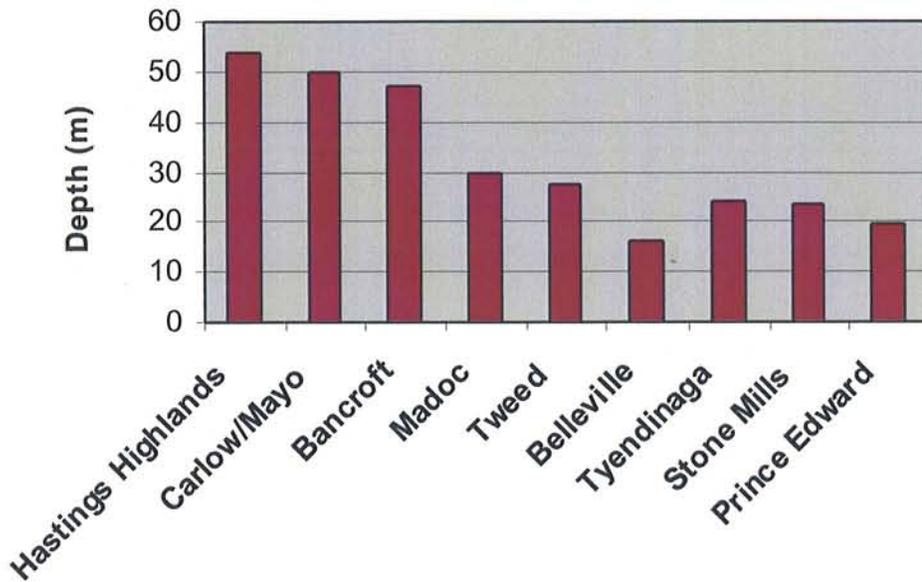
■ Bedrock Wells ■ Overburden Wells



OVERBURDEN/BEDROCK WELL DISTRIBUTION
 QUINTE REGIONAL GROUNDWATER STUDY

FIGURE 4.4

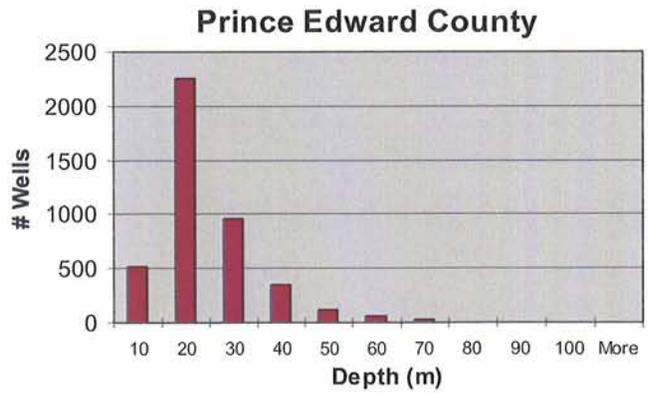
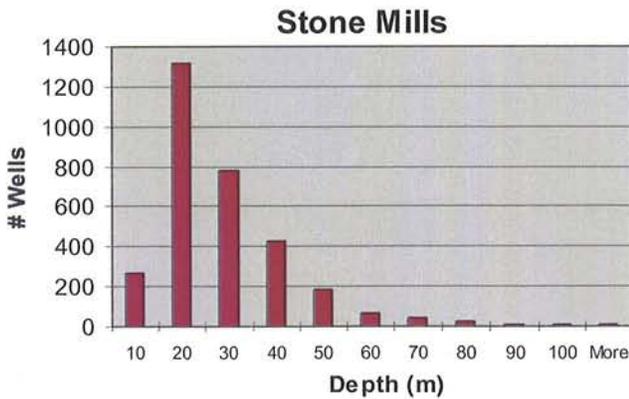
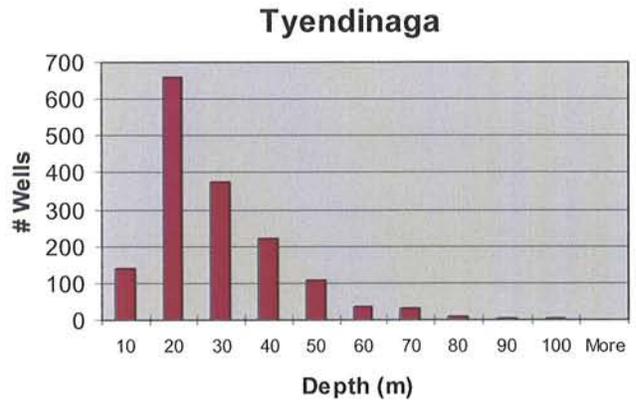
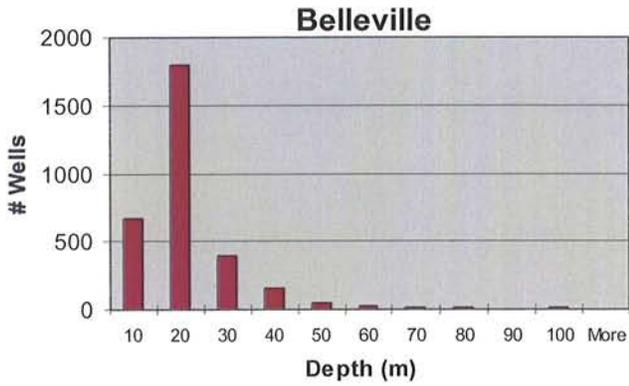
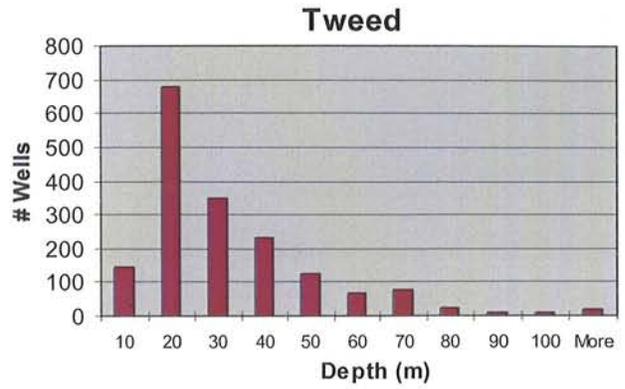
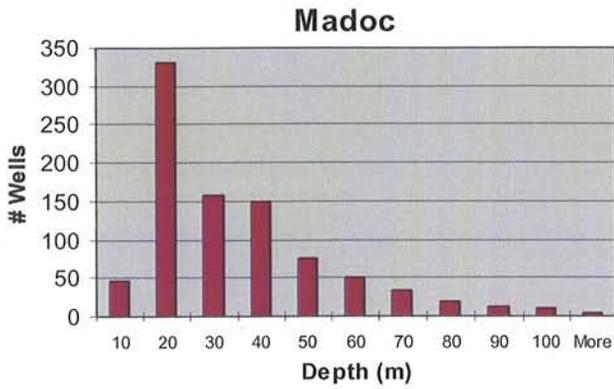
Average Well Depth



WELL DEPTH DISTRIBUTION

QUINTE REGIONAL GROUNDWATER STUDY

FIGURE 4.5

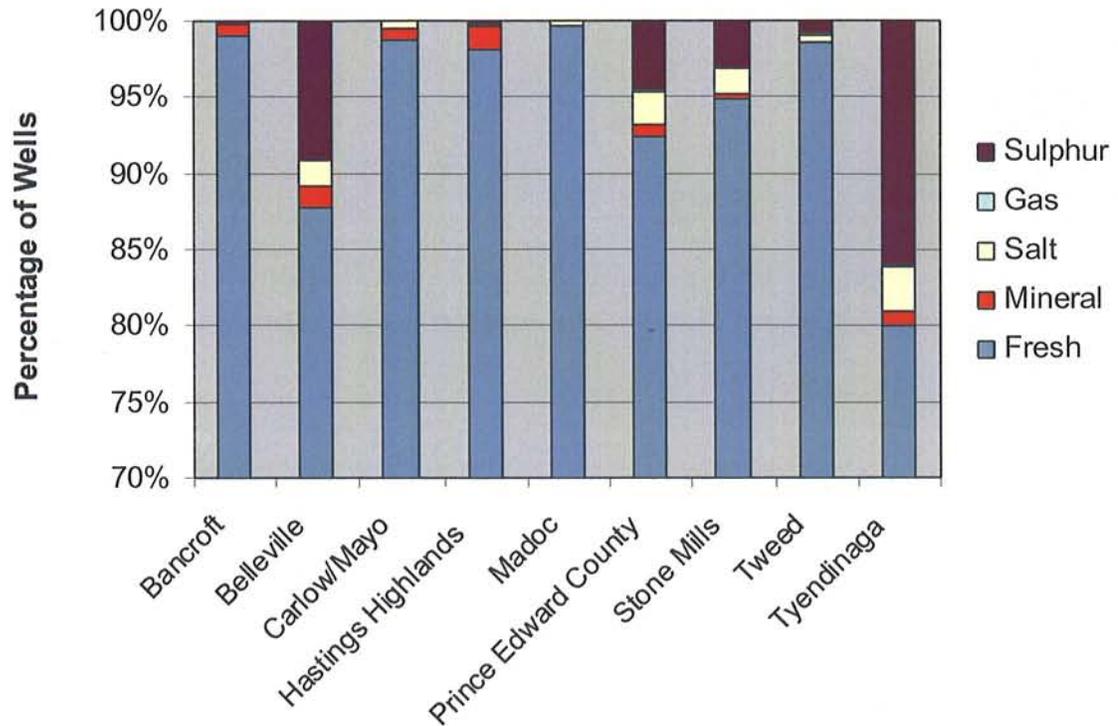


WELL DEPTH DISTRIBUTION

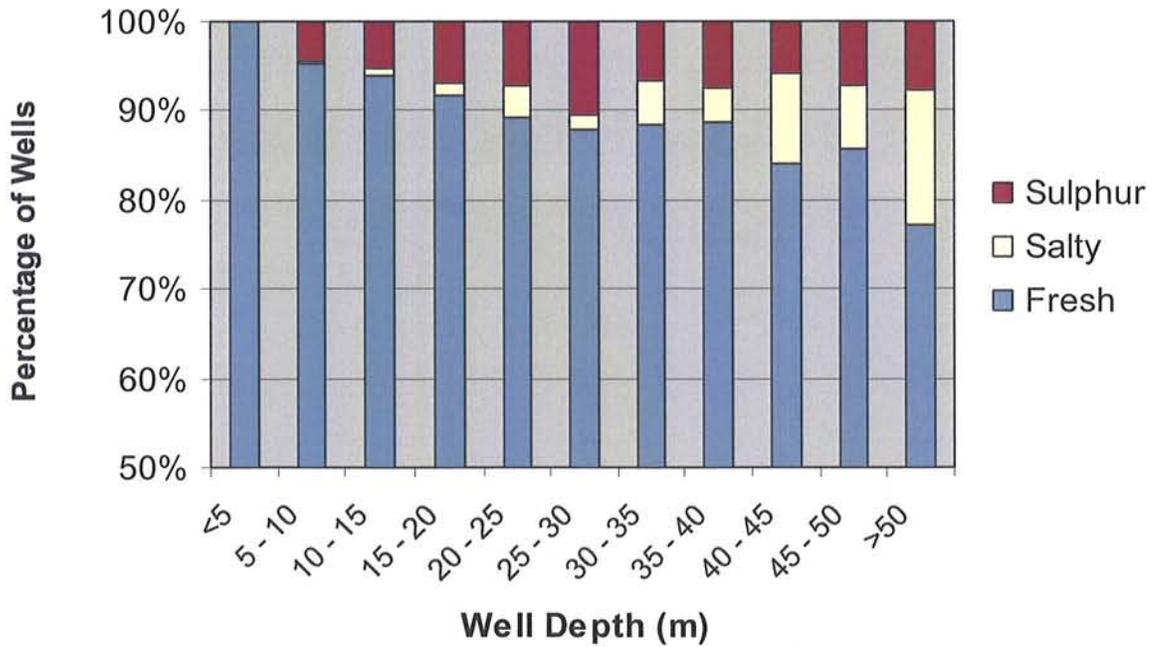
QUINTE REGIONAL GROUNDWATER STUDY

FIGURE 4.5
cont

Type of Water



Well Driller Reported Water Quality vs Well Depth: Belleville and PEC Area



WATER QUALITY

QUINTE REGIONAL GROUNDWATER STUDY

FIGURE 4.6

sand point and shore wells are often susceptible to contamination from near-surface sources because of poor well seals or because they tap water from shallow unconfined aquifers that are more prone to impacts. Shore wells also can draw most of their water from surface water, rather than groundwater. Surface water often contains high levels of pathogens (bacteria, protozoa viruses and parasites), which are concerns if the water is consumed without treatment.

Depth of Water Wells

Figure 4.5 presents a statistical analysis of water well depths. Wells are plotted by depth on **Map 4.1**. This analysis only includes wells for which a water well record was issued. The statistics do not take into account the many shallow dug or blasted wells where no well records are present. As a result, the analysis will likely overestimate the depth of wells for many of the municipalities.

In general, well depths are greatest (greater than 45 m) in the northern municipalities (Hastings Highlands, Carlow/Mayo and Bancroft) and lowest (less than 20 m) near Lake Ontario (Belleville, Prince Edward County). The range of well depths is greatest in the northern municipalities. The need for deeper wells for townships that pump mainly from the Precambrian rock is attributed to the deeper water table. In the municipalities in the south, the water table is often within 15 m and the aquifer more fractured; therefore, the need to drill deep wells to obtain a sufficient quantity is reduced.

Water Quality

An assessment of water quality was made using the water characteristics reported at the time of drilling. The MOE water well records report the water as being either fresh, salt, gas, mineral or sulphur, based primarily on smell and taste.

Figure 4.6 provides statistics on the reported well water quality by township. The vast majority of water (greater than 90%) is deemed fresh. Sulphur problems are present in Belleville and Tyendinaga in 10 to 15% of wells. Prince Edward County also has sulphur problems in 5% of the wells. Salt problems occur in Tyendinaga, Prince Edward, Belleville

and Stone Mills, but at a frequency of less than 5%. The least water quality problems were reported in Madoc, Tweed, Bancroft, Carlow/Mayo and Hastings Highlands.

Map 4.6 shows the distribution of well water quality based on the driller reports. The map shows that sulphur problems are restricted mainly to the sedimentary limestone aquifer and are greatest in areas that receive water from the Verulam Formation. This aquifer contains some shale, which is prone to produce sulphur water. The least water quality problems are reported in the municipalities that pump primarily from the Precambrian rock aquifer.

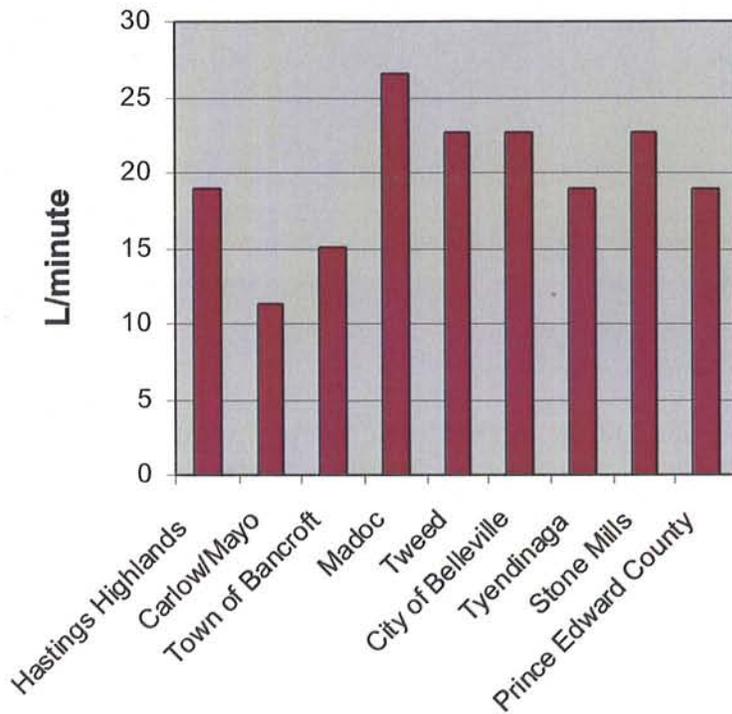
The bottom graph in **Figure 4.6** shows how the water quality varies with depth in the Belleville and Prince Edward County areas. These municipalities were chose, as they are both prone to natural water quality problems. The graph shows that the chance of intercepting salty water increases with well depth; however, the chance of experiencing sulphur problems remains relatively constant, irrespective of depth. The increase in salt problems with depth is attributed to the interception of older water that has become more saturated with dissolved salts in the aquifer. The relative consistency in the percentage of wells with sulphur, regardless of depth, indicates that sulphur is not related to depth of well. The presence of sulphur has likely more to do with the occurrence of shale beds in the Verulam and Lindsay aquifers.

Well Yields

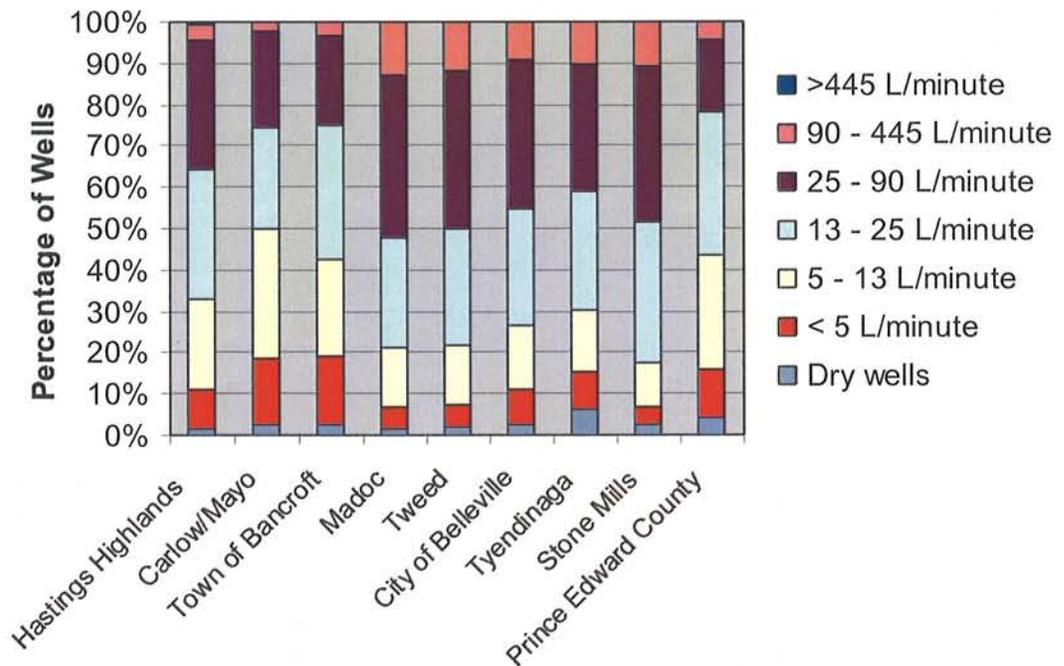
An assessment of well yields was performed at both the regional and municipal level. Summary statistics on pumping rates recommended by the driller at the time of well construction are presented in **Figure 4.7**. Driller recommended pumping rates for wells in each municipality are presented on maps at the back of the **Map Booklet**.

As shown in **Figure 4.7**, the average pumping rate in the Study Area ranges from 11 L/minute in Carlow/Mayo Township to greater than 25 L/minute in Madoc Township. Average pumping rates are generally higher in the southern municipalities, where sedimentary rock is the utilized aquifer, than in the northern municipalities, where the aquifer is Precambrian rock. This observation is attributed to the smaller amount of fractures in the Precambrian rock aquifer compared to the limestone. The analysis also shows that there is a greater chance of drilling a low producing well (less than 13 L/min) in the northern

Average Driller Recommended Pumping Rate



Well Pumping Rates (Yield)



municipalities (Hastings Highland, Carlow/Mayo and Bancroft) than in the southern municipalities. In Carlow/Mayo Township, there is a 50% chance that well yields will be less than 13 L/min, while in the Municipality of Stone Mills it is less than 18%. Prince Edward County also has a high percentage of low producing wells (42%), which is attributed to the difficulty in intercepting water bearing fractures in the aquifer.

Specific Capacity

Another measure of a well's productiveness is specific capacity. This term refers to the volume of water that is pumped to lower the water level in the well by 1 m. A well with a higher specific capacity for a given pumping rate will be a better producer than one with a lower specific capacity. Other regional groundwater studies conducted in similar terrain (Renfrew-Rideau-Mississippi Valley Regional Groundwater Study) indicate that specific capacity varies with aquifer type. Overburden aquifers usually have the highest specific capacity, while Precambrian rock the lowest. Limestone aquifers have a specific capacity that is between these two.

Specific capacity is shown on **Map 4.7**. No apparent trends are observed as both low and high specific capacity wells occur near each other. The lack of any regional trend suggests that well productivity is difficult to predict in the Study Area. This difficulty is likely caused by the irregularity in fracture width and density in the rock.

4.4.6 Aquifer Vulnerability

A map of aquifer vulnerability was developed following methodologies outlined in the MOE Terms of Reference. The MOE approach is based on calculating an Intrinsic Susceptibility Index. The value of this index, which is calculated for each well, is a reflection of the susceptibility of the shallow-most aquifer to surface contamination.

The results of this assessment are presented on **Map 4.8**. The map shows that the majority of wells in the Study Area are classified as highly vulnerable. This result is expected, considering the shallow nature of the fractured bedrock aquifer and the lack of significant deposits of clays or silts that would protect the aquifer from surface contamination. A few wells (marked in green) are drilled in areas of moderate vulnerability. Most of these wells are located in the municipalities of Tweed, Madoc, Hastings Highlands and Carlow Mayo,

and intercepted clay, silt or till layers that were of sufficient thickness to be deemed as providing some aquifer protection. Overall, the sporadic occurrence of these lower vulnerability areas is deemed regionally insignificant and the entire Study Area should be considered highly vulnerable. More detailed, site specific assessments may find these wells are a good starting point to identify local-scale areas of lower vulnerability.

4.4.7 Provincial Groundwater Monitoring Network Observations

A review of water level data was conducted for three monitoring wells that are part of the Quinte Conservation Provincial Groundwater Monitoring Network. The data was reviewed to assess seasonal trends in the water table elevations at select locations in the Precambrian rock, limestone and overburden aquifers. The time period of the data is short (7 to 24 months); however, general trends can be observed. Graphs of the water level data, relative to precipitation, snow cover and maximum daily temperature, as recorded at the Belleville Ontario Environment Canada climate station are presented in **Schedule B.3 in Appendix B.**

Data was reviewed for the following wells:

Well Id	Location	Aquifer	Depth	Data Period
GA131	Flinton	Precambrian	unknown	05/02 to 04/04
GA129	Plainfield	Verulam Formation (Limestone)	16.7 metres	12/02 to 04/04
GA374	Picton	Sand & Gravel esker	20.4 metres	09/03 to 04/04

Seasonal Trends

The data shows that the water level elevations vary seasonal throughout the year. In general, water level elevations are highest in the spring and fall, when precipitation is greatest and water demand by plants is low. Conversely, water level elevations are lowest in the winter when frozen ground conditions prevail and in summer when precipitation is low, and water demand by plants is highest.

During the winter months (January, February, early March) when the ground is frozen and no aquifer recharge is occurring, the water level elevations in all wells are low, and do not fluctuate greatly. During the time period analyzed, a sudden increase in water levels occurs over a 1 to 2 week period in March during the spring melt when maximum day temperatures reach above freezing and snow pack is decreasing. During this time, the water levels in the wells reach their highest elevation for the year.

Towards the end of June, as precipitation is reduced, and plant growth and warmer temperature increases, the water level elevations in the aquifer begin to fall. Water levels continue to fall over the summer and reach their yearly low in September and October. During the late fall (late October, November and early December) water level elevations again begin to increase as a result of fall rains and lower plant transpiration rates. The gradual increase stops in late December once the ground is frozen and water is no longer able to infiltrate into the aquifer.

The average difference in the yearly high and low water level elevations in well GA 131 (pumps from the Precambrian rock aquifer) is approximately 1.6 m. Well GA 139, completed in the limestone aquifer, and well GA 374, completed in the sand and gravel aquifer, have average water level elevation differences of approximately 0.7 m. The reason for the difference in ranges between these stations is not known. It is anticipated that the cause could be the proximity of each well to recharge zones and the amount of precipitation by each well. Wells that are closer to recharge zones may have a greater yearly fluctuation in water levels than those located in discharge zones. Wells that are in areas of greater seasonal fluctuations in precipitation will also experience greater variability in water levels.

Effects of Spring Thaw

As discussed in the section above, water levels in all wells increased the most during the spring thaw period. The spring thaw period is deemed to be the most significant period of aquifer recharge during the year.

The effects of the spring thaw were observed at each of the three wells. In general, the response to spring thaw for the Precambrian aquifer and limestone aquifer wells were similar, with a rapid increase in water levels within the wells occurring over a 1 to 2 week period.

The increase corresponded with a maximum daily temperature significantly above freezing, and a decrease in depth of the snow pack. In comparison, the sand and gravel aquifer behaved slightly different to the spring thaw event in 2003, with the relative increase in water levels being lower than those observed in the fractured rock wells.

Effects of Rainfall

For the two wells that are completed in fractured rock aquifers, rainfall events cause a sudden and rapid increase in well water levels. The water levels in the fractured rock aquifers often increase the same day as the rainfall event. In comparison, the response of rainfall events on the well completed in the sand and gravel aquifer is more muted and gradual.

Discussion

The analysis of the water levels in the aquifer, albeit over a limited time period (7 to 24 months) shows several key features:

Firstly, spring thaw provides a significant proportion of recharge water to the aquifer. This observation suggests that the volume of water available to be pumped from an aquifer during the remainder of the year is related to the amount of precipitation received during the winter and the severity of the spring freshet. Some winters have deep snow accumulation over very little frozen earth, combined with a gentle spring melt leads to great recharge. On the contrary, deeper frost and rapid melt leads to great surface runoff and lesser recharge.

Secondly, water levels will change suddenly and dramatically in response to rainfall events. This phenomenon is a further illustration of how fractures within bedrock aquifers extend to surface and can intercept infiltrating precipitation over a short period of time. This observation is significant, as it provides further evidence that the shallow bedrock aquifers are very susceptible to surface water run-off, and are therefore highly vulnerable to contamination.

Thirdly, while based on only 7 months of data, the sand and gravel aquifer appears to have lower fluctuations of water levels, and appears to be less prone to dramatic water level changes during changes in precipitation. This observation is expected considering that the

sand and gravel aquifers have a higher groundwater storage capacity. As a result, more recharging water is required to increase water levels within overburden wells. The higher storage capacity of overburden aquifers also results in a higher volume of water being available to be pumped when compared with most fractured rock aquifers.

4.5 Study Municipalities

This section provides a summary of the hydrogeological assessment results for each of the nine study partner municipalities.

Table 4.3: Summary of Hydrogeological Assessment: Township of Hastings Highlands

<p>Aquifer Location (Refer to Map 3.1, 3.3)</p>	<p>Bedrock is the main aquifer from which 89% of the 1,090 registered wells are pumped. The main type of bedrock aquifer is fractured Precambrian rock.</p> <p>Overburden aquifers provide water to 11% of the wells. Aquifers include glacial outwash sand and gravel that has filled in bedrock valley's eskers, and thick sandy till. Overburden can be up to 70 m thick.</p> <p>Significant overburden aquifers are found as:</p> <ul style="list-style-type: none"> • sand and gravel deposits in bedrock valleys in York River – Birds Creek Area, Hickey Settlement and Maynooth • kame deposits northeast of Maynooth • esker and kame deposits between Lake Ste. Peter and Baptiste Lake • potential for other overburden aquifers in sand filled valley areas including the York River, Papineau Creek, and other tributaries (see Overburden Geology Map 3.3)
<p>Groundwater Flow Direction (Refer to Map 4.2; and Municipal Map 1)</p>	<p>Deep regional flow is assumed to be northeast similar to surface drainage. Shallow groundwater flow to topography-driven. Flow is directed from highland areas to lowlands such as lakes, wetlands and rivers. The irregular terrain and drainage network causes the development of numerous small-scale flow patterns that differ in direction from the regional pattern. Significant surface drainage features that shallow groundwater flows towards include Baptiste Lake, Papineau Lake, and Kamaniskeg Lake</p>
<p>Vertical Gradient (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Little data are available to predict vertical gradient patterns. In general, downward gradients occur in highland areas and upward gradients in lowlying areas. Examples include:</p> <p>Vertical downward gradients (potential groundwater recharge) at:</p> <ul style="list-style-type: none"> • highland areas in former McClure township • Scott Settlement, McAlpine Corners, Bell Rapids • North and east of Birds Creek <p>Vertical upward gradients (potential groundwater discharge) are present at:</p> <ul style="list-style-type: none"> • Baptiste Lake, Papineau Lake, Big Mink Lake, Kamaniskeg Lake and York River valley and tributaries.
<p>Groundwater/Surface Water Interaction (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Most surface water features are in either a groundwater discharge or transitional environment. Where vertical upward gradients exist, surface water features may be fed in part by groundwater. Most creeks, wetlands and lakes are in a groundwater discharge environment. Examples include: Baptiste Lake, Papineau Lake, Kamaniskeg Lake and Big Mink Lake and adjoining tributaries.</p>

Well Depth <i>(Refer to Map 4.1)</i>	80% of wells are <75 m deep with average depth being 55 m. Shallowest wells are overburden wells located in sand filled bedrock valleys.
Well Yields <i>(Refer to Municipal Map 3)</i>	Average yield is 17 L/min (3.8 igpm), with 32% of wells producing <13 L/min (3 igpm). 11% of wells reported as being < 5 L/min (1 igpm) or dry. No apparent broad trends of high or low yielding well areas were observed. Yield will depend greatly upon local conditions, namely local density of rock fractures. Overburden wells generally have a higher yield than bedrock wells.
Water Quality <i>(Refer to Map 4.6)</i>	Almost all (97%) wells reported to have good water quality, with the remaining 3% being reported as mainly mineral.
Aquifer Vulnerability <i>(Refer to Map 4.8)</i>	All of Hastings Highlands is classified as being highly vulnerable because of predominance of shallow fractured rock aquifer with little protective cover. In areas where clay occurs over bedrock, the bedrock aquifer may be less vulnerable; however, the surficial sand aquifer is not protected. Wells where clay was intercepted and aquifer vulnerability is low to medium are shown on Map 4.8.

Table 4.4: Summary of Hydrogeological Assessment: Township of Carlow/Mayo

<p>Aquifer Location (Refer to Map 3.1, 3.3)</p>	<p>Bedrock is the main aquifer from which 90% of the 297 registered wells are pumped. The main type of bedrock aquifer is Precambrian rock, consisting of fractured igneous and metamorphic rock.</p> <p>Overburden aquifers provide water to 10% of the wells. They occur as glacial outwash sands and gravels that have filled in bedrock valleys but can also be thick sandy till. Overburden can be up to 70 m thick in the region. Significant overburden aquifer areas include:</p> <ul style="list-style-type: none"> • till deposits south of Boulter • sand and gravel deposits between New Herman and MacArthur • sand deposits (kame) north of Rowland and Boulter • potential for other overburden aquifers in sand filled valley areas including the York River and Little Mississippi River and other sand filled valleys (see Overburden Geology Map 3.3)
<p>Groundwater Flow Direction (Refer to Map 4.2; and Municipal Map 1)</p>	<p>Deep regional flow is assumed to be northeast in the direction of surface drainage. Shallow groundwater flow is topography driven with flow generally from highland areas directed to lowlands such as the tributaries of Little Mississippi River, York River and Papineau Creek. The irregular terrain and drainage network cause the development of numerous small-scale flow patterns that differ from regional patterns.</p>
<p>Vertical Gradient (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Little data are available to predict vertical gradient patterns. In general, downward gradients occur in highland areas and upward gradients in lowlying areas. Examples include:</p> <p>Vertical downward gradients at:</p> <ul style="list-style-type: none"> • highland areas in the southern part of former Mayo Township • Burgess Mine, south of McArthur Mills • south of Mayo Lake, Gin Lake and Gin Creek • west of Mallard Lake <p>Vertical upward gradients (potential groundwater discharge) are present at:</p> <ul style="list-style-type: none"> • Boulter Road from New Carlow to Boulter to McArthur Mills • Highway 28 , County Road 517, Fort Steward to Boulter.
<p>Groundwater/Surface Water Interaction (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Most surface water features are in either a groundwater discharge or transitional environment. Where vertical upward gradients exist, surface water features may be fed in part by groundwater. Possible surface water features with a strong groundwater discharge component are Little Mississippi River, York River, and lakes south of Childs Mine.</p>

Well Depth <i>(Refer to Map 4.1)</i>	80% of wells are <70 m deep with average depth being 50 m. Shallowest wells are overburden wells located in sand filled bedrock valleys.
Well Yields <i>(Refer to Municipal Map 3)</i>	Average yield is 12 L/min (2.7 igpm), with 50% of wells producing <13 L/min (3 igpm). 19% of wells reported as being < 5 L/min (1 igpm) or dry. No apparent broad trends of high or low yielding well areas were observed. Yield will depend greatly upon local conditions, namely local density of rock fractures. Overburden wells generally have a higher yield than bedrock wells.
Water Quality <i>(Refer to Map 4.6)</i>	Almost all (97%) wells reported to have good water quality, with the remaining 3% being reported as mainly mineral with some salt.
Aquifer Vulnerability <i>(Refer to Map 4.8)</i>	All of Carlow/Mayo is classified as being highly vulnerable because of predominance of shallow fractured rock aquifer with little protective cover. In areas where clay occurs over bedrock, the bedrock aquifer may be less vulnerable; however, the surficial sand aquifer is not protected. Wells where clay was intercepted and aquifer vulnerability is low to medium are shown on Map 4.8.

Table 4.5: Summary of Hydrogeological Assessment: Town of Bancroft

<p>Aquifer Location (Refer to Map 3.1, 3.3)</p>	<p>Bedrock is the main aquifer from which 91% of the 580 registered wells are pumped. The main type of bedrock aquifer is fractured Precambrian rock.</p> <p>Overburden aquifers provide water to 9% of the wells. Aquifers are glacial outwash sands and gravels that have filled bedrock valleys. Overburden can be up to 70 m thick. Significant overburden aquifer areas include:</p> <ul style="list-style-type: none"> • outwash sand and gravel deposits along Highway 62 between L'Amable and York River • potential for other overburden aquifers in sand filled valley areas including the York River, L'Amable Creek and Egan Creek valleys and other sand filled areas (see Overburden Geology Map 3.3).
<p>Groundwater Flow Direction (Refer to Map 4.2; and Municipal Map 1)</p>	<p>Deep regional flow is generally northeast. Shallower flow is topography driven with flow directed from highland areas to lowlands such as the tributaries of L'Amable Creek, Egan Creek, and York River. The irregular terrain and drainage network cause the development of numerous small-scale flow patterns that vary considerably in direction across the Study Area.</p>
<p>Vertical Gradient (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Vertical downward gradients (potential groundwater recharge) are present at:</p> <ul style="list-style-type: none"> • highland areas between Bancroft and Maxwell • isolated elevated areas near Bowen Corner, L'Amable. <p>Vertical upward gradients (potential groundwater discharge) are present along most river valleys. Examples include:</p> <ul style="list-style-type: none"> • east of Bronson Station to northeast corner of Bancroft • Bronson • SE corner of municipality? (Insufficient data to confirm).
<p>Groundwater/Surface Water Interaction (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Most surface water features are in either a groundwater discharge or transitional environment. Where vertical upward gradients exist, surface water features will be fed in part by groundwater. Possible areas of strong groundwater discharge conditions include York River, Egan Creek, and L'Amable Creek. Net recharge conditions may exist at Clark Lake, Holland Lake and Jamieson Lake.</p>

Well Depth <i>(Refer to Map 4.1)</i>	80% of wells are <70 m deep with average depth being 48 m. Shallowest wells completed in overburden aquifers in sand and gravel filled bedrock valleys.
Well Yields <i>(Refer to Municipal Map 3)</i>	Average yield is 15 L/min (3.5 igpm), with 42 % of wells producing <13 L/min (3 igpm). 19% of wells have been reported as being < 5 L/min (1 igpm) or dry. No apparent broad trends of areas of high or low yielding wells were observed. Yield will depend greatly upon local conditions, namely local density of rock fractures. Overburden wells generally have a higher yield than bedrock wells.
Water Quality <i>(Refer to Map 4.6)</i>	Almost all (98%) wells reported to have good water quality, with the remaining 2% being reported as mineral.
Aquifer Vulnerability <i>(Refer to Map 4.8)</i>	All of the Town of Bancroft is classified as being highly vulnerable because of predominance of shallow fractured rock aquifer with little protective cover. In areas where clay occurs over bedrock, the bedrock aquifer may be less vulnerable; however, the surficial sand aquifer is not protected. Wells where clay was intercepted and aquifer vulnerability is low to medium are shown on Map 4.8.

Table 4.6: Summary of Hydrogeological Assessment: Township of Madoc

<p>Aquifer Location (Refer to Map 3.1, 3.3)</p>	<p>Fractured bedrock is the main aquifer from which 99% of the 895 registered wells are pumped. The main type of bedrock aquifer is Precambrian rock; however, some Shadow Lake Formation sandstones and Gull River Formation limestones exist in isolated areas (e.g., southwest corner of township).</p> <p>Overburden aquifers provide water to 1% of the wells. Areas where locally significant overburden aquifers are present include:</p> <ul style="list-style-type: none"> • eskers running north-south from Cooper – Queensborough and south near Hunt Club Road • Sand and gravel glaciofluvial deposit west of Keller Bridge
<p>Groundwater Flow Direction (Refer to Map 4.2; and Municipal Map 1)</p>	<p>Deep regional flow is generally north to south towards Lake Ontario. Shallow flow is topography driven with flow directed away from highlands to lowlands such as the tributaries of Moira River and Black River, and Moira Lake to the south. The irregular terrain and drainage network cause the development of numerous small-scale flow patterns that vary considerably with depth and horizontal position.</p>
<p>Vertical Gradient (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Vertical downward gradients (potential groundwater recharge) are present in highland areas such as:</p> <ul style="list-style-type: none"> • east of Malone to Hazard Corners to SE corner of township • along Bannockburn Road <p>Vertical upward gradients (potential groundwater discharge) are present along most river valleys. Examples include:</p> <ul style="list-style-type: none"> • Barry Road between Cooper and Queensborough • County Road #11, east of Fox Corners • O’Hara Settlement/Johnston Road area • Highway #7 east of Madoc Village
<p>Groundwater/Surface Water Interaction (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Most of surface water features are in either a groundwater discharge or transitional environment. Where vertical upward gradients exist, surface water features will be fed in part by groundwater. Mapping suggests a possible strong groundwater discharge interaction with Black River and Moira River tributaries, and Jarvis Lake. Net recharge conditions may exist at Eldorado Lake, lake north of Hazzards Corners, and surface water features east and west of Bannockburn. Cool/cold water tributaries mapped north of Madoc.</p>

Well Depth <i>(Refer to Map 4.1)</i>	80% of wells are <45 m deep with an average depth being 30 m. Depth of wells is quite variable across the township and does not follow any particular pattern.
Well Yields <i>(Refer to Municipal Map 3)</i>	Average yield is 27 L/min (5 igpm), with 20% of wells producing <13 L/min (3 igpm). 7% of wells have been reported as being < 5 L/min (1 igpm) or dry. No apparent broad trends of areas of high or low yielding wells were observed. Yield will depend greatly on local conditions such as the density of rock fractures intercepted in the well.
Water Quality <i>(Refer to Map 4.6)</i>	Almost all (>99%) wells reported to have good water quality.
Aquifer Vulnerability <i>(Refer to Map 4.8)</i>	All of Madoc is classified as being highly vulnerable because of predominance of shallow fractured rock aquifer with little protective clay or silt cover.

Table 4.7: Summary of Hydrogeological Assessment: Municipality of Tweed

<p>Aquifer Location <i>(Refer to Map 3.1, 3.3)</i></p>	<p>Bedrock is the main aquifer from which 95% of the 1,755 registered wells are pumped. The type of bedrock aquifer varies with location. Limestone of the Gull River Formation predominates south of Tweed and along the western municipal boundary. Precambrian shield igneous and metamorphic rock is the aquifer present elsewhere.</p> <p>Overburden aquifers provide water to 5% of the wells. These wells are completed in either marginal till or esker deposits where sufficient saturated thickness is present. Areas where significant overburden aquifers are present include:</p> <ul style="list-style-type: none"> • eskers south of Tweed in Moira River valley, especially near Sugar Is. • esker between Lime Lake and Marlbank • eskers and gravel deposits near Actinolite and Highway #7
<p>Groundwater Flow Direction <i>(Refer to Map 4.2; and Municipal Map 1)</i></p>	<p>Deep regional flow is generally north to south towards Lake Ontario. Shallow flow is topography driven. Flow is away from highlands to lowlands such as the Moira River/Stoco Lake valley and associated tributaries. The irregular terrain and drainage network cause the development of numerous small-scale flow patterns that vary considerably with depth and horizontal position.</p>
<p>Vertical Gradient <i>(Refer to Map 4.4; and Municipal Map 2)</i></p>	<p>Vertical downward gradients (potential groundwater recharge) are present in highland areas such as:</p> <ul style="list-style-type: none"> • between river valleys and tributaries south, north and west of Tweed • along Precambrian/Paleozoic bedrock fringe • north of Actinolite to Queensborough • insufficient data to comment on Grimsthorpe and Elzevir geographic townships, but regional recharge areas expected in upland areas such as Mount Moriah and east of Black River <p>Vertical upward gradients (potential groundwater discharge) are present along most river valleys. Examples include::</p> <ul style="list-style-type: none"> • strong upward gradient along Moira River valley, Parks Creek and Otter Creek tributaries, valleys along Paleozoic fringe. • Lingham Lake? (Insufficient data to confirm)
<p>Groundwater/Surface Water Interaction <i>(Refer to Map 4.4; and Municipal Map 2)</i></p>	<p>Most surface water features are in either a groundwater discharge or transitional environment. Where vertical upward gradients exist, surface water features will be fed in part by groundwater (e.g., Stoco Fen). Possible strong groundwater discharge interaction with Moira River and Parks Creek tributary south of Stoco, Goose Creek, Clare River and east of Otter Creek tributaries. Groundwater springs have been reported in Thomasburg. Cold/cool water tributaries mapped north and east of Tweed Village.</p>

Well Depth <i>(Refer to Map 4.1)</i>	80% of wells are <40 m deep with average depth being 28 m. Shallowest wells are in the lowlands around Stoco Lake and the Moira River valley, and near Lime Lake.
Well Yields <i>(Refer to Municipal Map 3)</i>	Average yield is 23 L/min (5 igpm), with 20% of wells producing <13 L/min (3 igpm). 7% of wells have been reported as being < 5 L/min (1 igpm) or dry. No apparent trend of high or low yielding well areas was observed. Yield will depend greatly on local conditions, namely local density of rock fractures. Several high yielding wells are located near Thomasburg (>90 L/min).
Water Quality <i>(Refer to Map 4.6)</i>	98% of wells reported to have good water quality, with <1% having sulphur or salt problems at the time of drilling. Problem wells are usually associated with limestone to the south.
Aquifer Vulnerability <i>(Refer to Map 4.8)</i>	All of Tweed is classified as being highly vulnerable because of predominance of shallow fractured rock aquifer with little protective cover.

Table 4.8: Summary of Hydrogeological Assessment: City of Belleville

<p>Aquifer Location (Refer to Map 3.1, 3.3)</p>	<p>Bedrock is the main aquifer from which 90% of the 3,000 registered wells are pumped. The bedrock aquifer is primarily the limestone and shale Verulam Formation; however, deeper wells and wells in the northeast, near Roslin, and west, near Foxboro, tap into the limestone Bobcaygeon and Gull River Formations.</p> <p>Overburden aquifers provide water to 10% of the wells. These aquifers are found within the drumlins north of Foxboro as well as in eskers. Areas where significant overburden aquifers are present include:</p> <ul style="list-style-type: none"> • line along Harmony Road, Highway 37 and Thrasher Road (Till and Eskers) • Highway 62 north of Zion Road (Drumlins) • County Road #5 east of Foxboro (eskers) • esker running North of Foxboro-Zion Hill – Thomasburg (Tweed) • general drumlin area north of Moira River.
<p>Groundwater Flow Direction (Refer to Map 4.2; and Municipal Map 1)</p>	<p>Deep regional flow is generally north to south towards the Bay of Quinte and Lake Ontario. Shallow flow is generally directed from highland areas to lowlands or surface water features such as Moira River and related tributaries.</p>
<p>Vertical Gradient (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Vertical downward gradients (potential groundwater recharge) are present at:</p> <ul style="list-style-type: none"> • Roslin, drumlin areas north of Plainfield • NW Corner of Belleville (near Halloway and Madoc Junction) • between Highway 401 and Highway 37, west portion of Belleville • north and south of Plainfield • west and east side of Belleville urban area <p>Vertical upward gradients (potential groundwater discharge) are present at:</p> <ul style="list-style-type: none"> • Moira River valley, Blessington Creek • along Bay of Quinte • base of highland areas west of Phillipston and north of Moira River near Latta
<p>Groundwater/Surface Water Interaction (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Most surface water features are in either discharge or transitional environment. Moira River at Plainfield and the large swamp east of Thrasher’s Corners may be in a recharge environment. Areas where surface water features are in a strong discharge environment include Moira River in Belleville and south of Roslin. Tributaries with a strong groundwater discharge component likely feed the large swamp north of Foxboro. Possible groundwater/surface water interactions in “karstic” areas near Latta (Moira Caves).</p>

Well Depth <i>(Refer to Map 4.1)</i>	80% of wells are <20 m deep with average depth being 16 m. Deepest wells are in NW corner in drumlin area north of Foxboro.
Well Yields <i>(Refer to Municipal Map 3)</i>	Average yield is 23 L/min (5 igpm), with 30% of wells producing <13 L/min (3 igpm). Slightly over 10% of wells have been reported as being < 5 L/min (1 igpm) or dry. Areas prone to dry wells include just north of 401 in Belleville, Point Anne, east of Cannifton.
Water Quality <i>(Refer to Map 4.6)</i>	87% of wells reported to have good water quality, with 10% having sulphur problems and the remaining 3% either having salt or mineral problems. Sulphur problems are associated with shale in the Verulam limestone and shale aquifer. Sulphur problems are greatest near the Bay of Quinte (Belleville urban area, Cannifton, Corbyville, Point Anne) and decrease further north. Water in overburden in drumlins and eskers is generally of good quality.
Aquifer Vulnerability <i>(Refer to Map 4.8)</i>	All of Belleville is classified as highly vulnerable because of predominance of shallow fractured rock aquifer with little protective cover. The aquifer is considered extremely vulnerable near the Moira River near Latta where “karstic” conditions occur (Moira Caves).

Table 4.9: Summary of Hydrogeological Assessment: Township of Tyendinaga

<p>Aquifer Location (Refer to Map 3.1, 3.3)</p>	<p>Bedrock is the main aquifer from which 98% of the 1,500 registered wells are pumped. The type of bedrock aquifer varies with location. Limestone and shale of the Verulam Formation predominates in the southeast and as a 3 km wide band northwest of the Salmon River. Bobcaygeon Formation (limestone) predominates in the northwest while Gull River Formation (limestone) predominates in the northeast.</p> <p>Overburden aquifers provide water to only 2% of the wells. These wells are completed in either marginal till or esker deposits where sufficient saturated thickness is present. Areas where significant overburden aquifers are present include:</p> <ul style="list-style-type: none"> • esker running from south of Halston to Lime Lake • contact zone between clay and bedrock (shallow wells)
<p>Groundwater Flow Direction (Refer to Map 4.2; and Municipal Map 1)</p>	<p>Deep regional flow is generally north to south towards the Bay of Quinte and Lake Ontario. Shallow flow is away from highlands, and directed to lowlands or surface water features such as Salmon River, Parks Creek, and Moira River.</p>
<p>Vertical Gradient (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Vertical downward gradients (potential groundwater recharge) are present at:</p> <ul style="list-style-type: none"> • Roslin • Halston to Myrehall area • area parallel and south of Parks Creek through Read • area parallel and north of Salmon River (Melrose to Ebenezer) • area parallel and south of Salmon River <p>Vertical upward gradients (potential groundwater discharge) are present at:</p> <ul style="list-style-type: none"> • Moira River valley, Salmon River valley, and Parks Creek valley • Blessington Creek valley • Deseronto.
<p>Groundwater/Surface Water Interaction (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Most surface water features are in either in a discharge or transitional environment. Weak recharge environments may exist at Parks Creek just east of Halston, Blessington Creek by Tyendinaga/Belleville boundary, Mud Lake and Fisher Creek. Areas where surface water features are possibly in a strong discharge environment include Moira River, Salmon River east of Lonsdale Station, and Parks Creek/wetland area south of Naphan. Possible groundwater/surface water interaction in “karstic” area south of Parks Creek.</p>

Well Depth <i>(Refer to Map 4.1)</i>	80% of wells are <30 m deep with average depth being 24 m. Shallowest wells are in NW corner near Roslin, Shannonville and along Bay of Quinte (Reserve).
Well Yields <i>(Refer to Municipal Map 3)</i>	Average yield is 18 L/min (4 igpm), with 30% of wells producing <13 L/min (3 igpm). 15% of wells have been reported as being < 5 L/min (1 igpm) or dry. Areas prone to dry wells include Shannonville, south of Marysville and Reserve; however, dry wells are also located sporadically elsewhere where local fractures in the bedrock are infrequent.
Water Quality <i>(Refer to Map 4.6)</i>	80% of wells reported to have good water quality, with 16% having sulphur problems and the remaining 4% either having salt or mineral problems. Sulphur problems are worse in the Verulam limestone and shale aquifer. Sulphur problems are greatest north and south of the Salmon River and improve north of line between Blessington - Read and Mud Lake
Aquifer Vulnerability <i>(Refer to Map 4.8)</i>	All of Tyendinaga is classified as highly vulnerable because of predominance of shallow fractured rock aquifer with little protective cover. The aquifer is considered extremely vulnerable near Parks Creek in the western portion of the Township where "karstic" conditions occur.

Table 4.10: Summary of Hydrogeological Assessment: Stone Mills Township

<p>Aquifer Location (Refer to Map 3.1, 3.3)</p>	<p>Fractured bedrock is the main aquifer from which 98% of the 3,163 registered wells are pumped. North of a line between Clareview and Carmanville the aquifer is Precambrian rock; south of this line the aquifer is limestone of the Gull River and Bobcaygeon Formations.</p> <p>Overburden aquifers provide water to 2% of the wells. These wells are completed in either till or esker deposits where sufficient saturated thickness is present. Areas where significant overburden aquifers are present include:</p> <ul style="list-style-type: none"> • esker between Marlbank-Erinsville-Beaver Lake and near Arden Road • esker deposits south of Tamworth • sand deposits near Newburgh and Napanee River.
<p>Groundwater Flow Direction (Refer to Map 4.2; and Municipal Map 1)</p>	<p>Deep regional flow is generally north to south towards Lake Ontario. Shallower flow is topography driven with flow being generally away from highlands and directed to lowlands such as the Napanee River, Salmon River and associated tributaries. The irregular terrain and drainage network in former Sheffield township cause the development of numerous small-scale flow patterns that vary considerably with depth and horizontal position. Regional and local flow patterns expected to be more uniform in former Camden East township.</p>
<p>Vertical Gradient (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Vertical downward gradients (potential groundwater recharge) are present in highland areas such as:</p> <ul style="list-style-type: none"> • N-S line running from Puzzle Lake through Reidville, Hinch to SW corner of township • E-W line running just along southern township boundary, and northeast of Newburgh • Clareview area. <p>Vertical upward gradients (potential groundwater discharge) are present at:</p> <ul style="list-style-type: none"> • southwest of Newburgh and between Yarker-Colebrook • Desmond-Moscow area • Croydon – Tamworth area, Balaheck area, NW of McGuire Settlement.
<p>Groundwater/Surface Water Interaction (Refer to Map 4.4; and Municipal Map 2)</p>	<p>Most of surface water features are in either a groundwater discharge or transitional environment. Strong vertical upward gradients exist near Mellon, Otter and West Fork Otter Creek, Shibagau Creek, Napanee River south of Newburgh, Salmon River and Pennells Creek. Possible downward gradient at Puzzle Lake area, Napanee River near Camden East and Yarker, and marsh area north of Lens.</p>

Well Depth <i>(Refer to Map 4.1)</i>	80% of wells are <35 m deep with average depth being 25 m. Shallowest wells are in the lowlands around Beaver Lake, Varty Lake, and in the overburden wells drilled in eskers.
Well Yields <i>(Refer to Municipal Map 3)</i>	Average yield is 23 L/min (5 igpm), with 18% of wells producing <13 L/min (3 igpm). 6% of wells have been reported as being < 5 L/min (1 igpm) or dry. In general, there is no apparent trend of high or low yielding well areas, as yield will depend greatly on local conditions, namely local density of rock fractures. However, poor yielding wells are clustered around Hinch and Roblin. Areas of good yield wells (>45 L/min or 10 igpm) include Tamworth, Erinsville, and Centreville.
Water Quality <i>(Refer to Map 4.6)</i>	95% of wells were reported to have good water quality, with 4% having sulphur and 1% having salt. Most of the water quality problems were in the Bobcaygeon Formation northeast of Newburgh.
Aquifer Vulnerability <i>(Refer to Map 4.8)</i>	All of Stone Mills is classified as being highly vulnerable because of the predominance of a shallow fractured rock aquifer with little protective cover.

Table 4.11: Summary of Hydrogeological Assessment: Prince Edward County

<p>Aquifer Location <i>(Refer to Map 3.1, 3.3)</i></p>	<p>Bedrock is the main aquifer from which 98% of the 4,350 registered wells are pumped. The bedrock aquifer is primarily the limestone and shale Verulam Formation (sole bedrock aquifer north of Mountain View Escarpment) and the limestone Lindsay Formation (intercepted south of Mountain View Escarpment); however, deeper wells also intercept the top of Verulam Formation south of Mountain View.</p> <p>Overburden aquifers provide water to 2% of the wells and are found in esker and beach deposits. Areas where significant overburden aquifers are present include:</p> <ul style="list-style-type: none"> • east of West Lake (beach and esker deposits) • south of East Lake (esker) • north shore by Bay of Quinte/Carrying Place • south of Rednersville and Fenwood Gardens (beach) • Black River (beach).
<p>Groundwater Flow Direction <i>(Refer to Map 4.2; and Municipal Map 1)</i></p>	<p>Deep regional flow is generally north to south towards Lake Ontario; shallow groundwater flow to radial from highlands and directed to the nearest shoreline or surface water features (wetland, creek etc). Refer to municipal water table map to show anticipated groundwater flow patterns (flow from red and yellow areas to blue).</p>
<p>Vertical Gradient <i>(Refer to Map 4.4; and Municipal Map 2)</i></p>	<p>Vertical downward gradients (potential groundwater recharge) are present at:</p> <ul style="list-style-type: none"> • escarpment area running from Carrying Place – Ameliasburgh – Mountain View – Demorestville – Green Point • Big Island, uplands between Albury and Rednersville, east of Fenwood Gardens • Highland area between Consecon – Huff’s Corners - Fawcettville • Highland area between Picton, Cherry Valley, Black Creek, Glenora • Rock Cross Rd to Kellars Cross Rd (North Marysburgh) • Port Milford to County Rd 24, and south of Cove Beach <p>Vertical upward gradients (potential groundwater discharge) are present at:</p> <ul style="list-style-type: none"> • Melville – Little Swamp – Big Swamp • north of Mountain View escarpment • Black Creek and East of West Lake • land areas at base of escarpments, most low lying areas near surface water.

<p>Groundwater/Surface Water Interaction <i>(Refer to Map 4.4; and Municipal Map 2)</i></p>	<p>Most surface water features are in either discharge or transitional environment. Some surface water features that may have a significant groundwater component include Sawguin Creek, Muscote Bay, Consecon Lake, Black Creek, Bloomfield Creek, Little Swamp, and Big Swamp.</p> <p>Large surface water features that maybe located in groundwater recharge environments include Roblin Lake, Fish Lake, Lake on the Mountain and associated wetlands, marsh north of Swamp College Road.</p>
<p>Well Depth <i>(Refer to Map 4.1)</i></p>	<p>65% of wells <20 m deep with average depth being 20 m. Deepest wells are along the edges of escarpments, such as by Mountain View, Rednersville Road, Glenora, and Long Reach. Shallowest wells are located along coastlines.</p>
<p>Well Yields <i>(Refer to Municipal Map 3)</i></p>	<p>Average yield is 18 L/min (4 igpm), with 43% of wells producing <13 L/min (3 igpm). Slightly over 16% of wells have been reported as being < 5 L/min (1 igpm) or dry. Areas prone to low yield wells include Consecon Lake, Muscote Bay, Burr Road, Rossmore, and the top of most escarpment areas. Higher yielding wells are located along West Lake Road and Ridge road, and are generally associated with overburden aquifers. In general, high and low yield wells can be found in proximity, with well yield controlled by the number and spacing of intercepted fractures.</p>
<p>Water Quality <i>(Refer to Map 4.6)</i></p>	<p>93% of wells reported to have good water quality, with 5% having sulphur problems and the remaining 2% either having salt or mineral problems. Sulphur problems are associated with shale in the Verulam limestone and shale aquifer. Sulphur problems are greatest north of the Mountain View escarpment where the Verulam Formation is the bedrock aquifer; however, salty water is also encountered north of Bowerman’s Corners in the lower portion of the Lindsay Formation.</p>
<p>Aquifer Vulnerability <i>(Refer to Map 4.8)</i></p>	<p>All of Prince Edward County is classified as highly vulnerable because of predominance of shallow fractured rock aquifer with little protective cover.</p>

5. WATER USE

5.1 Background

The Quinte Regional Groundwater Study has been undertaken to assess the nature, condition and use of groundwater resources within the Study Area. Groundwater is used as a potable water source to municipalities and private homes, for irrigation and livestock watering, and as a source of water for manufacturing and industry. Groundwater also has an important role in sustaining natural ecological habitats by maintaining base flow to surface water and wetlands.

This chapter presents an outline of the current and future demands on the groundwater supply, and an assessment of the capability of the aquifers in the Study Area to satisfy these demands at a regional level.

Specific objectives of this investigation include:

- Identifying the major groundwater users and the annual volumes of groundwater they consume;
- Determining whether the groundwater supply can be expected to meet future groundwater demands;
- Assessing the role that groundwater has in ecological systems; and,
- Inventorying large year-round residential, municipal and large non-residential groundwater systems that fall under O. Reg 170.

5.2 Methodology

5.2.1 Approach

Details on specific approaches used in this assessment follow.

Calculation of Existing Groundwater Demand

An evaluation of the existing groundwater demand was based on the protocols outlined in the MOE Terms of Reference. The approach taken was to inventory the water usage by the following categories:

- Category 1: Public Supply
- Category 2: Self Supply (Residential and Commercial/Industrial)
- Category 3: Self Supply Irrigation
- Category 4: Self Supply Livestock
- Category 5: Self Supply Industrial (Manufacturing)
- Category 6: Self Supply Industrial (Mining)
- Category 7: Self Supply Other.

A description of each of these categories is as follows.

Category 1: Public Supply, includes municipal potable water systems that use groundwater as the water source. Information was gleaned from MOE Water Treatment Plant records and through municipal water use surveys completed by municipal staff. In some cases the municipal data were augmented with information supplied by the MOE Permit To Take Water (PTTW) Database, information collected in MOE Groundwater Under the Direct Influence of Surface Water (GUDI) studies, and from Ontario Regulation 459 Engineering Reports.

Category 2: Self Supply, includes non-municipal potable water supply wells. This category includes privately owned communal systems as well as non-communal systems that serve <5 residents. For residential supplies, information on water use was calculated from 2001 population census data and the MOE Water Well Information System (WWIS). Commercial/Industrial usage data were supplied from the MOE PTTW database.

Category 3: Self Supply Irrigation, includes water that is primarily used by farmers for irrigation of crops or orchards. The Ministry of Natural Resources (MNR) supplied this data. Water used for golf course irrigation, as provided in the MOE PTTW database, was included in this category.

Category 4: Self Supply Livestock, includes water used for watering cattle and farm animals. The MNR supplied this data.

Category 5: Self Supply Industrial (Manufacturing), includes water used for cooling, food processing, and other manufacturing and industrial operations. The information source was the MOE PTTW database.

Category 6: Self Supply Industrial (Mining), includes water used for aggregate washing and quarry dewatering. The information source was the MOE PTTW database.

Category 7: Self Supply Other, includes miscellaneous groundwater uses not covered in the above categories, such as groundwater remediation.

Inventorizing of Regulated Water Supply Systems

An inventory of communal water supply systems that serve municipal, year round residential or large non-residential users, as defined by O.Reg 170, was performed. The sources of data were:

- Municipal Clerks Survey;
- MOE (Eastern Region) list of known and potential communal wells;
- MOE (Eastern Region) list of approved water works;
- MOE PTTW database; and,
- Health Unit information.

5.2.2 Data Sources and Limitations

The data sources that were used in this analysis, and their limitations, are discussed below.

MOE Permits To Take Water (PTTW)

Information on the types of commercial and industrial uses of the groundwater resource was assessed through the available MOE PTTW database. Under the Ontario Water Resources

Act (R.S.O. 1990), a permit is required for any water withdrawal that exceeds 50,000 L/day. The PTTW system classifies the permits as being from a groundwater source, a surface water source or an unidentified source. For the analyses conducted in this study, all permits that were active on January 13, 2003 were included in the analysis. This approach provides a “snap-shot” in time of water taking permits at the beginning of the study. It is important to note that at the time of writing of the final report (August, 2004), some of these permits are no longer in force, and others have been issued.

The limitations to this data set include:

- Permitted volumes are usually greater than the volumes actually withdrawn. Furthermore, once a permit is issued, there is no commitment on the part of the permit holder to withdraw any water. As a result, the PTTW records may overestimate the actual quantity of water that is taken.
- PTTW records do not identify smaller withdrawals of groundwater of <50,000 L/day; therefore, many commercial/industrial uses cannot be identified.
- The identification of the water source is problematic for some water usages. Water takings from ponds are classed as surface water; however, in reality a portion of the water flowing into the pond may be groundwater base flow.
- Large inaccuracies are associated with PTTW records for quarry dewatering. The reported maximum daily pumping rates usually exceed the volume of water taken. Furthermore, pumping rates vary tremendously with the season, with most pumping occurring during spring. In addition, the water source is often largely surface water from runoff or snowmelt, rather than groundwater. As a result of this limitation, groundwater usage results for each municipality are reported with and without groundwater use in quarry or mine dewatering or aggregate washing.

While data limitations exist, this method does provide an adequate means to identify the larger and more significant groundwater users in the Study Area.

2001 Census Population Data

Population statistics from the Statistics Canada 2001 Census were used to determine the number of municipal residents that may rely on groundwater as a potable water supply through the use of their own private water well. The volume of water used by private residents is based on population statistics. It was assumed that the average water use per capita is 175 L/day.

This census data set is considered high quality and accurate. Possible errors are introduced into the analysis when estimating the population of groundwater users who live in municipalities that are serviced by both municipal systems and individual wells. Errors occur when the census boundaries do not correspond to the boundary of the municipal servicing limits. This problem may result in either over or underestimation of groundwater use.

Agricultural Water Use Data

Agriculture Water Use data were supplied by the MNR. Rob de Loe Consulting Services, on behalf of the MNR, generated the data. The data contain agricultural livestock watering and irrigation information, by watershed, derived from analysis of the 1996 Agricultural Census data.

The main limitation of this data set is that the data were collected at the Ontario Consolidated Census Subdivision (CCS) level and interpreted through the application of agricultural water use coefficients. Because of census confidentiality reasons, the actual location of the water user (farm) is not provided, and only consolidated total water use data are available at the broader CCS level.

Limitations to Aquifer Capability Analysis

Estimation of the capability of an aquifer to meet the demands of groundwater uses is based on comparing estimated groundwater recharge with groundwater pumping at a regional scale. It is important to note that the method provides only regional indications of water use, and cannot be used to estimate potential groundwater interference problems at specific locations. The method has several limitations, including:

- it does not take into account groundwater that is returned to the aquifer through discharge after it has been used (e.g., septic systems). This limitation will result in an overestimation of the net groundwater demand on the system;
- it does not take into account the ability of the aquifer (permeability and aquifer storage) to provide water to a well; and,
- it does not take into account well depth. Changes in infiltration will affect shallow wells more than deeper wells.

While these concerns are noted, it is realized that a more accurate assessment of the effects of aquifer recharge and pumping would require a numerical groundwater flow model and more detailed water use data. Nevertheless, the approach used here to assess aquifer capability is considered valid to identify broad areas where demand may exceed supply.

Limitations to Communal Well Inventory

The inventory of communal well systems is not exhaustive as data sources that list properties that may be candidates for these designations are few. The largest omissions will likely be for systems that pump less than 50,000 L/day, but serve more than five residences, as they will not necessarily have a PTTW.

5.3 Regional Summary

This section presents a summary of the total water use for the Study Area. Results specific to each of the study municipalities are outlined in **Section 5.4**.

5.3.1 Total Water Usage

The estimated groundwater usage for each category is shown in **Table 5.1** and presented graphically in **Figure 5.1**. Overall, the estimated groundwater use (excluding quarry/mine dewatering and aggregate washing) is approximately 5,400,000 m³/year. The largest groundwater use, by quantity, is for potable water supply from individual private wells (54%

Table 5.1: Summary of Average Annual Groundwater Usage by Municipality

Municipality	Public Supply m ³ /a	Self Supply, Domestic (Residential) m ³ /a	Self Supply, Domestic (Commercial / Institutional) m ³ /a	Self Supply, Irrigation m ³ /a	Self Supply, Livestock m ³ /a	Self Supply, Industrial (manufacturing) m ³ /a	Self Supply, Industrial (mining) m ³ /a	Self Supply, Other m ³ /a	TOTAL VOLUME (excluding mining) m ³ /a
Prince Edward County	8,030	954,931	265,168	979,190	313,319	0	16,111,555	0	2,520,638
City of Belleville	0	379,162	0	1,630	67,942	0	6,280,305	188,028	636,762
Stone Mills	0	468,651	0	0	133,194	0	0	0	601,845
Tyendinaga	0	240,745	0	0	74,958	0	0	0	315,703
Tweed	282,875	262,654	0	11,649	77,511	0	0	0	634,689
Madoc	0	130,561	0	0	49,289	75,281	0	0	255,131
Bancroft	0	98,559	0	0	1,972	0	0	0	100,531
Hastings Highlands	0	254,989	0	7,227	4,110	0	0	0	266,326
Carlow/Mayo	0	53,208	0	0	3,094	0	0	0	56,302
Not including dewatering or aggregate washing									
Total Study Area	290,905	2,843,460	265,168	999,696	725,389	75,281	not included	188,028	5,387,927
Use by %	5%	53%	5%	19%	13%	1%	not included	3%	

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Note: an unknown but large percentage of water used for quarry dewatering is expected to have a surface water source

of total). The second largest user by volume is for irrigation (19%) followed by livestock watering (13%). All other uses (public water supply, commercial/industrial and manufacturing) each comprise less than 10% of the total water use.

In addition to the water use amounts listed above, approximately 22,400,000 m³/year has been permitted for quarry/mine dewatering or aggregate washing; however, considering the inaccuracies associated with estimating actual groundwater use for these categories from the permits, these figures are listed separately from the other water use estimates.

The municipality with the largest groundwater usage is Prince Edward County (2,500,000 m³/year). The relatively high amount of groundwater usage is a result of the large percentage of the population that receives their potable water from individual private water wells.

5.3.2 Potable Water Usage

Most of the municipalities in the Study Area rely heavily on groundwater to meet their potable water needs, whether through individual private wells or municipal well field systems. A summary of the estimated water usage for all the study municipalities is presented in **Table 5.2** and **Figure 5.2**.

Table 5.2 shows that 46% of the population (46,100 people) in the Study Area relies on groundwater, of which the majority (45% of total population) rely on private wells to supply their potable drinking water needs. Groundwater users, by percentage of total population, are:

Stone Mills (100%)	Carlow/Mayo (100%)
Tyendinaga (100%)	Prince Edward County (59%)
Tweed (100%)	Town of Bancroft (38%)
Madoc (100%)	Belleville (13%)
Hastings Highlands (100%)	

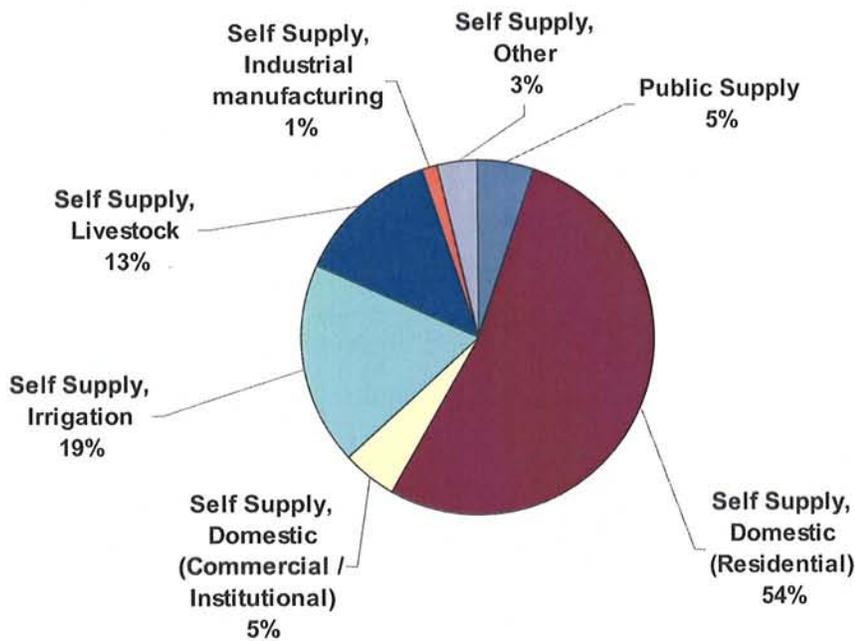
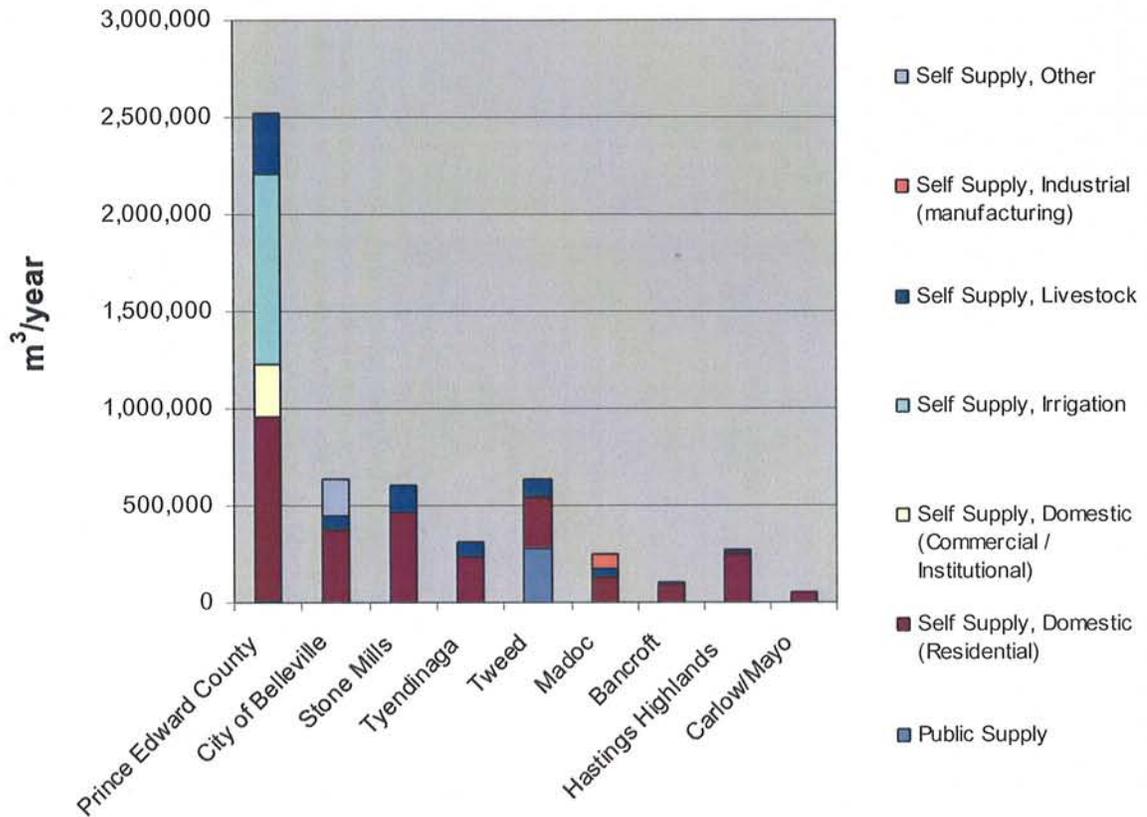
Potable groundwater use is expected to increase during the summer months, especially in the northern municipalities of Hastings Highlands, Carlow/Mayo, Bancroft, Madoc and Tweed

Table 5.2: Summary of Potable Water Source By Municipality

Municipality	Total Population	Population on Municipal Groundwater Wells		Population on Surface Water	Population on Private Wells		% Population supplied by Groundwater	
		Groundwater Wells	Surface Water		Private Wells	Municipal wells	Total	Private Wells
Prince Edward County	24901	50	9,901	14,950	60.2%	60.0%	0.2%	
City of Belleville	45986	0	40,050	5,936	12.9%	12.9%	0.0%	
Stone Mills	7337	0	0	7,337	100.0%	100.0%	0.0%	
Tyendinaga	3769	0	0	3,769	100.0%	100.0%	0.0%	
Tweed	5612	1,500	0	4,112	100.0%	73.3%	26.7%	
Madoc	2044	0	0	2,044	100.0%	100.0%	0.0%	
Bancroft	4089	0	2,546	1,543	37.7%	37.7%	0.0%	
Hastings Highlands	3992	0	0	3,992	100.0%	100.0%	0.0%	
Carlow/Mayo	833	0	0	833	100.0%	100.0%	0.0%	
Total Study Area	98563	1550	52497	44516	47%	45%	2%	
Use by %		2%	53%	45%				

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GROUNDWATER USAGE



GROUNDWATER USAGE IN STUDY AREA

QUINTE REGIONAL GROUNDWATER STUDY

FIGURE 5.1

as a result of the increase in temporary cottage residents and tourists. In addition, an undefined proportion of water use will be from surface water sources (lakes). While the water may not be used for drinking, it does have non-potable usages such as irrigation and washing

5.3.3 Large Permitted Water Takings

An inventory of large permitted groundwater takings (greater than 50,000 L/day) within the Quinte watershed or in study partner municipalities is presented on **Map 5.1**. A summary of the PTTW associated with these takings is presented as **Schedule C.1** in **Appendix C**. Only permits that were active as of January 13, 2004 are shown.

5.3.4 Ecological Use

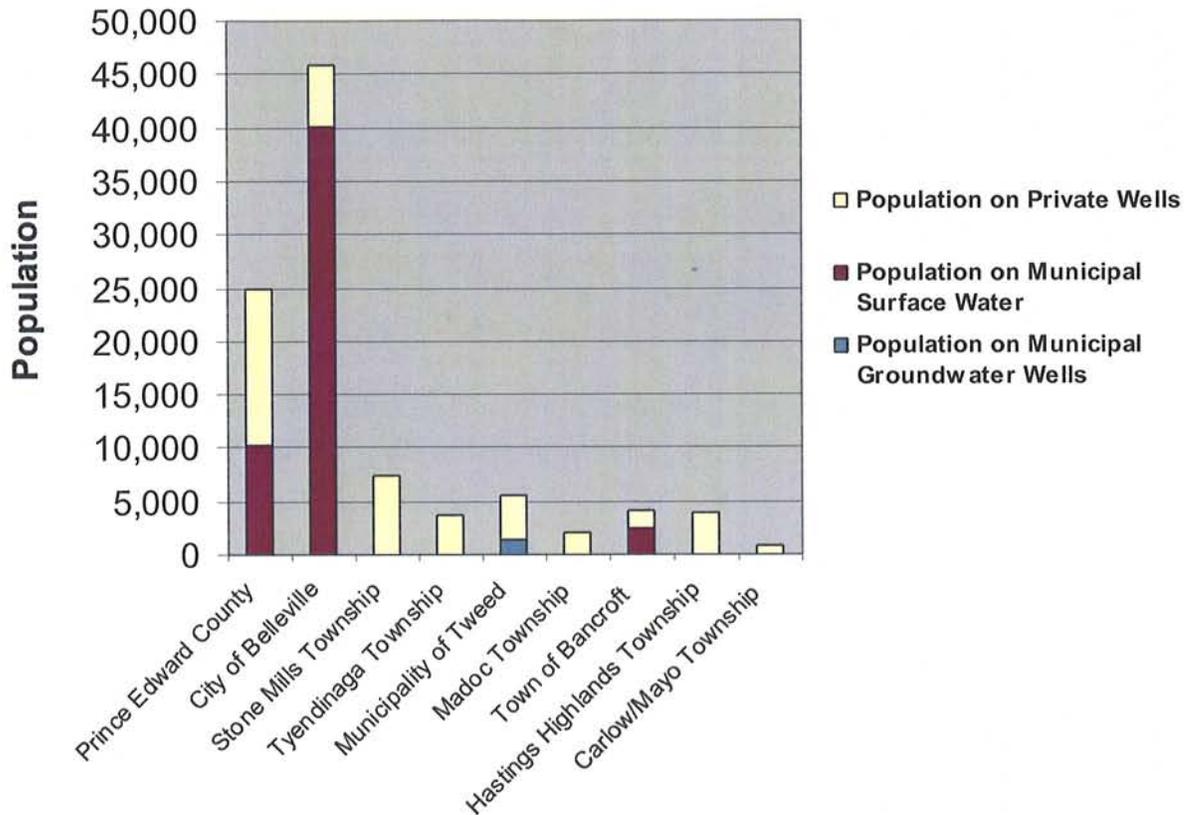
Groundwater has a very important role in the environment, whether it is supplying cool water to fish habitats, maintaining water levels in a wetland or providing needed baseflow to streams during times of drought. Streams, lakes and wetlands that have been identified as having a potential significant baseflow component are discussed by municipality in **Tables 4.3** through **4.11** in **Section 4** of this report.

In stream environments, baseflow provides cooler uniform temperatures for fish spawning areas and maintains required water levels, especially during the summer and winter months when precipitation is reduced. Baseflow also provides a source of clean water to streams that may be polluted by surface runoff from land activities such as field drainage, or from sewage treatment plant discharges.

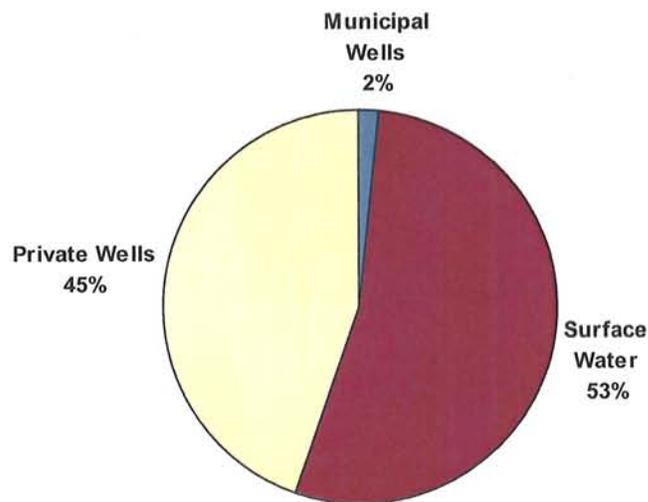
Groundwater flow also helps maintain high water tables in wetland environments. Many of the fauna, flora and inhabitants of the wetland require high water tables. Wetlands are often found in groundwater discharge environments but can also appear in groundwater recharge areas.

Groundwater flow is also important to the growth of specific vegetation types (e.g., forest cover) by keeping water levels within reach of root systems.

POTABLE WATER SOURCE BY POPULATION



WATER SOURCE BREAKDOWN OVER STUDY AREA



5.3.5 Water Budget

A regional water budget was performed to determine if there is potential for regional depletion of groundwater within the Study Area aquifers from over use. The analysis involved comparing the yearly quantity of groundwater used with the total volume of precipitation that infiltrates and recharges the aquifers.

The assessment was based on a review of the groundwater inputs and output components of the hydrologic cycle as it applies to the Study Area. The hydrological cycle consists of precipitation, evaporation and transpiration that govern the flow of water within the surface and groundwater systems. The general equation describing the hydrological cycle is:

$$P = ET + R + I$$

Where;

P = Precipitation

ET = Evapotranspiration (evaporation + transpiration)

R = Runoff into watercourses

I = Infiltration to the subsurface

The combined runoff and infiltration (to groundwater) components are frequently referred to as “surplus”.

The precipitation component includes rainfall, snow, hail and sleet. Evapotranspiration includes all the processes by which water becomes atmospheric water vapour. It includes evaporation from rivers, lakes, bare soil and vegetative surfaces, and from within the leaves of plants.

Runoff is that part of the surplus water that travels over the ground surface and through channels to reach an outlet location.

Infiltration is made up of two components:

- 1) Interflow or subsurface flow: Precipitation that infiltrates the surface soil and moves laterally through the upper soil horizon towards watercourses above the main groundwater level. It is generally a lateral flow of water in a perched saturated soil layer. This flow moves downslope until it reappears at the surface as seepage or springs. Parts of the subsurface flow may enter the streams promptly, but other parts may take longer before joining the stream flow.
- 2) Deep percolation: Infiltration that recharges the groundwater and produces base flow. Base flow in watercourses represents a withdrawal from the groundwater table. Although the component entering the aquifer may change the groundwater storage, generally this change is assumed to be negligible over a year.

Groundwater infiltration was estimated by subtracting estimated regional evapotranspiration (ET) amounts from the regional annual precipitation (P). The data used were climate normals and calculated ET rates for the period between 1961 and 1990, organized by Agriculture Canada (Agriculture Canada, 1997) for Ecodistricts. The Study Area falls within 4 Ecodistricts (413, 552, 553 and 555). A summary of the climate data is in **Schedule C.6, in Appendix C**.

The average annual precipitation for the Study Area is calculated to be 926 mm. Of this amount, 561 mm is estimated to be lost through evapotranspiration, leaving 365 mm available for either runoff or infiltration. A detailed water budget analysis conducted in the Mississippi and Rideau Watersheds (Dillon, 2003) indicated that the percentage of surplus water that becomes infiltration is 69%. Considering that the terrain in the Mississippi and Rideau watersheds is similar to that of the Study Area, this value should be representative of conditions. As a result, it is estimated that of the 926 mm of average precipitation, 252 mm becomes infiltration (interflow and baseflow).

A comparison of infiltration and groundwater use can be made by estimating the percentage of water that falls within the study municipalities and the estimated infiltration. The results of the comparison are listed below. Prince Edward County has been separated from the other partner municipalities as its boundaries are congruent with the Prince Edward County watershed, which assists the comparison.

Table 5.3: Results of Water Budget

Municipality	Area Km²	Infiltration (1000 m³/year)	Groundwater Use (1000 m³/year)
Prince Edward	1,070	270,000	2,521
Other Partner Municipalities	4,230	1,066,000	2,867
TOTAL	5,300	1,336,000	5,388

Based on this comparison, the estimated volume of infiltrating groundwater greatly exceeds the estimated volume of water withdrawal by a factor of greater than 200. Considering that the groundwater use estimate is likely an overestimation, as it does not include returns to the aquifer after use, the comparison indicates that there is no reason to suspect wide-scale aquifer depletion.

While the analysis indicates that there is no evidence of regional scale groundwater depletion on an average annual basis, lowering of the water table is expected in localized areas, especially during summer and winter months. A lower water table will be most common during the months of May to September, when groundwater recharge from precipitation is lowest and evapotranspiration is highest. Water tables will also be low during January and February when precipitation does not infiltrate the ground. The problem may be further enhanced in areas where there is a seasonal population increase and, therefore, an increased seasonal demand on groundwater wells. However, no problems of this type were identified in this study. Shallow wells in highland (groundwater recharge) areas will be most susceptible to water problems during dry months, whereas, wells in discharge areas will be least vulnerable. Significant areas of potential recharge and discharge are presented in **Map 4.4**, and are discussed in **Section 4** of this report.

Future studies could be undertaken to provide a more rigorous approach for evaluating the capabilities of the aquifer, through the collection of more accurate groundwater use data, and inputting this information into numerical groundwater flow models. The model should take into account the hydraulic conductivity of the aquifer, hydraulic gradients, and the aerial distribution of the groundwater recharge and discharge areas.

5.3.6 Inventory of Communal Wells

An inventory of communal wells that were once regulated under O.Reg 459, and now fall within the regulatory domain of O.Reg 170, was performed. These wells are listed as **Schedule C.7** in **Appendix C**.

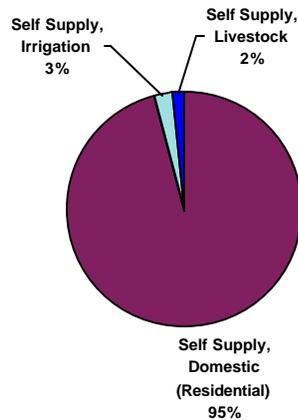
5.4 Study Municipalities

This section summarizes groundwater use in each of the study municipalities in terms of quantity and type of use. The discussion is organized based on the following seven water use categories:

- Category 1: Public Supply
- Category 2: Self Supply (Residential and Commercial/Industrial)
- Category 3: Self Supply Irrigation
- Category 4: Self Supply Livestock
- Category 5: Self Supply Industrial (Manufacturing)
- Category 6: Self Supply Industrial (Mining)
- Category 7: Self Supply Other.

5.4.1 Hastings Highlands

The total estimated quantity of water use in Hastings Highlands is 266,000 m³/year. The distribution of water use is shown on the following graphic and explained below.



Public Supply

Groundwater is not used within the public water supply system. All water is obtained from individual private sources.

Self Supply, Domestic (Residential)

The population of Hastings Highlands is approximately 4,000. Potable water is supplied mainly from individual private systems. Assuming that the majority of water comes from wells, it is estimated that the total residential water usage is 255,000 m³/year. It is expected that many of the residences, especially those that are seasonal, may use surface water as their water supply; however, the percentage of water use from this source has not been determined.

Self Supply, Commercial/Institutional

The MOE records do not indicate any large (>50,000 L/day) groundwater takings for commercial or institutional uses. Nevertheless, schools, hospitals and care facilities located in rural areas of the municipality will draw upon groundwater as a potable resource.

Self Supply, Irrigation

Groundwater used for irrigation purposes is estimated to be 7,200 m³/year, based on Census of Agriculture statistics.

Self Supply, Livestock

The volume of water used for livestock watering is estimated to be approximately 4,100 m³/year. MOE water well records indicate that < 1% of the water wells were drilled for farm use.

Self Supply, Industrial (manufacturing)

There are no records of any significant uses of groundwater for manufacturing.

Self Supply, Industrial (mining)

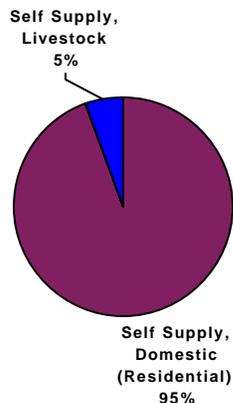
There are no records of any significant uses of groundwater for quarry or aggregate washing activities.

Self Supply, Other

There are no records of any groundwater use for other purposes, such as site remediation.

5.4.2 Carlow/Mayo Township

The total estimated quantity of water use in Carlow/Mayo is 56,000 m³/year. The distribution of water use is shown on the following graphic and explained below.



Public Supply

Groundwater is not used in the public water supply system. All water is obtained from individual private sources.

Self Supply, Domestic (Residential)

Carlow/Mayo Township's 830 residences receive their potable water from individual private systems. The total estimated groundwater use is 53,200 m³/year. It is expected that many of the residences, especially those that are seasonal, may use surface water as their water supply; however, the percentage of water use from this source has not been determined. The water use is expected to increase in the summer months as a result of seasonal water use.

Self Supply, Commercial/Institutional

The MOE records do not indicate any large (>50,000 L/day) groundwater takings for commercial or institutional uses. Nevertheless, schools, hospitals and care facilities located in rural areas of the municipality will draw upon groundwater as a potable resource.

Self Supply, Irrigation

Census of Agriculture data indicated that very little groundwater is used for irrigation purposes.

Self Supply, Livestock

The volume of water used for livestock watering is estimated to be approximately 3,100 m³/year. MOE water well records indicate that 1% of the water wells were drilled for farm use.

Self Supply, Industrial (manufacturing)

There are no records of any significant uses of groundwater for manufacturing.

Self Supply, Industrial (mining)

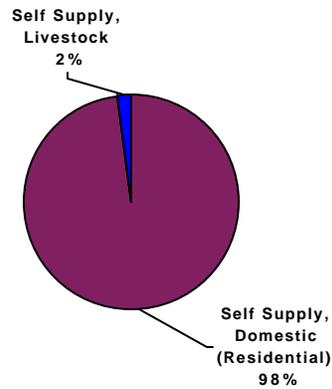
There are no records of any significant uses of groundwater for quarry or aggregate washing activities.

Self Supply, Other

There are no records of any groundwater use for other purposes, such as site remediation.

5.4.3 Bancroft

The Town of Bancroft uses approximately 100,000 m³/year of groundwater in the following distribution.



Public Supply

Groundwater is not used as a source of public water supply in Bancroft. Clarke Lake is the source of potable water to 1,500 of Bancroft's 4,000 inhabitants.

Self Supply, Domestic (Residential)

Bancroft has an estimated rural population of approximately 2,500 residents who rely on private water wells to supply their potable water needs. The total estimated volume of groundwater used for potable water consumption is 99,000 m³/year. It is expected that an undetermined amount of these residents will use lake water rather than well water. Water use is also expected to be greater in summer months, with an increase in seasonal residents and tourists.

Self Supply, Commercial/Institutional

The MOE records do not indicate any large (greater than 50,000 L/day) groundwater takings for commercial or institutional uses. Nevertheless, schools, hospitals and care facilities located in rural areas of the municipality will draw upon groundwater as a potable resource.

Self Supply, Irrigation

The MOE classification of Self Supply Irrigation includes water used for both agricultural irrigation as well as commercial irrigation (e.g., golf courses). Agricultural water use data did not identify any significant volumes of water being used for irrigation. A review of MOE records did not reveal any other large-scale water takers (greater than 50,000 L/day).

Self Supply, Livestock

The volume of water used for livestock watering is estimated to be approximately 2,000 m³/year. MOE water well records indicate that less than 1% of the water wells were drilled for farm use.

Self Supply, Industrial (manufacturing)

There are no records of any significant uses of groundwater for manufacturing.

Self Supply, Industrial (mining)

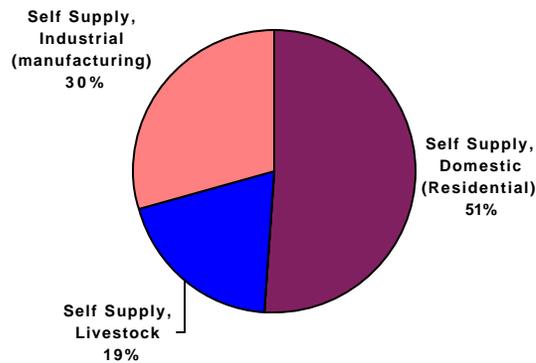
There are no records of any significant uses of groundwater for quarry or aggregate washing activities.

Self Supply, Other

There are no records of any groundwater use for other purposes, such as site remediation.

5.4.4 Township of Madoc

Madoc Township uses approximately 255,000 m³/year of groundwater in the following distribution.



Public Supply

There are no public groundwater systems in Madoc Township.

Self Supply, Domestic (Residential)

Madoc has a population of approximately 2,000 residents, of which 100% rely on groundwater as their potable water source through individual private wells. 87% of all wells recorded in the township were drilled for domestic water use consumption.

Self Supply, Commercial/Institutional

The MOE records do not indicate any large (greater than 50,000 L/day) groundwater takings for commercial or institutional uses. Nevertheless, schools, hospitals and care facilities located in rural areas of the municipality will draw upon groundwater as a potable resource.

Self Supply, Irrigation

The MOE classification of Self Supply Irrigation includes water used for both agricultural irrigation as well as commercial irrigation such as golf courses. Agricultural water use data did not identify any significant volumes of water being used for irrigation. A review of MOE PTTW records did not reveal any other large (>50,000 L/day) water takings.

Self Supply, Livestock

The volume of water used for livestock watering is estimated to be approximately 49,000 m³/year. MOE water well records indicate that over 8% of the water wells were drilled for farm use.

Self Supply, Industrial (manufacturing)

A review of the MOE PTTW records indicate that there were 2 permits of >50, 000 L/day for a total water taking of 75,280 m³/year. The water is used for industrial and drinking water purposes at a manufacturing facility.

Self Supply, Industrial (mining)

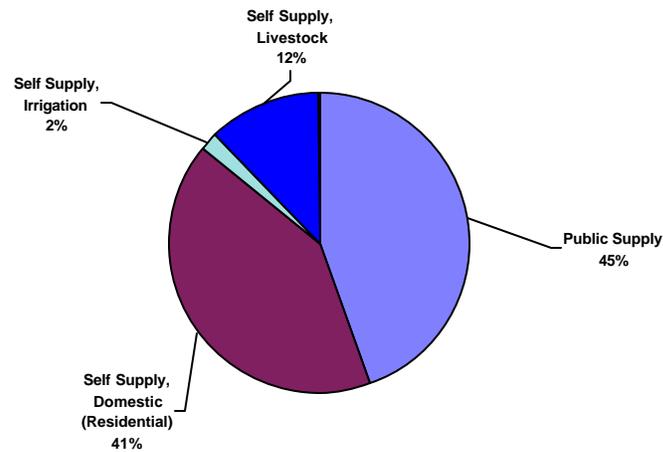
There are no records of any groundwater use for quarries or aggregate washing activities.

Self Supply, Other

There are no records of any groundwater use for other purposes such as site remediation.

5.4.5 Municipality of Tweed

The total volume of groundwater used in the Municipality of Tweed is 635,000 m³/year. A breakdown of this usage is presented below.



Public Supply

The village of Tweed is located in the Municipality of Tweed, and is supplied by two wells (Main Well, Crookston Well) that pump from a fractured bedrock aquifer. The population serviced by these wells is approximately 1,500 or 17% of the total population of the municipality. The average daily water use is 775 m³/day and the maximum daily water use is 1,940 m³/day. The calculated water use per person is 517 L/day, which is higher than the provincial average of between 270 and 450 L/day. It is estimated that 85% of the water usage is for residential consumption purposes, and 15% is for commercial or industrial uses. The wells are permitted to pump a combined volume of 2,583 m³/day.

Recently, water from the Main Well has contained exceedances of uranium above the Ontario Drinking Water Standards. The source of the exceedance is believed to be natural uranium bearing minerals in the Precambrian aquifer. The Municipality of Tweed is currently looking at treatment options and the possibility of drilling of a new well.

Self Supply, Domestic (Residential)

The estimated volume of groundwater used by private wells is 262,000 m³/year. Private wells supply the potable water needs of approximately 4,100 residents or 73% of the population of Tweed.

Self Supply, Commercial/Institutional

The MOE records do not indicate any large (greater than 50,000 L/day) groundwater takings for commercial or institutional uses. Nevertheless, schools, hospitals and care facilities located in rural areas of the municipality will draw upon groundwater as a potable resource. A water bottling company operates a well in the village of Tweed, across the road from the Crookston municipal well. The company currently pumps less than 50,000 litres/day and, therefore, does not require a PTTW. Granite Springs, which operates the well, has recently applied for a PTTW for 672,480 litres/day; however, the application has been denied.

Self Supply, Irrigation

The MOE classification of Self Supply Irrigation includes water used for both agricultural irrigation as well as commercial irrigation such as golf courses. The estimated total water use for irrigation purposes is approximately 11,600 m³/year, of which 100% of this amount is for agricultural irrigation. No large-scale water takers (less than 50,000 L/day) were listed in the MOE PTTW records.

Self Supply, Livestock

The estimated volume of water used for livestock watering is 77,500 m³/year. MOE water well records indicate that over 7% of the water wells drilled are for farm use.

Self Supply, Industrial (manufacturing)

The estimated volume of groundwater used for manufacturing purposes is considered zero, since there are no PTTW records for this category.

Self Supply, Industrial (mining)

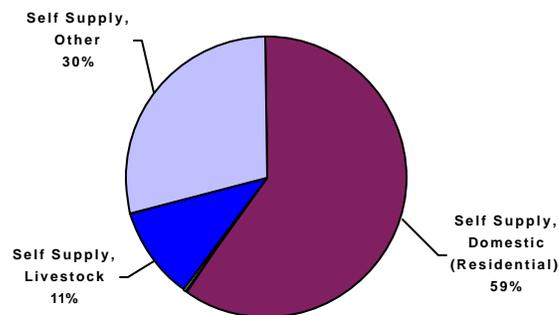
This category includes water used for aggregate washing and quarry dewatering. The estimated volume of groundwater used for quarries or aggregate washing activities is considered zero, since there are no PTTW records for this category.

Self Supply, Other

There are no records of any groundwater use for other purposes such as site remediation.

5.4.6 City of Belleville

The City of Belleville uses an estimated 2,500,000 m³/year of groundwater. In addition to this volume, another 6,300,000 m³/year of water taking has been permitted for the purposes of quarry dewatering; however, considering the inaccuracies associated with estimating actual groundwater use from the permits, this amount is not included in the estimation of total groundwater use by the City. The water use breakdown (not including quarry dewatering) is shown in the graphic below.



Public Supply

Groundwater is not used as a source of public water supply in Belleville. Public supply water is provided from the Belleville Water Treatment Plant (WTP) that receives water from the Bay of Quinte. The Belleville WTP services approximately 40,000 of the municipality's 45,986 inhabitants. A smaller system, the Point Anne WTP, services 50 people and is located on the north shore of the Bay of Quinte, approximately 3 km east of Belleville.

Self Supply, Domestic (Residential)

The estimated 6,000 residents that live in the rural portions of Belleville are serviced mainly from individual private wells. MOE water well records indicate that over 90% of wells in the Belleville area are for domestic potable water use. The total volume of groundwater used for domestic residential purposes is estimated to be 380,000 m³/year.

Self Supply, Commercial/Institutional

The MOE records do not indicate any large (greater than 50,000 L/day) groundwater takings for commercial or institutional uses. Nevertheless, schools, hospitals and care facilities located in rural areas of the municipality will draw upon groundwater as a potable resource. Furthermore, a review of the MOE water well record database indicates that 3% of the wells were classed as being drilled for commercial purposes.

Self Supply, Irrigation

The MOE classification of Self Supply Irrigation includes water used for both agricultural irrigation as well as commercial irrigation such as golf courses. The estimated total water use for irrigation purposes is approximately 1,630 m³/year, of which 100% of this amount is for agricultural irrigation. A review of MOE PTTW records did not reveal any other large (greater than 50,000 L/day) water users.

Self Supply, Livestock

The volume of water used for livestock watering is estimated to be approximately 68,000 m³/year. MOE water well records indicate that over 3% of the water wells drilled are for farm use.

Self Supply, Industrial (Manufacturing)

The estimated volume of groundwater used for manufacturing purposes is considered zero, since there are no PTTW records for this category.

Self Supply, Industrial (Mining)

This category includes water used for aggregate washing and quarry dewatering. The estimated volume of water is 6,280,000 m³/year, based on a review of 3 MOE PTTW records. The largest water taking is for almost 5,000,000 m³/year for dewatering activities at the Point Anne quarry. As is common for many water taking permits for quarry dewatering,

water takings mainly occur in the spring months. In addition, considering the close proximity of the Point Anne quarry to the Bay of Quinte, a certain proportion of this water may come from surface water. The actual volume of groundwater taken may be much lower than the permitted volume.

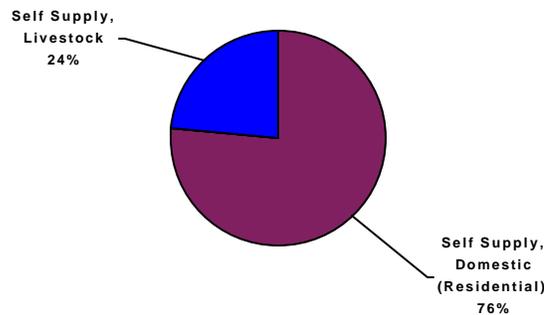
Self Supply, Other

In this category, MOE has issued 4 permits to take water for a total permitted water taking of 188,000 m³/year. Three of the four permits are for groundwater pump and treat systems for site remediation. The fourth permit is for dewatering of an elevator shaft.

In addition to the permits that were used in this assessment (permits valid as of January 13, 2003), a permit has recently been issued for three groundwater extraction wells as part of a remediation project at a petroleum tank farm near Belleville. The total permitted taking is approximately 38,000 L/day for each of the three wells.

5.4.7 Township of Tyendinaga

The estimated groundwater use in Tyendinaga Township (not including Tyendinaga Indian Reservation) is 315,000 m³/year. A breakdown of the water use is presented below:



Public Supply

There are no public groundwater systems in the Township.

Self Supply, Domestic (Residential)

The estimated 3,800 residents of Tyendinaga are supplied by individual private wells. MOE water well records indicate that over 88% of wells drilled in the area are for domestic potable water uses. The total volume of groundwater used for domestic residential purposes is estimated to be 240,700 m³/year.

Self Supply, Commercial/Institutional

The MOE records do not indicate any large (greater than 50,000 L/day) groundwater takings for commercial or institutional uses. Nevertheless, schools, hospitals and care facilities located in rural areas will draw upon groundwater as a potable resource. Furthermore, a review of the MOE water well record database indicates that 2% of the wells were drilled for commercial purposes.

In addition to the permits that were used in this assessment (permits valid as of January 13, 2003), a permit has recently been issued for aquaculture purposes. The total permitted taking is approximately 1,300,000 L/day.

Self Supply, Irrigation

The MOE classification of Self Supply Irrigation includes water used for both agricultural irrigation as well as commercial irrigation such as golf courses. No significant groundwater irrigation use was identified. A review of the MOE PTTW records did not reveal any large-scale (greater than 50,000 L/day) water users.

Self Supply, Livestock

The volume of water used for livestock watering is estimated to be approximately 75,000 m³/year. MOE water well records indicate that over 8% of the water wells were drilled for farm use.

Self Supply, Industrial (manufacturing)

There are no PTTW records on groundwater use for manufacturing as of January 13, 2003; however, a permit was issued recently for water taking from a pond for industrial purposes. The permitted taking volume is approximately 135,000 L/day.

Self Supply, Industrial (mining)

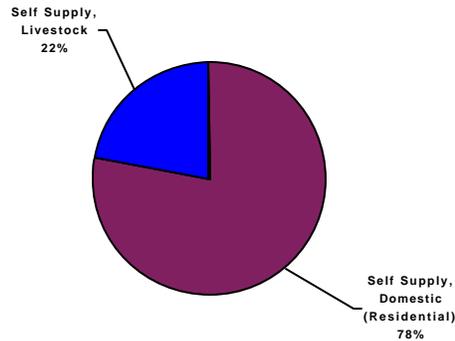
There are no records of any groundwater use for quarries or aggregate washing activities as of January 13, 2003. However, in 1994, a permit was issued for quarry dewatering for a maximum taking of 560,000 L/day.

Self Supply, Other

There are no records of any groundwater use for other purposes, such as site remediation.

5.4.8 Stone Mills Township

Stone Mills Township uses an estimated 600,000 m³/year of groundwater. The breakdown of the water use is presented below.



Public Supply

There are no public groundwater systems in Stone Mills.

Self Supply, Domestic (Residential)

Stone Mills has a population of approximately 7,340 residents, of which 100% rely on groundwater as their potable water resource through the use of individual private wells. 90% of all wells recorded in the Township were drilled for domestic water use purposes.

Self Supply, Commercial/Institutional

The MOE records do not indicate any large (greater than 50,000 L/day) groundwater takings for commercial or institutional uses. Nevertheless, schools, hospitals and care facilities located in rural areas of the municipality will draw upon groundwater as a potable resource.

Self Supply, Irrigation

The MOE classification of Self Supply Irrigation includes water used for both agricultural irrigation as well as commercial irrigation (e.g., golf courses). Agriculture water use data did

not identify any significant volumes of water being used for irrigation. A review of MOE PTTW records did not reveal any large (greater than 50,000 L/day) groundwater users.

Self Supply, Livestock

The volume of water used for livestock watering is estimated to be approximately 133,000 m³/year. MOE water well records indicate that over 8% of the water wells were drilled for farm use.

Self Supply, Industrial (manufacturing)

There are no records of any groundwater use for manufacturing.

Self Supply, Industrial (mining)

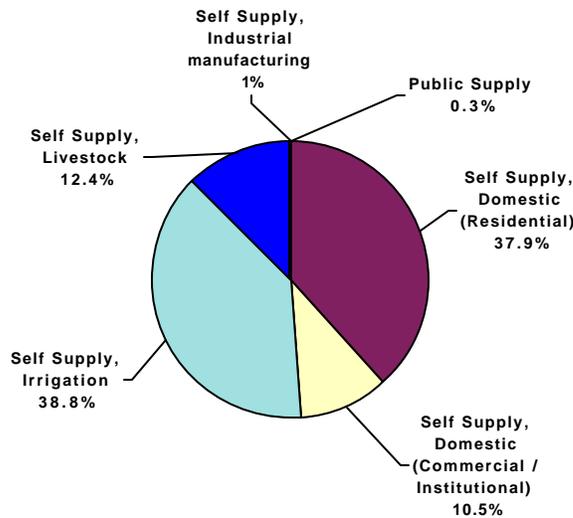
There are no records of any groundwater use for quarries or aggregate washing activities.

Self Supply, Other

There are no records of any groundwater use for other purposes, such as site remediation.

5.4.9 Prince Edward County

The total volume of groundwater used in Prince Edward County is 2,520,000 m³/year. In addition to this volume, another 16,100,000 m³/year of water has been permitted to be taken for the purposes of quarry dewatering or aggregate washing; however, considering the inaccuracies associated with estimating actual groundwater use from the permits, this amount is not included in the estimation of total groundwater use by the City. The water use breakdown (not including quarry dewatering or aggregate washing) is shown in the graphic below.



Public Supply

The only public groundwater supply system in Prince Edward County serves the Peats Point Subdivision, located along the northern shore of Bay of Quinte, approximately 3 km east of the hamlet of Rossmore. The system consists of one well that pumps from a fractured limestone aquifer. The well supplies approximately 22 m³/day to 18 homes, or approximately 50 individuals. The calculated per person water usage is 440 L/day, which falls within the provincial average of between 270 and 450 L/day. One hundred per cent of the water used is for residential purposes.

The well has had a history of intermittent turbidity problems; however, the quality of the water has been reported to be very good. The Municipality of Prince Edward County has recently drilled a replacement well.

Self Supply, Domestic (Residential)

Of the estimated 25,000 people who live within Prince Edward County, it is estimated that almost 60% or 15,000 residents rely on private wells. Well records indicate that 80% of the water wells are drilled for domestic use purposes.

The remaining 40% of the population (with the exception of Peats Point Subdivision) use mainly municipal systems that have a surface water source. Treated surface water piped from the Belleville WTP supplies the communities of Rossmore, Fenwood Gardens and residents part way along Rednersville and Massassauga Roads. The communities of Carrying Place and Consecon are hooked up to the Trenton WTP (Bay of Quinte source). The Picton WTP (Picton Bay source) services Picton and Bloomfield, while a relatively new WTP in Wellington (Lake Ontario source) services that community. The hamlet of Ameliasburgh receives water from Roblin Lake.

Self Supply, Commercial/Institutional

A review of MOE PTTW records indicates that the following permits have been issued for water takings greater than 50, 000 L/day.

- Private Campground (Cherry Valley): 294,490 L/day; and
- Sandbanks Provincial Park: 432,000 L/day.

A review of the MOE water well records indicates that 65 wells (or 2% of the total 3487 registered wells) were drilled for commercial purposes.

Self Supply, Irrigation

The MOE classification of Self Supply Irrigation includes water used for both agricultural irrigation as well as commercial irrigation (i.e., golf courses). The estimated total water use for irrigation purposes is approximately 980,000 m³/year. Of this total, 260,000 m³/year is used for agriculture irrigation and 720,000 m³/year is used for other purposes.

A review of the MOE PTTW records identified 3 permits of greater than 50,000 L/day, for a total water taking of 718,383 m³/year. The largest permit was for a nursery that is permitted to pump 530,505 m³/year from a shore well by Lake Ontario. The permit is registered as a groundwater source; however, most of the water will likely come from Lake Ontario.

Self Supply, Livestock

The volume of water used for livestock watering is estimated to be approximately 310,000 m³/year. MOE water well records indicate that over 15% of the water wells were drilled for farm use.

Self Supply, Industrial (manufacturing)

The estimated volume of groundwater used for manufacturing purposes has been considered zero, since there are no PTTW records for this category.

Self Supply, Industrial (mining)

This category includes water used for aggregate washing and quarry dewatering. The estimated volume is based on a review of MOE PTTW records for large takings in excess of 50,000 L/day. The MOE records indicate that several permits have been issued at two locations, a large quarry in Sophiasburgh ward, and a aggregate operation in Hallowell Ward. The total permitted water taking for the quarry is almost 16,000,000 m³/year; however, much of the water is expected to be surface water runoff or infiltration from the nearby lake. The permit also includes the temporary transfer of groundwater from one quarry to the other before it is used as process water. The maximum permitted taking for the aggregate operation is approximately 400,000 m³/year; however, much of this water is recirculated at the site during the aggregate washing operation.

6. CONTAMINATION ASSESSMENT

6.1 Background

The identification and assessment of potential contaminant sources is an essential element for the protection and management of groundwater. Known sources of contaminants pose potential long-term risks to groundwater aquifers. These include potential point sources of potential contaminants such as gas stations, dry cleaners, landfills, and manufacturing plants, as well as larger scale sources (non-point sources) such as the use of fertilizers and pesticides or the spreading of sewage on agricultural land.

The information in this section can be used to form a basis upon which potential contaminant sources should be viewed, and provides support for the implementation of future planning and development strategies. An example of how this data source can be used by planners is the identification of properties that may be contaminated by nearby sources. Proponents seeking severances, subdivisions or development of property near contaminant sources may require additional investigations to ensure that impacts are not present, prior to receiving municipal approval.

6.2 Objectives and Scope of Work

The overall objective of the Contaminant Assessment was to develop an inventory of potential contaminant sources across the Study Area, and to assign a geographic coordinate to each source, where possible. A secondary objective was to develop and detail the methodology used in conducting this inventory, such that the procedure can be repeated by stakeholders when newer or more accurate data become available. The study did not include the sampling or analysis of groundwater quality data; however, future studies that involve a groundwater sampling program can use information collected in this report to aid in selecting areas for groundwater monitoring.

The Contaminant Source Inventory (CSI) includes data from all levels of government, as well as a number of commercial sources. The specific tasks involved in developing the CSI included:

- collecting and compiling information from various sources, including private, local, provincial and federal agencies;
- performing a QA/QC review of the data to remove duplicate information;
- geocoding the potential contaminant sources and generating a variety of potential contaminant source maps; and,
- developing a database using ArcView^J and MS Access^J that can be updated in the future.

6.3 Methodology

The primary task for the CSI involved researching, assembling and geo-coding various contaminant sources from a variety of public and private databases and other sources. Several commercial and public databases were obtained from Ecolog Environmental Risk Information Services (ERIS) and certain provincially maintained databases were obtained directly from the MOE. Additionally, local municipal staff were interviewed so that local knowledge of potential contaminant sources could be entered into the database.

To simplify the presentation of the available information and to eliminate some of the redundant information within each database, fifteen typical operations or categories were selected for the CSI. **Table 6.1** presents each category, the applicable database and the author or supplier of the information. It is important to understand that not all information collected could be geo-referenced due to the amount and quality of information supplied within the dataset. Each site that could be identified was geo-referenced and is graphically presented on a regional map (**Map 6.1**). Geo-referenced information is also shown on individual municipal maps for the nine study partners.

The details for each database are presented in the following section.

Table 6.1: Contaminant Site Inventory Data Sources

Study Categorization	Database (Author/supplier)
Gas Stations	Retail Fuel Storage Tanks (MOE/TSSA/ERIS) Municipal Survey
Fuel/Chemical Storage	Retail Fuel Storage Tanks (MOE/TSSA/ERIS) Private Fuel Storage Tanks (TSSA/ERIS)
Landfills – Active	Waste Disposal Site Inventory, (MOE/ERIS)
Landfills - Closed	Anderson's Waste Disposal Sites (ERIS) Municipal Survey
Sewage Treatment Plants	Wastewater Discharger Database (MOE)
Waste Generators	Ontario Regulation 347 Waste Generators (MOE/ERIS)
Waste Receivers	Ontario Regulation 347 Waste Receivers (MOE/ERIS)
Manufacturing/Industrial	Scott's Manufacturing Directory (Scott's) Municipal Survey
Coal Gasification	Inventory of Coal Gasification Plants (MOE/ERIS)
PCB Storage	Ontario Inventory of PCB Storage Sites (MOE/ERIS)
Pesticide Storage	Pesticide Register (MOE/ERIS)
Salt Storage	Municipal Survey
Auto Scrap yard	Automobile Wrecking & Supplies (ERIS) Municipal Survey
Spills	MOE Spills Database (MOE)
Known Contaminated Sites	Federal Contaminated Sites (Canada) Ontario MOE Interviews Municipal Survey

MOE: Ministry of the Environment

ERIS: Ecolog Environmental Risk Information Services

Scott's: Scott Business Directories

TSSA: Technical Standards & Safety Authority

Limitations

The information collected from available databases is considered third party information and has generally been interpreted with a reasonable degree of accuracy. A number of these data sources did not contain sufficient information to allow geo-referencing of the data points. Where information was limited, the data were not included in the inventory. The main limitation with any exercise of this nature is that some of the most significant potential

contaminant sources will not be listed in any of the data sources. Additionally, of the many contaminant sources that are used in this study, it can be expected that many of these sites will never experience releases sufficient to impact the local groundwater.

6.3.1 Provincial and Federal Data Sources

Federal Contaminated Sites June 2000-Sept 2002

The Treasury Board of Canada Secretariat maintains an inventory of all known contaminated sites held by various Federal departments and agencies. This inventory does not include properties owned by Crown corporations, but does contain non-federal sites for which the Government of Canada has accepted some or all financial responsibility. All sites have been classified through a system developed by the Canadian Council of Ministers of the Environment. The database provides information on company name, location, site ID #, property use, classification, current status, contaminant type and plan of action for site remediation.

MOE Spills Database (Occurrence Reports)

Spill data were provided for over 900 occurrences pertaining to contaminant releases to air, land or water in the Study Area between 1988 and 2002. This database includes the location (street address or legal description), quantity, type and affected media of the spill.

Ontario Inventory of PCB Storage Sites (MOE)

The MOE Waste Management Branch maintained an inventory of PCB storage sites within the Province between 1987 and 2000. During these years, the MOE required that facilities storing or disposing inactive PCB storage equipment and/or PCB waste register with the Waste Management Branch. This database contains information on waste quantities, major and minor sites storing liquid or solid waste, and a waste storage inventory.

Ontario Regulation 347 - Waste Generators Summary (EcoLog Eris)

Regulation 347 of the Ontario Environmental Protection Act (EPA) defines a waste generation site as any site, equipment and/or operation involved in the production, collection, handling and/or storage of regulated wastes. A generator of regulated waste is required to register the waste generation site and each waste produced, collected, handled, or stored at the site. This database contains the registration number, company name and address of registered generators, including the types of hazardous wastes generated. This information is a summary of all years from 1986, including the most currently available data. Some records may contain within the company name, the phrase "See & Use..." followed by a series of letters and numbers. This occurs when one company is amalgamated with or taken over by another registered company. The number listed as "See & Use", refers to the new ownership and the other identification number refers to the original ownership. This phrase serves as a link between the 2 companies until operations have been fully transferred.

Ontario Regulation 347 Waste Receivers Summary (EcoLog Eris)

Part V of the Ontario EPA regulates the disposal of regulated waste through an operating waste management system or a waste disposal site operated or used pursuant to the terms and conditions of a Certificate of Approval or a Provisional Certificate of Approval. Regulation 347 of the Ontario EPA defines a waste-receiving site as any site or facility to which waste is transferred by a waste carrier. A receiver of regulated waste is required to register the waste receiving facility. This database represents registered receivers of regulated wastes, identified by registration number, company name and address. This information is a summary of all years from 1986, including the most currently available data.

Private Fuel Storage Tanks (EcoLog Eris)

The Fuels Safety Branch of the Ontario Ministry of Consumer and Commercial Relations maintained a database of all registered private fuel storage tanks. Public records of private fuel storage tanks are only available since the registration became effective in September 1989. The Technical Standards and Safety Authority (TSSA) now collects this information.

Inventory of Coal Gasification Plants (EcoLog Eris)

The Inventory of Coal Gasification Plants was maintained by the MOE up to 1988. The database includes all known and historical coal gasification sites that produced or used coal tar and other related tars. The locations of these sites were cross-referenced with the Study Area and were incorporated into the database of potential contaminant sources.

Pesticide Register (EcoLog Eris)

The Pesticide Register is an MOE database that includes all manufacturers and vendors of registered pesticides. The locations of these sites were cross-referenced with the Study Area and were incorporated into the database of potential contaminant sources.

Wastewater Discharger Registration Database (MOE)

The Wastewater Discharger Registration Database is a conglomerate of two programs maintained by the MOE between 1990 and 1998. Original data included in the database were collected under the MOE Municipal/Industrial Strategy for Abatement (MISA). The data have included all direct dischargers of toxic pollutants within nine sectors including: Electric Power Generation; Mining; Petroleum Refining; Organic Chemicals; Inorganic Chemicals; Pulp & Paper; Metal Casting; Iron & Steel; and Quarries. All information is now collected and stored within the Sample Result Data Store (SRDS). The locations of these sites were cross-referenced with the Study Area and were incorporated into the database of potential contaminant sources.

Sample Result Data Store – Sewage Treatment Plants (MOE)

The MOE maintains the Sewage Treatment Plant SRDS to provide detailed information pertaining to municipal sewage treatment plants. In particular, data include design specifications and performance. The performance data for the municipal systems within the Quinte area were reviewed and locations were incorporated into the database of potential contaminant sources.

Certificates of Approval

This database contains the following types of approvals: Certificates of Approval (Air) issued under Section 9 of the Ontario EPA; Certificates of Approval (Industrial Wastewater) issued under Section 53 of the Ontario Water Resources Act ("OWRA"); and Certificates of Approval (Municipal/Provincial Sewage and Waterworks) issued under Sections 52 and 53 of the OWRA. Because of the poor addressing in this data base, the data could not be geo-referenced, but are presented within the digital database.

Waste Disposal Site Inventory

The Ontario MOE Waste Management Branch maintains an inventory of known active, inactive and closed disposal sites in the Province of Ontario. Active sites maintain a Certificate of Approval and are approved to receive and are receiving waste. Inactive sites maintain Certificate(s) of Approval but are not receiving waste. Closed sites have no Certificate of Approval and are not receiving waste. Information from this dataset was merged with the Anderson Waste Disposal site inventory.

MOE District Office Interviews

Staff at the MOE district office in Belleville were interviewed to determine where significant known historic contaminant occurrences exist within the Study Area. Sites where significant contaminant issues are outstanding or investigations are ongoing were provided and incorporated into the database of known contaminated sites.

6.3.2 Commercial Databases

In addition to the available provincial and federal databases and reports, a number of commercial datasets were obtained and, where necessary, geo-coded. The datasets were ordered from EcoLog Environmental Risk Information Services (ERIS) Ltd. The descriptions of each dataset, below, are taken from EcoLog's published material.

Retail Fuel Storage Tanks

Until 1996, the Fuels Safety Branch of the Ontario Ministry of Consumer and Commercial Relations (MCCR) maintained a database of licensed retail fuel outlets. Historic information was obtained from the MCCR and current information, for the ERIS database, was collected from private sources. This database includes an inventory of retail fuel outlet locations that have on their property gasoline, oil, natural gas, waste oil and/or propane storage tanks.

Anderson's Waste Disposal Sites

The Anderson database uses historical documentation to locate and characterize the likely positions of former waste disposal sites in Ontario. It aims to identify those sites that are missing from the Ontario MOE's Waste Disposal Site Inventory (also included in EcoLog ERIS). The Anderson database also provides revisions and corrections to the positions and descriptions for sites listed in the MOE database. In addition to historic waste disposal facilities, the database also identifies certain auto wreckers and scrap yards that have been extrapolated from documentary sources.

Scott's Manufacturing Directory

Scott's Directories is a data bank containing information on over 20,000 manufacturers in Ontario. Even though Scott's listings are voluntary, it is the most comprehensive database of Ontario manufacturers available. Information concerning a company's address, plant size and main products are included in this database. This database begins with 1992 information and is updated annually. The database was used to identify industries that may store or handle chemicals that, if released, could impact groundwater.

Automobile Wrecking & Supplies

This database provides an inventory of all known locations that are involved in the scrap metal, automobile wrecking/recycling, and automobile parts and supplies industry. Information is provided on the company name, location and business type.

6.3.3 Municipal Survey

To better understand local concerns within a township area, three additional databases were created by compiling township-specific information for: gas stations, salt storage facilities and known industrial contaminate sources. The township-specific information was collected, geo-referenced and incorporated into the CSI.

Salt Storage Facilities

Local surveys were conducted to inventory municipal and provincial salt storage facilities. These facilities often include salt and sand storage domes, equipment parking, a maintenance shop and a small office. Typically, contaminants of concern include sodium, chloride and cyanide (from ferrous cyanide, a salt caking agent). The high concentration of salt in a relatively small area creates a point source worth including in the CSI. Municipalities are continually implementing salt management programs to reduce the amount of salts used during the course of the winter season.

Gas Stations

In order to make the locations of retail and private fuel storage tanks more recognizable, a local survey was completed to identify locations that primarily use underground storage tanks for refuelling. Gas stations were located and cross-referenced with the provincial, federal and private fuel storage databases. It should also be noted that gas stations often service vehicles, creating the potential for the storage of other chemicals such as antifreeze, lubricants and waste oils.

Quinte Area Contaminant Inventory

Near the completion of the CSI, the study team was made aware of another contaminant inventory being conducted in the Quinte area as part of the Quinte Remediation Action Plan (RAP). It is our understanding that many of the data sources of this inventory are similar to those used in Quinte Regional Groundwater study CSI. It is recommended that the RAP contaminant inventory be reviewed, and any additional entries that are included in this

database be added to the CSI. Of special interest will be any contaminant sites whose geo co-ordinates have been verified using global positioning survey equipment (GPS).

6.3.4 Geo-coding Methods

In order to use the information contained in the collected databases, an effort was made to assign geographic coordinates to each unique point, where applicable. The Fuel Storage Tanks, PCB Sites, and Spills data were located solely by street address, postal code, primary intersection or general descriptions. The following section describes the methodology used to convert these various location descriptions into UTM easting and northing coordinates (geo-coding).

The contaminant information was geo-coded against the following base data:

- **Six Digit Postal Code Polygons:** A commercial product purchased from DMTI Spatial Inc., this is a GIS polygon layer where each polygon corresponds to one of Canada Post's unique six-digit postal codes.
- **DMTI Spatial Street Network:** This is a commercial product that contains street segments that are typically attributed with street name and the range of addresses that are located along that segment (block).

The address fields in the MOE database were often incomplete or incorrectly entered and a significant effort was made to parse the address fields properly prior to geo-coding.

The initial approach attempted to match the six-digit postal codes to the DMTI postal code database, with geo-coded locations assigned the UTM coordinate of the postal code polygon centroid. Because rural postal code polygons are quite large, only urban postal codes were used at this initial stage.

The second technique used was to geo-code against the DMTI street segment layer. Again, the precision of this technique varied considerably but was, in general, accurate to a particular block. Finally, a combination of street address and postal code attributes was used, typically to provide a more precise location in rural areas.

The success of the geo-coding effort was variable and was generally dependent on the quality of data in the Contaminant Database. As mentioned in the sections above, future efforts could concentrate on field truthing the geo co-ordinates of the data by the use of global positioning survey equipment.

6.3.5 Database

The information collated in this report was inputted into an Access2000™ database. Separate database tables were created for each of the potential contaminant source groups. Information (attributes) on the data columns within these tables are provided where supplied by the data source. The format of the database allows for future updating of the tables as more information becomes available. An example of the stored data fields for some of the inventoried data is presented in **Appendix D**. The tables include both geo-referenced and non-geo-referenced data, while the produced maps show only geo-referenced data. It is important to note that the accuracy of the data depends upon the data source. Confirmation of the accuracy of the data, including checking the addresses and geographic co-ordinates of each entry, was beyond the scope of this project. As a result, errors in the data, especially the geographic co-ordinates, are expected. It is recommended that future efforts focus on improving the co-ordinates by visiting each site and recording the geographic co-ordinates using GPS equipment.

6.4 General Risks from Selected Land Use Activities

The United States Environmental Protection Agency (US-EPA) has developed a list of the major potential sources of groundwater contamination (**Figure 6.1**). While survey results for Canada are not available, the similarity between the two countries in terms of industrial, commercial and agricultural practices suggests that the results are likely representative of the major groundwater contaminant sources in Canada, as well. As shown on **Figure 6.1**, underground storage tanks (USTs) were the most frequently cited source of groundwater contamination.

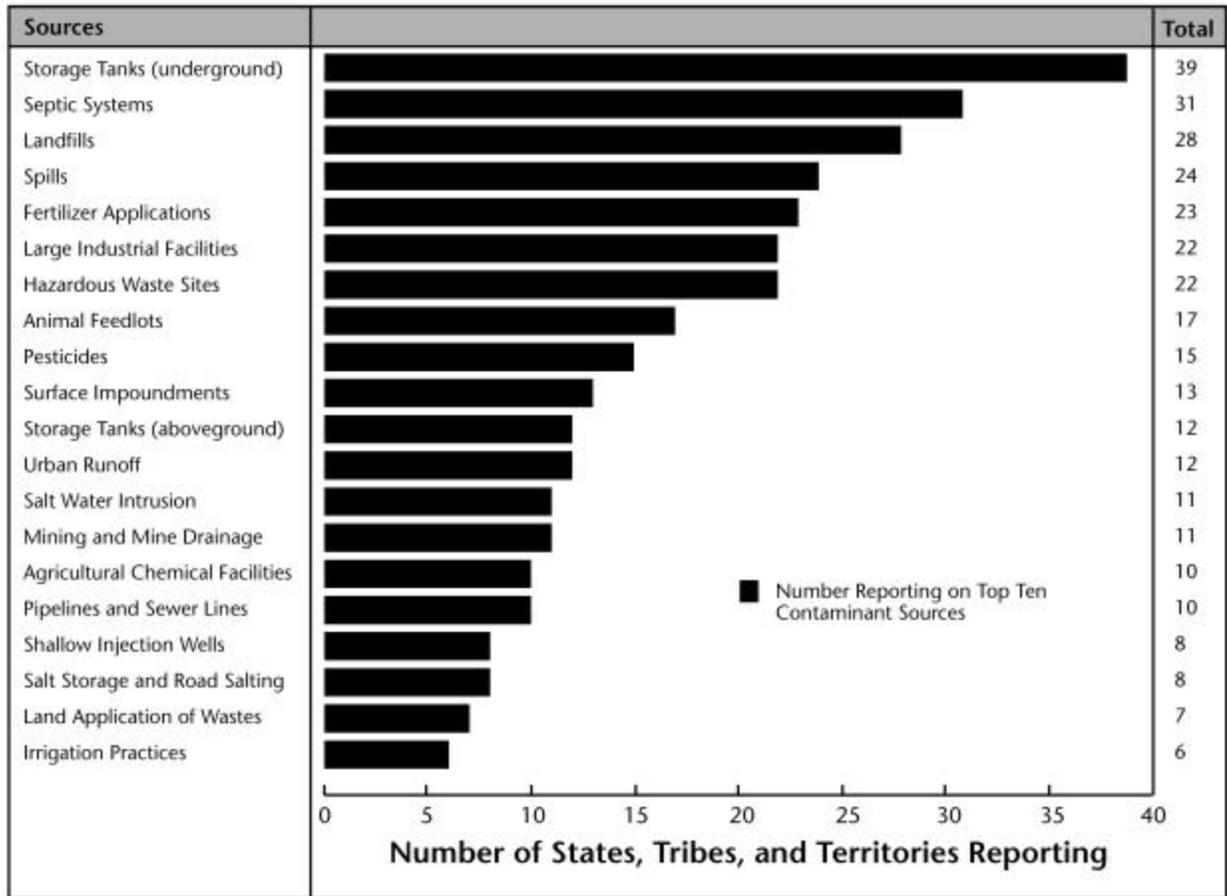
The list includes both large (e.g., landfills) and small (e.g., septic systems) point sources, as well as a number of non-point sources (e.g., urban runoff and fertilizer applications).

However, the sources are not correlated to general land use. A comparison of rural versus urban environments is likely to present variations in the major sources cited. For example, septic systems, animal feedlots, and widespread application of fertilizers and pesticides are more likely sources of groundwater contamination in a rural setting; while USTs, landfills and large industrial facilities are contaminant sources often associated with an urban environment.

The remainder of this section provides a more detailed discussion of some of the more significant potential sources of groundwater contamination in the Study Area, including:

- the application of agricultural and non-agricultural nutrients;
- road salt storage and application;
- landfills; and,
- industrial and commercial chemical usage.

Figure 6.1. Major Sources of Groundwater Contamination



US EPA National Water Quality Inventory, 2000 Report to Congress

6.4.1 Agricultural Activities

Agriculture is a potential source of impacts to the groundwater from nitrates, pesticides and micro-biological organisms. With this in mind, an assessment was performed on whether agriculture is likely to be a major contributor to groundwater quality impairment in the Study Area. Specific objectives included:

- determining the extent to which nitrogen used in agriculture may cause elevated groundwater nitrate concentrations;
- estimating the risk of micro-biological contamination of wells in the Study Area posed by livestock production; and,
- examining the potential for agricultural pesticide use to contaminate groundwater.

The approach taken was to predict areas that may be prone to nitrate, pesticide or micro-biological impacts based on aquifer vulnerability and agriculture land use intensity. Collection of new or existing groundwater quality data was beyond the scope of this study; however, this activity is recommended as a future step in the areas where an above average risk of contamination is predicted. The results from this analysis could be used to select target areas for groundwater monitoring, such as in areas where there is a higher than normal concentration of agricultural land use.

The results of the assessment are provided in a separate report in **Appendix E**. Highlights of the report are presented herein, along with a series of maps showing areas that are potentially prone to nitrogen impacts (**Map 6.2**), micro-biological impacts (**Map 6.3**), and pesticide impacts (**Map 6.4**).

Risk of Nitrate Impacts

Agricultural land use practices can introduce nitrogen into the groundwater. Sources of nitrogen include man-made fertilizers, manure, and crops that fix atmospheric nitrogen in the soil. **Map 6.2** shows the estimated nitrogen that is available for leaching into the groundwater. Overall, the estimated quantities of nitrogen remaining in the soil following crop production ("residual nitrogen") are believed to be lower in the Study Area than is

average for Ontario. Nitrogen in livestock manure was found to exceed the needs of crops in many areas of the southern part of the Study Area. When the "surplus" manure nitrogen is added to the "residual" nitrogen, many agricultural land areas are identified as having relatively high nitrate leaching potential.

The areas with the highest potential for leaching (greater than 30 kg nitrogen/ha) include the southern portion of Hillier Ward and the northern portion of Hallowell Ward in Prince Edward County, and the Newburgh area in Stone Mills Township. Other areas in Prince Edward County with higher than average residual nitrogen levels (20-30 kg nitrogen/ha) include southern Hallowell Ward, western Hillier Ward, Athol Ward, northern Ameliasburgh Ward, central Sophiasburg Ward, and the central portion of the City of Belleville (former Thurlow Township).

Risk of *E.Coli* Impacts

Micro-organism contamination of well water, usually by *E.coli*, is common throughout Ontario. Data collected by the Hastings and Prince Edward counties Health Unit indicates that between 2001 to 2003, 7% to 9% of all tested water samples contained *E.coli*. It is sometimes caused by livestock manures, but can come from other sources (e.g. septic system). Well contamination by *E.coli* is probably more likely in areas with large numbers of livestock, especially where aquifers are vulnerable. A number of areas have been identified in the Study Area where livestock densities and aquifer vulnerability are both high. These areas, which are shown on **Map 6.3**, include the Newburgh and Tamworth areas of Stone Mills, and the Waupoos and Cressy Point areas of Prince Edward County.

Risk from Pesticide Impacts

Pesticide contamination of groundwater is not a frequent problem in Ontario. In a 1991-1992 survey of 1,292 farm wells in Ontario, 12% had detectable levels of pesticides (Goss *et al*, 1998), but pesticides only exceeded drinking water guidelines in 0.3% of these wells. Considering that pesticide use in Hastings County, and Lennox and Addington County is below the provincial average, it is possible that the incidence of contamination in these counties would be lower than 0.3%, although the high aquifer vulnerability of the area may lead to the opposite conclusion. Pesticide use in Prince Edward County is above the

provincial average and so contamination in greater than 0.3% of wells is possible, especially considering the high vulnerability of the aquifer.

Areas that may be more prone to pesticide contamination are presented in **Map 6.4**. Agricultural pesticide use in the Study Area is mostly as herbicides, but insecticide and fungicide are also significant components, especially in Prince Edward County, where overall pesticide use is above the Provincial average. In Hastings County, and Lennox and Addington County, pesticide use is lower than the Provincial average, but is increasing. Crops on which pesticides are used are grown in areas where the aquifers are of high vulnerability to contamination. However, in the absence of any reported pesticide contamination of groundwater in the Study Area, there may not be reason for major concern about this potential source of contamination. Nevertheless, as more land with high aquifer vulnerability is converted from hay and pasture to cultivated crops, the potential for contamination of groundwater by pesticides can be expected to increase. It is also possible that significant local contamination may occur if pesticides are spilled, or leak from containers, or if equipment wash water is improperly handled. It is not possible to assess these risks at the scale of the Study Area, but individual wells may be at risk, especially if they are improperly constructed.

6.4.2 Application of Non-Agricultural Nutrients

The storage and application of non-agricultural nutrients on rural lands can present a significant risk for biological and nitrate contamination of groundwater, particularly in areas of high aquifer vulnerability. Nutrients are typically applied as biosolids from wastewater treatment plants and discharges from septic systems (sewage sludges). The operation of domestic septic tile beds can release biological contaminants and nitrate, as well as other household chemicals, into the shallow subsurface.

Biosolids

There are a number of wastewater treatment plants (WTP) across the Study Area, most of which use land application of biosolids as their primary means of sewage sludge disposal. Common contaminants from biosolids include nutrients (nitrates, phosphates), pathogens and metals. Prince Edward County and the City of Belleville are currently seeking alternative

methods of biosolids disposal to reduce the potential of bioaccumulation of potentially harmful contaminants on agricultural land.

Septic Systems

The use of private septic systems is widespread throughout the Study Area and is the most common form of waste disposal outside the municipally serviced areas. Private septic systems are a significant source of nitrate, bacteria, sodium and chloride. A conceptual model of the evolution of wastewater in a conventional septic system was developed by Wilhelm (1991). In this model, the wastewater chemistry can evolve in three different microbially mediated redox zones. The first zone exists in the septic tank and is where all of the nitrogen is first reduced to ammonium. The wastewater then flows into the septic absorption field, which constitutes the second zone. The second zone is an aerobic environment where ammonium and organic carbon are consumed and carbon dioxide and nitrate are produced. The nitrate produced here is the cause of nitrogen contamination to the groundwater. A third zone can occur near or below the water table if anaerobic conditions occur in the presence of organic carbon. The organic carbon in the anaerobic environment allows for microbial denitrification to occur, reducing the nitrate to N₂. This third zone is not often found beneath septic systems due to the lack of adequate organic carbon in most soil deposits; however, when it does occur, this process improves the groundwater quality.

Ritter and Eastburn (1988) report that conventional private septic systems undergo denitrification of between 0% to 35%, which results in typical nitrate concentrations in the groundwater of 30-50 mg/L (as Nitrogen) and ammonia concentrations of up to 1 mg/L (as Nitrogen) (Robertson and Cherry, 1991). Gold et. al. (1990) found that, based on a density of five homes per hectare (0.5 acre lots), conventional septic systems would generate nitrogen at a rate of 47.5 kg/ha/yr (42.4 lbs/acres/yr). This nitrogen loading is comparable to nitrogen losses observed from a urea fertilized silage corn field with an effective rye cover crop.

Typical sodium and chloride concentrations in groundwater from domestic septic systems are between 40 to 80 mg/L and 20 to 50 mg/L, respectively (Robertson and Cherry, 1991). The septic system has very little effect on the sodium and chloride concentrations, so these levels are released in the groundwater flow system without change (Wilhelm, 1991).

Interference between septic discharges and on-site wells is of greatest concern in rural subdivisions or in non-municipally serviced villages and hamlets, where septic beds and water wells are in close proximity to one another. Considering the predominance of shallow fractured rock, the risk of contamination to private wells from on-site or neighbouring septic beds is high. Discharges from water softeners can also impact nearby wells by introducing salt into the groundwater. In many cases, reported salt impacts to wells may be from water softener discharges rather than road salt.

This study did not attempt to map areas that are more or less prone to contamination from septic systems; however, it is reasonable to assume that such a map would be directly reflective of density of residents on individual services. Considering that the entire Study Area has a high aquifer vulnerability, most regions will be prone to septic system interference problems, especially areas where bedrock is shallow. Areas that may be less prone to impacts are those where the water table is deeper or there are beds of lower permeability material over the bedrock aquifer. **Map 3.4** shows areas where >1.5 m of silt and clay are present (Unit 7). These areas may potentially be less sensitive to septic and well interferences.

6.4.3 Road Salt Storage and Application

Road salts are used as de-icing and anti-icing chemicals for winter road maintenance. Environment Canada has determined that road salts in sufficient concentrations pose a risk to plants, animals and the aquatic environment (Environment Canada, 2001). A Risk Management Strategy for Road Salts was developed by Environment Canada outlining the measures that Environment Canada proposes in order to manage the risks associated with road salts. Under the *Canadian Environmental Protection Act, 1999*, the Government of Canada published a proposed Code of Practice for the Environmental Management of Road Salt on September 20, 2003 for a 60-day public comment period. Comments received during the period are being considered and the final Code of Practice will be published in Spring 2004. In general, the Draft Code of Practice requires a company or organization that uses >500 tonnes of road salt per year to implement a Salt Management Plan (SMP). The SMP should detail procedures that are to be implemented, reviewed and monitored to reduce the impact of salt on the environment.

Road maintenance applications include: chloride salts such as sodium chloride (NaCl), calcium chloride (CaCl₂), magnesium chloride (MgCl₂) and potassium chloride (KCl); brines used in road de-icing/anti-icing; and, additives commonly used in road salts (ferrocyanides). These salts can enter surface water, soil and groundwater and may impact soil properties, roadside vegetation, wildlife, groundwater, aquatic habitat, and surface water.

Road salt contamination of surface and groundwater is a concern in areas of high use on roadways and along major expressways, as well as near point contamination from salt storage areas. According to Environment Canada (2001), most of the claims from property owners against transport authorities are related to contamination of well water from salt released into groundwater. In stormwater drainage, salt is transported to surface waters such as creeks, rivers, lakes and can impact aquatic species. Plants can also be exposed to road salt through the soil, air and runoff water. In sensitive areas, road salt application can affect nearby crops and trees (Environment Canada, 2002).

In the Quinte Study Area, there are at least 13 municipal salt storage facilities, as well as a number of MTO facilities. **Map 6.1** shows the location of known salt storage sites across the Study Area.

6.4.4 Landfills

Landfills may contain a wide variety of domestic, industrial and commercial wastes. As precipitation percolates through a landfill, it comes into contact with these wastes and produces leachate. The composition of leachate depends on the nature of the waste within a landfill, but typically contains elevated concentrations of nitrogen (ammonia and/or nitrates), sodium, chloride, boron and iron, and has an elevated chemical and biochemical oxygen demand (COD/BOD). If leachate migrates out of a landfill, it may pose a threat to surface and/or groundwater.

Older landfills were often located in former gravel pits or quarries, in ravines, or on marginal land such as wetlands. These sites provide little in the way of natural protection for either groundwater or surface water. Further, the nature of the waste within these landfills is generally not well known.

Landfills that have been active in the past 15 to 20 years are generally better documented and monitored, and are often engineered to reduce the risks of leachate migration to groundwater or surface water. Where these more recent landfills have adversely impacted the environment, mitigation measures have often been put into effect. Active landfills are often of lesser concern than closed landfills, as most perform under strict Certificate of Approval requirements that mandate regular monitoring and require that any contaminant plume be controlled. On the other hand, closed landfills have been the most problematic, in that the ownership and responsibility of impacts is often uncertain, and the monitoring requirements are less strict and more difficult to enforce. For example, in Beckwith Township in Lanark County, a closed landfill has generated a 6 km long chlorinated solvent plume that was only recently discovered. This plume has impacted a considerable number of private wells.

In addition to the risks posed by known landfills, there are likely to be a number of historical landfills and waste dumps for which the location is not known, or which have not been assessed for potential environmental impacts.

Within the databases available for Quinte, there are 205 landfill records listed. Seventy-seven of these sites are considered active landfills. Of the 77 landfills, the municipal survey identified 17 landfills that are known to be operated by local municipalities. There are 60 landfills in the study area that are active and considered to be privately owned and operated for either industrial use or commercial use.

6.4.5 Industrial and Commercial Chemical Use

While industrial and commercial chemical use encompasses a wide variety of potential threats to groundwater, the most common potential contaminant sources are fuel storage tanks, historical use and disposal practices, and spills.

Fuel Storage Tanks

Fuel and related products such as lubricating oils and solvents are stored and used at a wide variety of commercial, industrial and agricultural facilities (as well as some private homes), either in above-ground storage tanks (ASTs) or underground storage tanks (USTs). These

tanks and the associated piping can present a threat to groundwater, either through catastrophic failure or, more commonly, through slow leaks that may go unnoticed for months or years.

The most common use of USTs and, therefore, a common source of resultant contamination, is at retail fuel outlets. Historically, the standards for UST construction and use did not require the incorporation of leak protection (e.g., double walls, corrosion resistance) or leak testing. In some cases, USTs were not removed when former retail fuel outlets were converted to other uses.

Because the Ontario Drinking Water Standards for contaminants such as fuels and their breakdown products is quite low (often in the part per billion range), only a small volume of contaminant is needed to affect a large volume of groundwater.

Historical Practices

Historically, chemicals were used in industry and business with little knowledge of the potential risks to the environment and to groundwater contamination, in particular. Practices such as strictly auditing the volume of chemicals to identify losses, building secondary containment around storage tanks, using ASTs instead of USTs, and properly disposing of hazardous chemicals were not common prior to the 1980s.

In the absence of good environmental management practices, industrial chemicals were often released to the environment through leaks in storage tanks and piping, or leaks in machinery, combined with cracked concrete floors or leaking floor drains. Historical disposal practices for liquids and empty storage containers often involved pouring waste chemicals on the ground, diverting them to unlined disposal lagoons or landfills, or burning them in unlined outdoor burn pits.

The solvents perchloroethylene (PCE) and trichloroethylene (TCE) are two of the more common industrial chemicals that pose a significant risk to groundwater. PCE is widely used as a dry-cleaning fluid, while TCE is a common degreaser and is widely used in industrial applications. Both TCE and PCE are denser than water and tend to sink through an aquifer

until they reach a low permeability horizon, providing a persistent, long-term source of groundwater contamination.

Spills

Even with modern best management practices for handling and disposing of chemicals, accidental releases of chemicals are still common. Often, the amount spilled is small or response actions are sufficiently fast that the environmental impacts of such spills are mitigated. However, in the case of larger spills, or undetected slow releases, there may be significant potential for groundwater impacts.

Unfortunately, the MOE Spills database is incomplete and is particularly difficult to geocode because of poor addressing. As such, it is difficult to assess the degree of risk to groundwater posed by the spills incidents recorded in this database. The data are provided in the digital Contaminant Site Inventory, but not plotted on the maps.

6.5 Known Significant Contaminated Sites

This sub-section summarizes the known contaminated sites that were identified through interviews with local municipal staff and MOE representatives. The list of sites is not exhaustive, but should be considered as a base of information that can be added upon. The sites are shown on **Map 6.1** and are referenced on the map with numbers, where possible. Individual maps for each municipality are produced at a larger scale and are presented at the back of the **Map Booklet**.

6.5.1 Township of Hastings Highlands

No known contaminated sites of significant concern were identified in the reviewed contaminant databases.

6.5.2 Township of Carlow/Mayo

Township representatives are not aware of any historic or current contaminated sites in the Township of Carlow/Mayo.

6.5.3 Town of Bancroft

No known contaminated sites of significant concern were reported in the Township of Bancroft. Interviews with Town representatives indicated a few areas that are of potential concern within the Town. They include: Lots 19 and 20, and Concessions 12 and 13, east of Bancroft that are currently used for the application of sewage sludges from local wastewater treatment plants; two bulk fuel storage facilities at the southern limits of Town, and, two former gas stations at L'Amble and the Detler intersection.

6.5.4 Township of Madoc

The closed **municipal landfill (10)** located on Lot 10, Concession 6, is known by local representatives to be a source of groundwater and/or soil contamination in the Township of Madoc. The landfill was closed in 1972. Other sites identified as having potential, by the nature of their land use, to impact the local groundwater are the Stockloser mine and the IKO sawmill.

6.5.5 Municipality of Tweed

The municipal survey does not indicate any known areas of contamination in Tweed. However, several areas of potential concern were identified: former gas station operations (Whalen's General store and the Thomasburg Restaurant) and salt storage facilities. Recently, public concern has been raised over the planned development of a large pig farm north of the village of Tweed.

6.5.6 City Of Belleville

The **East Zwicks Island Dump (1)** and the **West Zwicks Island Dump (2)** (Piggyback Dump) were municipal landfills active from 1966 to 1974. The Piggyback Dump abuts former railway land (hence "Piggyback" name). The sites are located in the centre of Belleville, south of Dundas Street. MOE representatives have indicated that contaminants are currently leaching into the Bay of Quinte from these sites. These landfills were officially closed under approval by the MOE. The City of Bellville is monitoring both groundwater

and surface water at these closed landfills and reporting results to the MOE on an ongoing basis.

The **Bakelite Site (3)** extends from the shoreline of the Bay of Quinte to Dundas Street in the City of Belleville. The Bakelite Manufacturing Plant was established in the 1940's and was previously owned by Union Carbide (Dow Chemical). The plant manufactured hard plastics for pot handles and dishes. Environmental issues at the site include soil and groundwater contamination originating from previous plant operations and buried drums of contaminated waste. The site is approximately 70 acres, consisting of buildings, open space and several acres of wetlands. A private landowner now owns the property and is seeking to re-develop the site.

The **Myers Pier Site (4)** is located south of Dundas Street East and extends to the Bay of Quinte shoreline. This site was originally an industrial port site with activities related to coal gasification, coal stockpiles, petroleum storage, lumber mills and other industrial use activities. MOE records indicate that contaminants at the site are leaching into Bay of Quinte. The City of Belleville and the federal government are currently investigating the property.

The **Nortel Site (8)** located on the west side of Belleville once had drums of chlorinated solvent waste buried at the site that have impacted the local groundwater aquifer. This aquifer (approximately 30 feet deep) is a former streambed, which at one time could have flowed either to the east to the Moira River or to the west. Investigation and remediation of the property is ongoing.

The **Rexcan Site (9)** was once used to manufacture electronic components. The site is under investigation by the MOE.

The **Tank Farm Site (11)** is an area of bulk petroleum fuel storage. Various groundwater monitoring and remediation efforts are currently underway.

The Ontario Clean Water Agency (OCWA) operates the City of Belleville's water treatment plant (WTP). Belleville's WTP is the largest plant within the Study Area, with an operating capacity of approximately 55 million gallons. OCWA currently land applies waste sludges to

agricultural lands in the summer season (containment is provided for the sludges during the winter months).

6.5.7 Township of Tyendinaga

The **Richmond Landfill (6)** is located on Lots 1, 2, and 3, Concession 4, in the former Richmond Township (now Town of Greater Napanee). The landfill is located near the eastern border of Tyendinaga Township and has been mentioned as a concern by municipal staff. The Richmond landfill is owned and operated by Canadian Waste Services (CWS). CWS wants to increase the site capacity from 125,000 tonnes a year to 750,000 tonnes annually for the duration of a 20-year licence. If the MOE grants approval, the landfill footprint would increase from 40 acres to 250 acres. The MOE has reported that the current site is located on fractured bedrock and there is potential for contaminant migration.

6.5.8 Township of Stone Mills

The municipal survey did not indicate any known areas of contamination in Stone Mills. Potential contaminant sources are local active and former paper mills in Strathcona and Newburgh, large pig farms, salt storage facilities and pesticide fertilizer facilities in Newburgh and Tamworth.

6.5.9 Prince Edward County

The **Crowe Property (5)**, as it is commonly known, is located on Lot 71, Concession 1, in Ameliasburgh Ward. The site was used as an illegal dump for numerous buried drums of contaminated material originating from a former Good Year Tire Plant. The main contaminant of concern is TCE, which is typically used as a solvent or de-greasing agent. TCE has impacted at least 20 drinking water wells in the area. Residents impacted by the contaminated groundwater now rely on bottled water as a potable water source.

7. GROUNDWATER MANAGEMENT ISSUES AND MEASURES

7.1 Background

The previous sections in this report summarize the data and analyses completed to develop a comprehensive understanding of the groundwater resources in the Quinte area. One important goal of the study was to develop a groundwater management strategy. This final step was of particular interest for many participants, as it focuses on how to apply the regional groundwater resource information and how to protect water resources for current and future uses.

The strategy was developed with reference to and within the context of the existing regulatory and non-regulatory framework in Ontario. It builds on the extensive foundation of legislation, policies and programs already in place for water resource protection. It also recognizes that water resource protection, like many environmental issues, requires an integrated, multi-sector approach, involving partnerships and the effective coordination of resources between municipal, provincial and federal levels of government, conservation authorities, health units, and interest groups. Information provided in this section can be used as input into the future development of watershed-based source protection plans that are being proposed to be developed at the watershed level.

The Strategy consists of five elements that are briefly described below in **Section 7.2**. The groundwater resource management principles are then presented in **Section 7.3** with specific considerations for municipalities in **Section 7.4**. A summary table of groundwater management components and a summary table of groundwater issues and options/initiatives are provided in **Table 7.1 and Table 7.2** at the end of this section. **Section 7.5** summarizes how land use planners and decision makers can use keys maps provided in this study. A detailed discussion of all the elements of the Strategy is presented in **Appendix F**.

In addition to the groundwater management strategy outlined in this Section, separate planning briefs, summarizing key maps and planning strategies, have been prepared for each municipality and are provided under separate cover. Well head protection area mapping for the municipal well systems in the municipalities of Tweed, Centre Hastings (Village of

Madoc) and Peats Point Subdivision in Prince Edward County are provided under separate cover.

7.2 Overview of the Groundwater Management Strategy Elements

The groundwater management strategy is divided into the following five elements:

First Element: Groundwater Resource Management Principles

The *first element* of the Strategy consists of a set of “first principles” of groundwater resource management identified during the course of the study. They are based on the predominant issues and common themes that emerged among the various groundwater protection issues and measures discussed, and they are considered fundamental to any groundwater protection strategy, regardless of local conditions and issues.

These first principles are presented in **Section 7.3** and include:

- better enforcement of existing rules;
- coordination of activities among government and agencies;
- encourage a “living strategy” with continuous improvement;
- adopt a watershed approach with Conservation Authority leadership consistent with the proposed provincial watershed-based source protection planning framework;
- utilize planning tools for smart growth; and,
- build upon and expand a non-regulatory programs.

Second Element: Existing Regulatory and Non-Regulatory Context for Groundwater Protection in Ontario

A summary of the key laws, regulations, reports and programs was developed as the *second element* of the Strategy. A wide variety of provincial and federal laws, regulations and standards are already in place that are relevant to the management and protection of water resources in Ontario. A number of influential provincial reports have also recently been issued, including the Report of the Walkerton Inquiry and the Report of the Advisory Committee on Watershed-based Source Protection Planning. In addition, various non-

regulatory programs have been developed, such as educational programs, stewardship activities, and funding initiatives that have a key role to play in groundwater protection and management.

In developing the Groundwater Resource Management Strategy, it was recognized that this existing and emerging regulatory and non-regulatory regime provides a good basis for the wise management of water resources. Municipalities, Conservation Authorities, agricultural associations, health units and provincial departments, through effective application of the existing rules and resources, can achieve many water protection goals without “reinventing the wheel”.

Like other elements of the Strategy, the summary of the existing protection framework is intended to serve as an initial reference or “sourcebook” when dealing with specific groundwater protection issues. It will need to be revised and updated as new regulatory requirements or non-regulatory programs are introduced. The most significant update will be the proposed future development of watershed-based source water protection plans, as outlined in the recent White Paper on Watershed-based Source Protection Planning (MOE, February 2004). The summary of the existing regulatory and non-regulatory context is presented in detail in **Section 4, Appendix F** and addresses the following:

- federal programs and initiatives related to water resource management;
- provincial legislation;
- key provincial policies and reports; and,
- non-regulatory programs.

Third Element: Existing Groundwater Protection Policies in Study Area

The *third element* of the Groundwater Resource Management Strategy consists of a review of the relevant planning policies contained in the current Official Plans for the Study Area’s municipalities. Similar to the summary of the provincial context, this review is provided as background information and as a basis for policy change and improvement. The review is included in **Section 5, Appendix F**.

***Fourth Element: Model Groundwater Protection
Initiatives in Other Ontario Municipalities***

Several municipalities in Ontario have developed “model” policies and programs related to the protection of groundwater resources, including policies to protect wellhead zones, recharge or infiltration areas, and areas vulnerable to contamination. Policies to prevent contamination are also incorporated. In this *fourth element* of the Groundwater Resource Management Strategy, examples of these model policies are highlighted. This information is also included in **Section 6, Appendix F** and presents a discussion of the Oak Ridges Moraine Conservation Plan and descriptions of model policies from the following municipalities:

- County of Oxford;
- Region of Peel;
- Region of Waterloo;
- Regional Municipality of Halton; and,
- County of Brant.

Fifth Element: Groundwater Management Issues and Options

The *fifth element* of the Groundwater Resource Management Strategy outlines specific groundwater resource management measures for the Study Area. First, land uses and activities that typically could affect groundwater resources anywhere within the Study Area are described. The following land uses and activities are defined in terms of their potential to affect groundwater resources:

- water well construction, maintenance and decommissioning;
- septic tank construction and maintenance;
- underground storage tanks;
- land application and storage of nutrients;
- application of pesticides and herbicides;
- use of road salt on highways;
- spills;
- aggregate extraction and reclamation;

- intensive livestock operations (\geq 300 Nutrient Units);
- solid waste landfills;
- drainage and water withdrawal;
- stormwater retention/detention facilities;
- irrigation pits and ponds;
- groundwater mining, and,
- water use during periods of drought.

For each use or activity, examples of potential protection measures are then summarized, including:

- the Province's role, if any, in the regulation of that use or activity;
- municipal regulatory options (i.e., the regulatory "tools" that could be used by municipalities to protect groundwater in relation to the use or activity); and,
- non-regulatory initiatives that could contribute to the specific protection goals.

The additional measures needed to protect important groundwater features are then described, including measures for wellhead protection areas within the Study Area, significant recharge/infiltration areas and vulnerable aquifer areas, where groundwater is particularly susceptible to contamination from surface activities.

The groundwater management issues and associated protection measures listed above are presented in detail in **Sections 7 and 8, Appendix F** and are summarized in **Table F.1 and F.2**.

7.3 General Principles for Groundwater Resource Management

In conducting the research and consultation activities undertaken in developing the Groundwater Resource Management Strategy, a number of common threads and predominant themes have emerged among the many groundwater issues and protection measures identified. They represent the "first principles" of groundwater resource management and would be applicable in implementing any groundwater protection strategy, regardless of the local conditions and specific issues being addressed. These first principles

are considered fundamental to any other individual or specific groundwater management measures and include the following:

- Implement the Study Recommendation: A committee should be formed that provides overall direction to groundwater management and protection in the Study Area. This committee, made up of members from the conservation authorities, municipalities and other stakeholders should consider, prioritize and implement recommendations made in this report.
- Adopt a watershed approach with Conservation Authority leadership: Water resources - both surface and groundwater - are best understood, monitored, managed, protected and enhanced from a watershed ecosystem perspective. This allows comprehensive consideration of water balance, water quantity and water quality, as well as water-related natural features, terrestrial resources, aquatic life and other key ecosystem indicators. Groundwater resource management plans and activities should be undertaken within a watershed framework. The 36 Conservation Authorities in Ontario were founded on the watershed approach to resource management and, with local municipal support, they have provided leadership in water resource management for more than half a century. Their established structure and base of expertise provides a foundation for a continued leadership role in water resource management and, with appropriate funding and resources, they would be well placed to lead the development and implementation of a watershed-based approach to groundwater protection. The proposed watershed-based source protection planning legislation will require that conservation authorities have a lead role in groundwater management.
- Utilize planning tools for smart growth: The existing land use planning regime in Ontario provides both the policy direction and mechanisms for a “multiple barrier” approach to groundwater protection. The Provincial Policy Statement issued under the Planning Act promotes wisely managed growth, resulting in communities that are environmentally and economically sound, and specifically refers to the need to protect or enhance the quality and quantity of groundwater and surface waters. Municipal Official Plans, secondary plans, subwatershed plans, and stormwater management master plans can provide or contribute to overall policies for the management, wise use and protection of water resources. Zoning By-laws,

development controls, site plans and by-laws for property standards, water use and tree-cutting can play a key role at the issue or site-specific level. This can include directing growth to urban areas and rural settlement areas, to lands that are suitable for development. It would also involve implementation of servicing policies that encourage development on full or communal services, and discourage multi-lot development on individual services.

- Better enforcement of existing rules: An extensive array of laws and regulations already exist that specify requirements relevant to the protection of water resources. Additional resources for and improved enforcement of the existing regulatory requirements would be beneficial in achieving groundwater resource management goals.
- Coordination of activities among government and agencies: Various federal and provincial government departments, municipalities, Conservation Authorities and health units have responsibilities related to water resource management and protection. Improved communication and coordination of effort among these responsible parties, including working agreements, partnerships, and data and resource sharing, would result in more efficient use of available resources and greater effectiveness in management of groundwater resources. Increased co-ordination will be a key element in the watershed-based source protection planning that is being proposed by the Provincial government.
- Encourage a “living strategy” with continuous improvement: A groundwater resource management strategy will, at any point in time, be the product of the technical data available, the environmental context, and the laws and regulations in place during its development. Updates and improvements will be needed through further studies and ongoing monitoring to allow for appropriate refinements and improvements. Establishment of a regional Groundwater Strategy Implementation Committee would assist in the continuous improvement process.
- Build upon and expand non-regulatory programs: Regulation and enforcement have a role to play in providing safeguards for the environment and in ensuring the remediation of negative effects. However, non-regulatory initiatives are often more

influential in raising awareness of environmentally sound practices and behaviours, and in encouraging such practices to become part of day-to-day activities. There are many non-regulatory programs in Ontario aimed at improving practices that have the potential to impact on water resources. These include the educational programs, stewardship activities, and funding initiatives that have been or are being undertaken by conservation authorities, agricultural associations, health units and community groups, either individually or in partnership with provincial or municipal organizations. With appropriate funding and resources, these groups have the depth of experience and local knowledge needed to continue to develop and deliver these important non-regulatory components of groundwater protection and management.

7.4 Recommendations for Specific Municipalities

This section identifies specific recommendations for each of the municipalities within the Study Area, and should be considered with the general recommendations presented in the previous section. Recommendations are provided for the Conservation Authority and other organizations in **Section 7, Appendix F**.

7.4.1 The County of Hastings (and Lower Tier Municipalities) and The Municipality of Stone Mills

The existing Official Plan of the County of Hastings applies to both the upper tier municipality and the majority of lower tier municipalities in the Study Area, specifically, the Town of Bancroft, the Municipality of Centre Hastings (including former Village of Madoc), the Municipality of Hastings Highlands, the Township of Madoc, the Municipality of Tweed, and the Township of Tyendinaga. The Municipality of Stone Mills is located in the County of Lennox and Addington, which does not have an upper tier Official Plan. Development in the Municipality of Stone Mills is guided by a separate lower tier Official Plan.

Both Official Plans for the County of Hastings and the Municipality of Stone Mills have fairly comprehensive goals, objectives and policies to protect groundwater resources. All development applications are reviewed against these goals and objectives to determine impacts on groundwater resources. It is recommended that additional groundwater policies be incorporated into the plans during the next 5-year review to ensure that all new development or redevelopment has no adverse impacts on the municipality's groundwater

resources. In addition, the municipalities, including the County of Hastings, should identify and monitor known and suspected areas of potential groundwater contamination such as former landfill and industrial sites.

The Official Plan can also incorporate groundwater mapping and identify categories of land uses that should [not] be allowed, or allowed subject to additional geotechnical study. The municipalities could also initiate a septic inspection program to ensure groundwater contamination is minimized as a result of septic systems. The County of Hastings and, specifically, the Township of Tyendinaga and the Municipality of Stone Mills should also continue to monitor the Environmental Assessment program currently being undertaken for the expansion of the Napanee landfill.

7.4.2 The Village of Madoc and Village of Tweed

Wellhead protection areas (WHPA) for the village of Madoc in the Municipality of Centre Hastings and the village of Tweed in the Municipality of Tweed were identified in the study and are presented under separate cover. Typically, within the 2-year time of travel (TOT) zone, surface activities that entail the use of very hazardous materials should be precluded or restricted. Within the larger 10-year and 25-year TOT zones, policies could be less restrictive. Details on planning strategies are presented in the separate WHPA reports.

7.4.3 The City of Belleville

The existing Official Plan for the City of Belleville includes minimal policies to maintain and protect the City's groundwater resources. It is recommended that additional specific groundwater protection goals, objectives and policies be incorporated into the plan during the next 5-year review to ensure that all new development or redevelopment has no adverse impact on the City's groundwater resources. Policies could require that all major development or redevelopment projects be supported with sufficient technical information to identify any groundwater impacts and provide recommendations for appropriate mitigation measures. The Official Plan can also incorporate groundwater mapping and identify categories of land uses that should [not] be allowed, or allowed subject to additional geotechnical study. In addition, the City should continue to monitor known areas of existing and potential groundwater contamination, such as the former Bakelite industrial site, East and

West Zwicks Park, and other former industrial sites on the Belleville waterfront in conjunction with the Ministry of Environment. The City could also initiate a septic inspection program for the rural portion of the municipality to ensure groundwater contamination is minimized as a result of septic systems.

7.4.4 The Municipality of Prince Edward County

The Official Plan for the Municipality of Prince Edward County includes policies to protect environmental features in Section 1.2.1(d). It is recommended that additional groundwater policies be incorporated into the plan during the next 5-year review. Policies could require that all major development or redevelopment projects be supported with technical information that would identify any adverse impacts on the County's groundwater resources and provide recommendations with respect to appropriate mitigation measures. In addition, the County should initiate a program to identify all potential sources of groundwater contamination, such as former landfill and industrial sites. The Official Plan can also incorporate groundwater mapping and identify categories of land uses that should [not] be allowed, or allowed subject to additional geotechnical study. The County could also initiate a septic inspection program in the rural areas to ensure that groundwater contamination is minimized as a result of septic systems.

One WHPA at Peats Point Subdivision is identified in the study. The results of the WHPA modelling are presented under separate cover. Typically, within the 2-year time of travel (TOT) zone, surface activities that entail the use of hazardous materials should be precluded or restricted. Within the larger 10-year and 25-year TOT zones, policies could be less restrictive. Details on planning strategies are presented in the separate WHPA report.

7.5 Application of Mapping and Database Information provided in this Study

Numerous maps and databases on the hydrogeology, land use and aquifer vulnerability of the Study Area have been created during this study. While all maps produced in this report will have different degrees of use, depending upon the stakeholder, several data sets are anticipated to be more applicable to local land use planning. These data sets include the water table map, recharge/discharge map, aquifer vulnerability map, water quality map, well pumping rate map, and the contaminant inventory map. All the maps are produced at the

regional scale (1:600,000), with select maps (water table, groundwater recharge/discharge, well pumping rate and contaminant inventory) produced at larger scale (1:70,000 to 1:100,000). These larger scale maps are reproduced in the **Map Booklet**, following the regional maps. A description of the potential uses of these maps for local stakeholders is provided below.

Water Table Elevation Map

The water table elevation map is produced at both the regional and municipal scales. The map provides stakeholders with a tool to estimate the approximate direction of groundwater flow across their Study Area. The direction of flow is most applicable to shallow conditions (within top 30 m of the aquifer). The flow directions represent natural flow conditions. The effects of nearby pumping wells or large water withdrawals are not considered. Users of this map are cautioned that the actual direction of groundwater flow at any given property can deviate from the directions portrayed. Deviations can be caused by nearby pumping wells or drainage courses. The direction of groundwater flow can also change seasonally and with the depth of the well.

Depth to Water Map

The estimated depth to the water table is shown on municipal scale maps only. The map can be used to estimate potential groundwater recharge and discharge areas. Recharge areas are often found in locations where the depth to groundwater is great, while discharge conditions are often found in locations where the water table is near surface.

Vertical Hydraulic Gradient Potential Recharge/Discharge Map

The vertical hydraulic gradient map shows the potential groundwater recharge/discharge areas at the regional scale. It shows areas where groundwater flow is potentially upward (discharge) and areas where groundwater flow is potentially downwards (recharge). As discussed in detail in **Section 4**, this map only shows the potential gradient (or force) of vertical groundwater flow and not necessarily the actual velocity. In addition, because the bedrock aquifer is shallow and fractured, most of the Study Area can be considered as a

recharge environment, in that most bedrock wells, regardless of location, will be recharged locally by precipitation and are susceptible to contamination.

Considering the significant uncertainty associated with this map, the map is best used to identify areas of potential regional groundwater recharge or discharge. Because of the scarcity of data in the northern municipalities, the accuracy of the map is very low in the municipalities of Hastings Highlands, Carlow/Mayo, Bancroft, Tweed and Madoc. Further detailed investigations, such as chemical testing, temperature monitoring and detailed hydrogeology investigations, would be required to confirm actual recharge/discharge conditions. Nevertheless, the map can be used to flag areas of potential discharge in the more southern municipalities (Bellville, Tyendinaga, Stone Mills, Prince Edward County), such as surface water features with a large groundwater influx (baseflow) component, and areas of potential recharge that should undergo additional study.

Aquifer Vulnerability Map

The aquifer vulnerability map is produced at the regional scale only. The map shows that the aquifer beneath the entire Study Area is vulnerable to contamination as a result of the lack of regionally thick protective clays or silts. While some wells did encounter localized pockets of clay that would provide local protection of the aquifer, these pockets were sporadic and considered regionally insignificant. The map can be used by stakeholders to emphasize the importance of good land use practices and the susceptibility of the aquifer to contamination.

While the map shows widespread high aquifer vulnerability, localized deposits of clay and silt do occur. These areas (e.g., Bay of Quinte, north of Tweed, etc.) may provide some level of localized protection that was not quantified in this study. These areas are shown as clay and silt deposits on **Map 3.3** (Overburden Geology). While these areas are still highly vulnerable relative to provincial conditions, stakeholders may wish to revisit these areas and refine the vulnerability assessment so that the limited protection that these deposits do afford can be considered.

Water Quality Map

A regional natural water quality map was created based on water quality observations made by well drillers at the time of well construction. The map can be used by local stakeholders to identify areas that are prone to natural water quality problems such as sulphur, salt or mineralization. The users of these maps are cautioned that the displayed data are not based on actual chemical testing results, but rather observations made by the well drillers and entered into the MOE Water Well Record database. As such, the actual water quality at any given location can be better or worse than what is shown. In addition, the map does not indicate whether an area has been contaminated from man-made contaminants, such as bacteria, nitrates, road salt, petroleum fuels, or from chemical pollutants.

Well Pumping Rate Map

A map of the well driller's recommended pumping rate was created for each of the municipalities. These maps have not been reproduced at the regional scale. These maps can be used by stakeholders to qualitatively identify areas that are more prone to low, medium or high water yields. The user is cautioned that the data are empirical in nature only and are not based on rigorous testing. The actual well yields can vary significantly from what is shown and, therefore, the maps can only be used as a general guide.

Contaminant Inventory Map and Database

The contaminant inventory maps and database can be used by local stakeholders in the following ways:

- Input into potential land severance/subdivision decisions: The maps can be used to help decision makers determine what information is needed from proponents of severances/subdivisions to ensure that future groundwater users are not at risk. Proposed future development in areas that are downgradient (down flow) of potential contaminated areas (especially closed landfills) may warrant additional scrutiny.
- Identify possible future sources of contamination to aquifers: Potential contaminant sources, such as closed landfills, should be flagged for future investigation,

considering the risk they may pose to the aquifer. Other municipalities (e.g., Ottawa, Waterloo) have undertaken investigations of closed landfills in order to prioritize them based on environmental risk. Municipalities in the Study Area may wish to consider this action.

- Identifying areas for regional groundwater monitoring programs: Areas of high agricultural land use may be flagged for inclusion into a regional groundwater monitoring network. Monitoring wells could be installed and sampled for pesticides, bacteria and nitrates to gain an understanding of the regional implications of agricultural land uses on groundwater quality.

Other Maps

Other maps and data provided in this study will provide stakeholders with a summary of background information on the geology, hydrogeology and groundwater use in the Study Area. The data can be a source of information for future initiatives, such as determining watershed water budgets, mapping areas susceptible to drought conditions, and selecting future well locations for watershed groundwater monitoring. The maps can also be used by educators, health agencies, conservation authorities and municipalities to prepare public information briefs, displays and other educational material.

Information Database

The database and maps generated from this study can provide the framework for a groundwater source protection framework for the region. The data and maps provide information on the geology, aquifer characteristics, groundwater use, aquifer vulnerability and known/potential contaminant sources that should be included in a master database to be used for land use decision making. The database should be regularly updated as new information becomes available.

All the data provided in this report have been provided to the Study Partners in both map and database form. Maps are provided in .pdf format and, where created using Geographic Information software, are provided in ESRI SHP file format. Metadata documentation is provided with the delivery of mapping and data layers. This information can be used by the

Study Partners to reproduce the maps. Care should be taken by the users of this data to ensure that any manipulation of the scales of the maps be accompanied by a written explanation that the accuracy of the maps has not changed from that stated in the report. In addition, any interpretation of the maps that will result in land use decisions should be made with input from environmental scientists who are aware of the limitations of the data set and maps.

TABLE 7.1: GROUNDWATER MANAGEMENT COMPONENTS

Management Strategy Component	Implementation*	Schedule**
General Planning Policy	Establish a Committee to consider, prioritize and implement the recommendations of this study.	Long Term
	Create/update Official Plan policy to protect groundwater.	Short & Long Term
	Official plans and zoning by-laws should consider categorizing land uses in terms of their potential risks to groundwater resources, such as the three category ranking system (A – high risk, B - moderate risk, C – lower risk) adopted in the County of Oxford and the Region of Waterloo.	Short & Long Term
Ecological and Habitat Areas	Most of the Study Area can be mapped as having a high infiltration rate. Encourage maintaining natural cover.	Long Term
	Control new land development involving large areas of impervious surfaces such as paving. Where infiltration to groundwater is significantly restricted, encourage artificial recharge.	Long Term
	Encourage BMPs for existing commercial/industrial and agricultural land uses in these areas.	Long Term
	Control / limit development on individual services. Encourage use of alternate septic treatment systems.	Long Term
Groundwater Monitoring Network	Identify areas where additional wells should be added to the groundwater-monitoring network. Target areas would be in recharge zones and by potential point source contaminate sources and regional sources (areas of dense agriculture or industrial land usage, and areas of concentrated development on private systems)	Long Term
	Identify additional areas of existing and potential groundwater contamination. (i.e. former landfill and industrial sites). The database developed during this study can be used as a starting point.	

* Refer to Table F.1 in Appendix F for details on rationale, implementing agency and compliance

** Short Term = within 1 year; Long Term = more than 1 year

TABLE 7.1: GROUNDWATER MANAGEMENT COMPONENTS

Management Strategy Component	Implementation*	Schedule**
Data/GIS Management	Continuously update environmental and groundwater quality related database information presented in this study.	Long Term
	Municipalities should require that all wells drilled for hydrogeology studies be geo-referenced for addition to the database.	Long Term
	The MOE should update the MOE Water Well Information System so that all wells are geo-referenced.	Long Term
	Perform detailed studies at the local scale to improve the accuracy of the data provided in this report, as needed. The regional maps should be ground truthed, and updated as necessary.	Long Term
	Assess the usage of shallow dug wells in the Study Area. These wells are usually not recorded in the MOE Water Well information System, and are most susceptible to contamination.	Short Term
Community Awareness and Education	Build community links and encourage information sharing. Groups such as Federation of Ontario Naturalists, Ontario Federation of Agriculture and local Land Trusts are three examples of groups that can contribute to groundwater protection.	Short and Long Term
	Create educational workshops/events and/or attend public events (e.g. fairs) to inform students and others about groundwater (e.g. groundwater festivals).	Short and Long Term
	Municipalities should work cooperatively to develop information related to groundwater protection for homeowners, including: how to maintain a septic system and well; hazardous waste disposal; advantages to tree planting, stream stabilization; proper use of pesticides; etc.	Short and Long Term

TABLE 7.2: GROUNDWATER ISSUES AND OPTIONS/INITIATIVES

Issue	Municipal Regulatory Options/Initiatives ^{***}
Wells, Septic Systems and Development on Private Services	
Water Well Construction, Maintenance and Decommissioning	Municipalities could use their powers related to development approvals and servicing to ensure that the requirements of Regulation 903 are being followed within the municipality. Of particular concern in the area is the use of improperly constructed shore wells.
	Municipalities could require proof of proper abandonment of unused water wells, monitoring wells or boreholes as a condition of development approval (i.e. for demolition permits, applications for consent, site plan approvals and subdivision approvals). There is a danger that poor seals on unused wells could cause surface contamination to enter the aquifer.
	Municipalities could require proof of proper abandonment of unused water wells, monitoring wells or boreholes as a precondition for hook-up to a municipal water system; for hook-up of an existing hamlet this would require proof of decommissioning of all the individual wells; grants for municipal water hook-ups could include funding for well decommissioning, with provision to amortize the cost over several years.
	A deposit system could be introduced whereby a deposit is paid prior to the drilling of investigative wells or boreholes on municipal lands or for municipal projects; the deposit would be returned once proper decommissioning has occurred.
	Both the municipalities and the MOE should ensure that proper well records are filed for shore wells and shallow dug or blasted wells distances.
	Municipality could require varying separation between wells and possible contamination sources.
	Municipal inspection duties for septic systems could be extended to/coordinated with inspection of wells.
	Municipalities could request to be given the responsibility of inspecting wells under Regulation 903; for example, the Township of North Grenville in eastern Ontario has been given this role by the MOE.
Septic System Construction and Maintenance	A primary role for municipalities in minimizing septic system risks to groundwater is to use municipal planning tools, including Official Plans, zoning by-laws and development controls, to implement the “smart growth” principle noted earlier in this report. This would facilitate “doing things right in the first place” by directing growth to serviced areas or areas with optimum subsurface conditions.
	Municipalities can require both a minimum lot size and minimum lot frontage for development on individual services.
	Municipalities can require additional study prior to authorizing septic system permits or approvals to address local geology or water quality issues.

^{***} Refer to Table F.2 in Appendix F for details on provincial role and non-regulatory initiatives

TABLE 7.2: GROUNDWATER ISSUES AND OPTIONS/INITIATIVES

Issue	Municipal Regulatory Options/Initiatives***
	Municipalities should undertake impact assessments for communities on private services to determine where growth can occur on private services without causing septic -well interference.
Use and Storage of Nutrients and Chemicals	
<i>Underground Storage Tanks</i>	Municipal regulatory option would be to use municipal powers related to development approvals and servicing to ensure that the provincial requirements are being followed within the municipality.
	Municipalities could require proof of proper installation, registration, upgrading or removal of any underground storage tanks as a condition of development approval (i.e. for applications for consent, site plan approvals and subdivision approvals), or as a precondition for hook-up to a municipal water system.
<i>Land Application and Storage of Nutrients</i>	Powers under the <i>Planning Act</i> to regulate where agricultural and related activities take place, subject to provincial policy statements and the <i>Farming and Food Production Protection Act 1998</i> .
	Powers to regulate with respect to operations or activities not addressed by the regulations (e.g. smaller operations).
	It is recommended that municipalities be involved in implementation duties, such as review and approval of nutrient management plans and the maintenance of registries of nutrient management plans and strategies that are not covered by the <i>Nutrient Management Act</i> . At a minimum, municipalities should have ongoing access to this data.
<i>Application of Pesticides and Herbicides</i>	Eliminate use of pesticides for certain uses through by-laws.
	Institute requirements for all property owners who apply pesticides to complete education and testing regarding pesticide use comparable to that required of farmers.
<i>Use of Road Salt on Highways</i>	Municipalities could consider alternatives to road salting. Use of these control mechanisms to minimize road salt impacts to water supplies could provide a foundation for future management plans.
	Appropriate separation distance should be required between major salt applications areas (e.g. provincial highways) and new development, based on groundwater supply.
	In the absence of an appropriate separation distance between a development and a major salt application area, a satisfactory supporting groundwater quality study should accompany the development application.
<i>Spills</i>	Municipalities could use development approval powers to ensure that emergency response teams and protocols will be in place for any new development with the potential for chemical spills.
	Municipal response teams and protocols should be developed in conjunction with fire departments and other emergency service personnel.

TABLE 7.2: GROUNDWATER ISSUES AND OPTIONS/INITIATIVES

Issue	Municipal Regulatory Options/Initiatives ^{***}
Large Agricultural and Industrial Operations	
<i>Aggregate Extraction and Reclamation</i>	Municipalities have a role that is subsidiary to the Provincial role in that municipal zoning by-laws, growth management strategies and official plans are reviewed by the Provincial MNR in granting permits and licences.
<i>Intensive Livestock Operations</i>	Same as for “Land Application and Storage of Nutrients.”
<i>Solid Waste Landfills</i>	Require groundwater impact assessment as a condition of Official Plan amendment, zoning by-law amendment, and/or site plan approval.
Drainage and Water Taking	
<i>Field Tile Drains</i>	Current role of municipalities in construction or alteration of field tile drainage systems is to ensure that the system follows the approved design before connecting the drainage systems to the municipal drain system.
	Water from municipal drains that discharges to surface water bodies must meet the Provincial Water Quality Objectives (PWQO’s) and, as a result, the quality of the water from field drains must be considered.
<i>Stormwater Retention/Detention Facilities</i>	Land use regulations imposed by the municipality under the <i>Planning Act</i> represents a regulatory control on stormwater management issues.
	The municipality should be actively involved in conjunction with the MOE in granting permits for completing stormwater management works.
<i>Irrigation Pits and Ponds</i>	Municipalities are concerned with the implementation of irrigation systems, as they can pose environmental damage as well as damage to public and private property.
	Policies could be imposed in the future by municipalities, that would be consistent with the Best Management Practices put forth by the Provincial Government.
<i>Groundwater Mining/Well Interference</i>	No official municipal regulatory mechanisms are in place to deal directly with the issue of groundwater mining; however, the <i>Planning Act</i> gives municipalities the authority to use official plans and zoning by-laws to regulate water use. Careful land use and growth management plans are essential in curbing over consumption of groundwater (thus preventing groundwater mining).
	Well interference from proposed large water takings is assessed prior to issuing a PTTW. An assessment of well interference on neighbour properties from proposed subdivisions should also be assessed prior to approval. Considerably for potential register impacts to neighbouring wells should be considered prior to issuing of a building permit or severance consent.

TABLE 7.2: GROUNDWATER ISSUES AND OPTIONS/INITIATIVES

Issue	Municipal Regulatory Options/Initiatives***
<i>Water Use During Periods of Drought</i>	Lawn watering bans are often imposed by municipal bodies when it becomes apparent that the rate of consumption is going to exceed the capacity of the municipal system to supply water to their residents.
<i>Groundwater Resource Features: Wellhead Protection Areas, Significant Recharge Areas, ISI Areas</i>	Conventional zoning approach: control or prohibit higher-risk land uses in wellhead capture zones and sensitive groundwater resource areas.
	Performance zoning approach: Require site-specific studies for higher-risk land uses in wellhead capture zones and sensitive groundwater resource areas.
	Install sentry wells in wellhead protection areas.
	Prepare contingency plans for alternative drinking water supplies, and spill response plans.
	Purchase lands in sensitive groundwater resource areas.
Provide compensation to land owners where land use restrictions are imposed.	

8. SUMMARY

The Quinte Regional Groundwater Study was undertaken to map the region's groundwater aquifers, to assess their risk to contamination, to quantify water use, and to inventory planning strategies for the consideration of local stakeholders. The study encompassed Hastings County, Prince Edward County and the Municipality of Stone Mills. Specific emphasis was placed on the study partner municipalities of Hastings Highlands, Carlow/Mayo, Bancroft, Madoc, Tweed, Belleville, Tyendinaga, Prince Edward County and Stone Mills. Well head capture zone modeling was performed for the municipal wells at the village of Tweed, village of Madoc and the Peats Point Subdivision in Prince Edward County. The results of these analyses are presented under separate cover.

A summary of the key findings of the regional study is presented below.

Groundwater Aquifer Characteristics and Location

The predominant aquifer in the Study Area is fractured bedrock, which is the pumped aquifer in >95 % of the wells. Precambrian rock is the main aquifer north of the villages of Tweed and Madoc. Limestone is the main aquifer in Prince Edward County, Belleville, Tyendinga, and the southern portions of Tweed and Stone Mills. Groundwater flow is through fractures within these rocks. In general, the top 10 to 30 m of the bedrock is considered to be regionally unconfined as a result of fracturing near the surface. Locally, the bedrock aquifer can be confined in areas where the overlying rock is not as heavily fractured.

Overburden sand and gravel aquifers are present in some localized areas but are exploited by <5% of registered wells. These aquifers exist as isolated occurrences of sand and gravel that were deposited as glacial eskers, outwash, or till. The majority of overburden aquifers are present as drumlins in former Thurlow township and as glacial outwash deposits in Hastings Highlands, Carlow/Mayo and Bancroft.

Groundwater Flow

The direction of large-scale regional groundwater flow mimics surface water drainage patterns. In the Moira and Napanee watersheds, the regional groundwater flow is directed south to southwest. In Prince Edward County, regional groundwater flow is outwards from the plateau areas and directed to the shorelines. Beyond the Quinte watershed, in the northern municipalities of Hastings County, regional groundwater flow is to the northeast.

Local-scale groundwater flow direction at the municipal level can deviate from the regional direction, and is often highly variable, especially in areas of rugged topography such as is found on the Precambrian Shield. In the rugged areas of Hastings Highlands, Carlow/Mayo and Bancroft, groundwater flow will be directed from elevated areas to topographic depressions in valleys, lakes and marshes. Over the Study Area, the variability in the water table surface decreases to the south, as the topography becomes more subdued, resulting in a closer alignment between the direction of regional and local scale groundwater flow.

Groundwater Recharge and Surface Water Interaction

The entire Study Area can be considered as a groundwater recharge area because of the predominance of fractures within the top portions of the bedrock aquifer. Precipitation that falls on the land will rapidly infiltrate these fractures and percolate to the aquifer below. On a regional scale, some areas provide deeper recharge than others. In general, the areas of regional recharge correspond with areas that are locally elevated. For example, bedrock outcrop areas in Hastings Highlands are potential recharge zones, whereas the sand filled valleys are potential discharge zones. Similarly, in Prince Edward County, the highland areas near the town of Picton and in Sophiasburgh Ward are indicated as recharge areas; while near the shorelines, transitional or discharge conditions prevail.

Groundwater discharge occurs in topographically depressed areas such as ravines and river valleys. Some of the surface water features that have been identified as potentially having a significant baseflow component include the Salmon River, Napanee River, Moira River,

York River, and Little Mississippi River. Many of the lakes and marshes in the northern municipalities also likely have a significant baseflow component.

Aquifer Vulnerability

The majority of the Study Area has been mapped as highly vulnerable. Isolated occurrences of clay are present in some localities, but rarely attain thicknesses that would allow for significant protection of the underlying bedrock aquifer. The high vulnerability of the aquifer makes the entire Study Area susceptible to contamination. A few small areas were identified as moderately vulnerable in the municipalities of Tweed, Madoc, Hastings Highlands and Carlow/Mayo. These wells intercepted clay, silt or till layers that were of sufficient thickness to potentially provide some aquifer protection at the local scale.

Well Yields

The average reported pumping rate in the Study Area ranges from 11 L/min in Carlow/Mayo to greater than 25 L/min in Madoc. Most wells yield sufficient volumes for residential use on private services (less than 13 litre/min or 3 igpm). Average pumping rates are generally higher in the southern municipalities, where sedimentary aquifers are pumped, than in the northern municipalities where the aquifer is Precambrian rock. The highest frequencies of poor yielding wells (less than 1 igpm) are in Hastings Highland, Carlow/Mayo, Bancroft and Prince Edward County. The probability of drilling a well with acceptable yield depends upon the amount of fractures intercepted by the well. Considering that these fracture patterns are somewhat irregular. It is difficult to predict an area of good water quantity.

Natural Water Quality

The natural well water quality is generally good. Sulphur problems are restricted mainly to the sedimentary limestone aquifer, and are greatest in areas that receive water from the shaley Verulam Formation. Areas prone to sulphur water problems include Prince Edward County, Tyendinga and Belleville. The risk of encountering salty water increases with depth beyond 30 m. The fewest water quality problems are reported in the municipalities

that pump primarily from the Precambrian rock aquifer, such as Hastings Highlands, Bancroft, Carlow/Mayo, Madoc and the northern portions of Tweed and Stone Mills.

Groundwater Use

Within the Study Area, groundwater is a major source of water for domestic, commercial, and agricultural activities. The estimated groundwater use over the nine study partner municipalities is approximately 5,400,000 m³/year. The largest groundwater use by quantity is for potable water supply from individual private wells (54% of total). The second largest user by volume is for irrigation (19%), followed by livestock watering (13%). All other uses (public water supply, commercial/industrial and manufacturing) are each less than 10%.

In addition to the water use amounts above, approximately 22,400,000 m³/year has been permitted for quarry/mine dewatering or aggregate washing.

A total of 46% (or 46,100 people) of the Study Area's population rely on groundwater, of which the majority rely on private wells to supply their potable drinking water needs. Groundwater users by percentage of total population are:

Stone Mills (100%)	Carlow/May (100%)
Tyendinaga (100%)	Prince Edward County (59%)
Tweed (100%)	Town of Bancroft (38%)
Madoc (100%)	Belleville (13%)
Hastings Highlands (100%)	

Based on a simplified water budget analysis conducted for the Study Area, there is no indication of regional depletion of the aquifers as a result of over use. Localized areas of aquifer mining or interference caused by over withdrawal likely occur; however, these situations are localized and do not reflect widespread problems.

Contaminant Inventory

Locations of potential current and future environmental risks were identified through an inventory of known and potential contaminant sources. Information was collected from a number of private and government databases.

Land uses identified as the highest potential concern were abandoned landfills and auto junkyards. Landfill sites that have been active during the past 15 to 20 years are not considered to pose as high a risk to groundwater users since there have been hydrogeological studies and monitoring programs undertaken to define the extent and degree of groundwater impacts.

The risk of contamination to the aquifers from agricultural land uses was deemed to be greatest in the southern municipalities (Prince Edward County, Stone Mills and Belleville). Potential impacts are from nutrients, bacteria and pesticides. No regional scale water quality problems were identified in this study but, considering the moderate intensity of agricultural operations in the area and the high vulnerability of the aquifer, the potential for impacts does exist.

Groundwater Resource Management Strategy

A Groundwater Resource Management Strategy was developed for the Quinte Area with reference to, and within the context of, the existing regulatory and non-regulatory framework for groundwater management in Ontario. It is built on the extensive foundation of legislation, policies and programs already in place for water resource protection. The strategy also recognizes that water resource protection, like many environmental issues, requires an integrated, multi-sector approach, involving partnerships and the effective coordination of resources among municipal, provincial and federal levels of government, conservation authorities, health units and interest groups.

The strategies outlined in the Groundwater Resource Management Strategy can be used as input into future watershed-based source protection plans.

9. RECOMMENDATIONS

This section presents the major recommendations of this study. Additional recommendations specific to each of the technical studies are presented in **Table 9.1**. A summary of the specific planning recommendations is presented in **Tables 9.2** and **9.3**.

- 1) The groundwater management strategies outlined in this report (**Tables 9.2 and 9.3**) should be considered for implementation by all municipalities and Conservation Authorities that participated in this study. It is recommended that a water resource committee be established to carry out the recommendations of this report.
- 2) It is recommended that the GIS environment established for this project be used to update the data as new information becomes available. To meet this end, a long-term maintenance plan would be required to maintain the GIS system and many of the study findings in a current state in order to facilitate future updates of the groundwater management strategy. The long-term maintenance plan could involve updates to the GIS at the municipal, Conservation Authority or provincial ministry level. Partnership opportunities also exist, as data sharing between public agencies and jurisdictions has become commonplace, as agencies endeavour to maximize the use of collected data and minimize the cost of collecting the data.
- 3) Approximately half of the MOE water well records available for use in the Study Area are not geo-referenced. It is recommended that all hydrogeological maps be updated once the MOE Water Well Record database has been fully geo-referenced, so as to improve map accuracy. Field truthing should be performed to verify the accuracy of maps at key locations. Field truthing would involve identifying areas on maps where the data density is low and confirming that the extrapolated data on the maps represent actual conditions. An example would be to measure water levels in the aquifer(s) where well density is low, or measuring the thickness of the protective clay. Field truthing would either involve new field work or incorporation of data from existing reports into the database.
- 4) The interrelationship between groundwater and sensitive surface water and wetland receptors should be further investigated. The results of this study identified several regions where water bodies are suspected to have a greater than average base flow component. A detailed evaluation of potentially sensitive surface water features would require a compilation of quality and quantity information from municipal and provincial studies, and the generation of a surface water quality and quantity

- database. Further field data collection involving chemical sampling and the use of seepage meters and thermal measurements may be required in potentially sensitive areas. This database could be used by stakeholders in identifying surface water bodies that are sensitive to groundwater impacts and may require the implementation of land use controls in their catchment areas.
- 5) Accurate estimation of actual water usage through the existing PTTW records is difficult. Efforts should be made to monitor or otherwise obtain information on the actual volume of water used by the large water users so that more realistic accounting of the water demand can be completed.
 - 6) Monitoring wells should be installed in select areas to record groundwater levels and assess groundwater quality over time. The data can be collected to assess long-term trends in aquifer storage, to act as an early warning system for any aquifer over pumping, and to assess the longer-term effects of particular land uses and/or the cumulative effects of development on groundwater quality. Wells could be strategically placed in all overburden and bedrock aquifers identified in this study. Priority can be given to installing wells near communities that rely on private wells. Some of the wells that were installed through the new Provincial Groundwater Monitoring Network may meet these needs.
 - 7) Consideration should be given to updating the database of potential and known contaminated sites on a regular basis as further data become available. This should include information on the measures undertaken to mitigate or remediate the contamination. The database generated for this study is not exhaustive and will become outdated with time. The database could be expanded to include zoning information for land uses that may pose a risk to the groundwater resource. The database should also list the status of the concern so that mitigated issues are identified. This will enable prioritization of remedial efforts.

Table 9.1: Summary of Technical Recommendations

No.	Primary Category	Recommendations	Implementation
1	Aquifer Characterization	The MOE should geo-reference the remaining 50% of the wells in the Study Area. Update study maps once the MOE Water Well Record database has been fully geo-referenced. The maps could also be updated periodically as new well data are generated. Maps should be field truthed in areas where data density is low.	Conservation Authorities, MOE
2	Aquifer Characterization	Investigate the extent and significance of karstic topography as it relates to groundwater near Plainfield (City of Belleville) and south of Parks Creek in Tyendinaga. Areas of potential karstic topography should be mapped as they represent extremely high vulnerability zones from a potable groundwater source perspective.	Conservation Authorities
3	Aquifer Characterization	Conduct an assessment of the use of shallow dug wells, shore wells and sand points in the Study Area. The assessment could incorporate data from well supplier pump tests. The analysis should focus on mapping areas of good/poor yield and areas susceptible to drought conditions. These wells should be geo-referenced and entered into the MOE WWIS.	Conservation Authorities
4	Aquifer Characterization	Install monitoring wells in the northern and central portions of the Study Area to improve aquifer and hydrogeological characterization. Currently, there is little well data in these regions. Chemical and physical data from high quality investigation reports can be inputted into the database.	Conservation Authorities
5	Aquifer Characterization	Install monitoring wells in all overburden and bedrock aquifers, with priority given to installing wells near communities that rely on private wells. Where possible, multi-level monitoring wells should be installed to produce information on vertical flow.	Conservation Authorities, Municipalities
6	Recharge/Discharge	Perform detailed mapping of recharge and discharge areas by incorporating the effects of vertical hydraulic conductivity and precipitation infiltration. Isotope analyses can be done to map regional recharge and discharge areas.	Conservation Authorities
7	Recharge/Discharge	Analyse the results of the groundwater monitoring network and correlate changes in waterlevel with precipitation events. The data can be used to determine the sensitivity of the aquifer recharge to precipitation. Analysis of long-term water levels can also be used to assess whether long-term aquifer dewatering is occurring, and can quantify the effects that drought conditions have on the aquifer. Areas prone to drought effects can be mapped.	Conservation Authorities
8	Groundwater/Surface Water Interaction	The study has identified several surface water features that have the potential to receive significant baseflow. These surface water features can be further assessed using thermal and chemical measurements. Areas deemed most sensitive to baseflow may warrant a hydrogeological investigation to measure upward flow gradients and rates.	Conservation Authorities

Table 9.1: Summary of Technical Recommendations

No.	Primary Category	Recommendations	Implementation
9	Water Quality	Collect water quality data and input into a database. The information can come from environmental investigations, Health Unit data, landfill reports and MOE investigation files. The data can be used to identify areas of point and non-point source contamination.	Conservation Authorities
10	Water Quality	Design programs of post-development groundwater sampling to investigate the effects of development on groundwater quality in vulnerable aquifers and to track changes in aquifer groundwater quality with time.	Conservation Authorities, Municipalities
11	Groundwater Use	Determine actual water use by large water users so a more realistic accounting of the water demand can be determined. Information should be gathered on the fate of the extracted groundwater to determine what % is actually removed from the aquifer system.	Conservation Authorities, Municipalities, Provincial ministries
12	Groundwater Use	Update the inventory of O.Reg 170 systems as new data become available.	Conservation Authorities, Municipalities, Provincial ministries
13	Aquifer Vulnerability	Improve the aquifer vulnerability maps by incorporating hydraulic conductivity and hydraulic gradients into the analysis. Modify the aquifer vulnerability mapping methodology to consider protective aspects of localized clay accumulation in lowland areas	Conservation Authorities, Municipalities
14	Aquifer Vulnerability	Create municipality-specific large scale (finer detail) aquifer vulnerability maps. The mapping methodology should incorporate local information from geotechnical and hydrogeological investigation reports.	Municipalities
15	Aquifer Vulnerability	Update aquifer vulnerability maps as new data become available.	Municipalities
16	Contaminant Inventory	Update the MOE spills database with information concerning the current or final status of the spill.	MOE
17	Contaminant Inventory	The location of abandoned and operating mines should be mapped and data added to the Contaminant Inventory.	Conservation Authorities, Municipalities
18	Contaminant Inventory	Update the contaminant database produced in this report. Plotted data should be ground truthed to verify accuracy. Data from the contaminant inventory should be combined with the recently completed Bay of Quinte Remedial Action Plan contaminant inventory.	Government Ministries, Conservation Authorities, Municipalities
19	Agriculture	Collect information on pesticide use and groundwater contamination in areas where aquifer vulnerability is high. A network of monitoring wells should be established and analysed for pesticides with above average leaching potential or toxicity.	Conservation Authorities, Municipalities

Table 9.1: Summary of Technical Recommendations

No.	Primary Category	Recommendations	Implementation
20	Agriculture	Collect information on nitrate concentrations in groundwater by establishing a network of groundwater monitoring wells in both agricultural and non-agricultural areas. Results will provide a clearer picture of the actual contribution that agricultural activities have on nitrate levels in the groundwater.	Conservation Authorities, Municipalities
21	Agriculture	Undertake a well water sampling program across agricultural portions of the Study Area to identify any wells contaminated with bacteria in order to assess the relationship between bacterial contamination and agricultural land use.	Conservation Authorities, Municipalities

TABLE 9.2: SUMMARY OF GROUNDWATER MANAGEMENT COMPONENTS

Management Strategy Component	Implementation *	Schedule **
General Planning Policy	Establish a Committee to consider, prioritize and implement the recommendations of this study.	Long Term
	Create/update Official Plan policy to protect groundwater.	Short & Long Term
	Official plans and zoning by-laws should consider categorizing land uses in terms of their potential risks to groundwater resources, such as the three category ranking system (A – high risk, B - moderate risk, C – lower risk) adopted in the County of Oxford and the Region of Waterloo.	Short & Long Term
Ecological and Habitat Areas	Most of the Study Area can be mapped as having a high infiltration rate. Encourage maintaining natural cover.	Long Term
	Control new land development involving large areas of impervious surfaces such as paving. Where infiltration to groundwater is significantly restricted, encourage artificial recharge.	Long Term
	Encourage BMPs for existing commercial/industrial and agricultural land uses in these areas.	Long Term
	Control / limit development on individual services. Encourage use of alternate septic treatment systems.	Long Term
Groundwater Monitoring Network	Identify areas where additional wells should be added to the groundwater-monitoring network. Target areas would be in recharge zones and by potential point source contaminate sources and regional sources (areas of dense agriculture or industrial land usage, and areas of concentrated development on private systems)	Long Term

* Refer to Table F.2 in Appendix F for details on rationale, implementing agency and compliance

** Short Term = within 1 year; Long Term = more than 1 year

TABLE 9.2: SUMMARY OF GROUNDWATER MANAGEMENT COMPONENTS

Management Strategy Component	Implementation *	Schedule **
	Identify additional areas of existing and potential groundwater contamination. (i.e. former landfill and industrial sites). The database developed during this study can be used as a starting point.	
Data/GIS Management	Continuously update environmental and groundwater quality related database information presented in this study.	Long Term
	Municipalities should require that all wells drilled for hydrogeology studies be geo-referenced for addition to the database.	Long Term
	The MOE should update the MOE Water Well Information System so that all wells are geo-referenced.	Long Term
	Perform detailed studies at the local scale to improve the accuracy of the data provided in this report, as needed. The regional maps should be ground truthed, and updated as necessary.	Long Term
	Assess the usage of shallow dug wells in the Study Area. These wells are usually not recorded in the MOE Water Well information System, and are most susceptible to contamination.	Short Term
Community Awareness and Education	Build community links and encourage information sharing. Groups such as Federation of Ontario Naturalists, Ontario Federation of Agriculture and local Land Trusts are three examples of groups that can contribute to groundwater protection.	Short and Long Term
	Create educational workshops/events and/or attend public events (e.g. fairs) to inform students and others about groundwater (e.g. groundwater festivals).	Short and Long Term
	Municipalities should work cooperatively to develop information related to groundwater protection for homeowners, including: how to maintain a septic system and well; hazardous waste disposal; advantages to tree planting, stream stabilization; proper use of pesticides; etc.	Short and Long Term

TABLE 9.3: SUMMARY OF GROUNDWATER ISSUES AND OPTIONS/INITIATIVES

Issue	Municipal Regulatory Options/Initiatives ^{***}
Wells, Septic Systems and Development on Private Services	
<i>Water Well Construction, Maintenance and Decommissioning</i>	Municipalities could use their powers related to development approvals and servicing to ensure that the requirements of Regulation 903 are being followed within the municipality. Of particular concern in the area is the use of improperly constructed shore wells.
	Municipalities could require proof of proper abandonment of unused water wells, monitoring wells or boreholes as a condition of development approval (i.e. for demolition permits, applications for consent, site plan approvals and subdivision approvals). There is a danger that poor seals on unused wells could cause surface contamination to enter the aquifer.
	Municipalities could require proof of proper abandonment of unused water wells, monitoring wells or boreholes as a precondition for hook-up to a municipal water system; for hook-up of an existing hamlet this would require proof of decommissioning of all the individual wells; grants for municipal water hook-ups could include funding for well decommissioning, with provision to amortize the cost over several years.
	A deposit system could be introduced whereby a deposit is paid prior to the drilling of investigative wells or boreholes on municipal lands or for municipal projects; the deposit would be returned once proper decommissioning has occurred.
	Both the municipalities and the MOE should ensure that proper well records are filed for shore wells and shallow dug or blasted wells distances.
	Municipality could require varying separation between wells and possible contamination sources.
	Municipal inspection duties for septic systems could be extended to/coordinated with inspection of wells.
	Municipalities could request to be given the responsibility of inspecting wells under Regulation 903; for example, the Township of North Grenville in eastern Ontario has been given this role by the MOE.
<i>Septic System Construction and Maintenance</i>	A primary role for municipalities in minimizing septic system risks to groundwater is to use municipal planning tools, including Official Plans, zoning by-laws and development controls, to implement the “smart growth” principle noted earlier in this report. This would facilitate “doing things right in the first place” by directing growth to serviced areas or areas with optimum subsurface conditions.
	Municipalities can require both a minimum lot size and minimum lot frontage for development on individual services.
	Municipalities can require additional study prior to authorizing septic system permits or approvals to address local geology or water quality issues.

^{***} Refer to Table F.2 in Appendix F for details on provincial role and non-regulatory initiatives

TABLE 9.3: SUMMARY OF GROUNDWATER ISSUES AND OPTIONS/INITIATIVES

Issue	Municipal Regulatory Options/Initiatives***
	Municipalities should undertake impact assessments for communities on private services to determine where growth can occur on private services without causing septic-well interference.
Use and Storage of Nutrients and Chemicals	
Underground Storage Tanks	Municipal regulatory option would be to use municipal powers related to development approvals and servicing to ensure that the provincial requirements are being followed within the municipality.
	Municipalities could require proof of proper installation, registration, upgrading or removal of any underground storage tanks as a condition of development approval (i.e. for applications for consent, site plan approvals and subdivision approvals), or as a precondition for hook-up to a municipal water system.
Land Application and Storage of Nutrients	Powers under the <i>Planning Act</i> to regulate where agricultural and related activities take place, subject to provincial policy statements and the <i>Farming and Food Production Protection Act 1998</i> .
	Powers to regulate with respect to operations or activities not addressed by the regulations (e.g. smaller operations).
	It is recommended that municipalities be involved in implementation duties, such as review and approval of nutrient management plans and the maintenance of registries of nutrient management plans and strategies that are not covered by the <i>Nutrient Management Act</i> . At a minimum, municipalities should have ongoing access to this data.
Application of Pesticides and Herbicides	Eliminate use of pesticides for certain uses through by-laws.
	Institute requirements for all property owners who apply pesticides to complete education and testing regarding pesticide use comparable to that required of farmers.
Use of Road Salt on Highways	Municipalities could consider alternatives to road salting. Use of these control mechanisms to minimize road salt impacts to water supplies could provide a foundation for future management plans.
	Appropriate separation distance should be required between major salt applications areas (e.g. provincial highways) and new development, based on groundwater supply.
	In the absence of an appropriate separation distance between a development and a major salt application area, a satisfactory supporting groundwater quality study should accompany the development application.
Spills	Municipalities could use development approval powers to ensure that emergency response teams and protocols will be in place for any new development with the potential for chemical spills.

TABLE 9.3: SUMMARY OF GROUNDWATER ISSUES AND OPTIONS/INITIATIVES

Issue	Municipal Regulatory Options/Initiatives***
	Municipal response teams and protocols should be developed in conjunction with fire departments and other emergency service personnel.
Large Agricultural and Industrial Operations	
<i>Aggregate Extraction and Reclamation</i>	Municipalities have a role that is subsidiary to the Provincial role in that municipal zoning by-laws, growth management strategies and official plans are reviewed by the Provincial MNR in granting permits and licences.
<i>Intensive Livestock Operations</i>	Same as for “Land Application and Storage of Nutrients.”
<i>Solid Waste Landfills</i>	Require groundwater impact assessment as a condition of Official Plan amendment, zoning by-law amendment, and/or site plan approval.
Drainage and Water Taking	
<i>Field Tile Drains</i>	Current role of municipalities in construction or alteration of field tile drainage systems is to ensure that the system follows the approved design before connecting the drainage systems to the municipal drain system.
	Water from municipal drains that discharges to surface water bodies must meet the Provincial Water Quality Objectives (PWQO’s) and, as a result, the quality of the water from field drains must be considered.
<i>Stormwater Retention/Detention Facilities</i>	Land use regulations imposed by the municipality under the <i>Planning Act</i> represents a regulatory control on stormwater management issues.
	The municipality should be actively involved in conjunction with the MOE in granting permits for completing stormwater management works.
<i>Irrigation Pits and Ponds</i>	Municipalities are concerned with the implementation of irrigation systems, as they can pose environmental damage as well as damage to public and private property.
	Policies could be imposed in the future by municipalities, that would be consistent with the Best Management Practices put forth by the Provincial Government.
<i>Groundwater Mining/Well Interference</i>	No official municipal regulatory mechanisms are in place to deal directly with the issue of groundwater mining; however, the <i>Planning Act</i> gives municipalities the authority to use official plans and zoning by-laws to regulate water use. Careful land use and growth management plans are essential in curbing over consumption of groundwater (thus preventing groundwater mining).

TABLE 9.3: SUMMARY OF GROUNDWATER ISSUES AND OPTIONS/INITIATIVES

Issue	Municipal Regulatory Options/Initiatives***
	Well interference from proposed large water takings is assessed prior to issuing a PTTW. An assessment of well interference on neighbour properties from proposed subdivisions should also be assessed prior to approval. Considerably for potential register impacts to neighbouring wells should be considered prior to issuing of a building permit or severance consent.
<i>Water Use During Periods of Drought</i>	Lawn watering bans are often imposed by municipal bodies when it becomes apparent that the rate of consumption is going to exceed the capacity of the municipal system to supply water to their residents.
<i>Groundwater Resource Features: Wellhead Protection Areas, Significant Recharge Areas, ISI Areas</i>	Conventional zoning approach: control or prohibit higher-risk land uses in wellhead capture zones and sensitive groundwater resource areas.
	Performance zoning approach: Require site-specific studies for higher-risk land uses in wellhead capture zones and sensitive groundwater resource areas.
	Install sentry wells in wellhead protection areas.
	Prepare contingency plans for alternative drinking water supplies, and spill response plans.
	Purchase lands in sensitive groundwater resource areas.
Provide compensation to land owners where land use restrictions are imposed.	

10. REFERENCES

- Barnett, P.J. 1989. Quaternary Geology of the Bancroft Area, Southern Ontario; Ontario Geological Survey, Report 262, 93p. Accompanied by Map 2500, Scale 1:50,000.
- Barnett, P.J., and Leyland, J.G. 1980. Quaternary Geology of the Bancroft Area, Southern Ontario; Ontario Geological Survey, Map P. 2376. Geological Series-Preliminary Map. Scale 1:50,000, Geology 1978, 1979.
- Barry, D.J.A., Goss, M.J., Hamill, A.S., Lafrance, P., Milburn, P.H., Simard, R.R. and Zearth, B.J. 2000. Groundwater Quality. Pages 61-73 in Coote, D.R. and Gregorich, L.J. (Eds.) *The Health of our Water - toward sustainable agriculture in Canada.* Agriculture and Agri-Food Canada, Ottawa, ON. Publ. 2020/E 173pp.
- Carson, D.M., 1982, Paleozoic Geology of the Bath-Yorkshire Island Area, Southern Ontario; Ontario Geological Survey, Map P.2497, Geological Series – Preliminary Map, Scale 1:50,000. Geology 1981.
- Carson, D.M., 1981, Paleozoic Geology of the Kaladar-Tweed Area, Southern Ontario; Ontario Geological Survey, Map P.2411, Geological Series – Preliminary Map, Scale 1:50,000. Geology 1980.
- Carson, D.M., 1981, Paleozoic Geology of the Belleville-Wellington Area, Southern Ontario; Ontario Geological Survey, Map P.2412, Geological Series – Preliminary Map, Scale 1:50,000. Geology 1980.
- Carson, D.M., 1980, Paleozoic Geology of the Tichborne-Sydenham Area, Southern Ontario; Ontario Geological Survey, Map P.2413, Geological Series – Preliminary Map, Scale 1:50,000. Geology 1980.
- Carson, D.M., 1980, Paleozoic Geology of the Trenton-Consecon Area, Southern Ontario; Ontario Geological Survey, Map P.2375, Geological Series – Preliminary Map, Scale 1:50,000. Geology 1979.
- Carson, D.M., 1980, Paleozoic Geology of the Bannockburn-Campbellford Area, Southern Ontario; Ontario Geological Survey, Map P.2374, Geological Series – Preliminary Map, Scale 1:50,000. Geology 1979.

CH2M Hill, 2001, Final Report of the Eastern Ontario Water Resources Management Study (EOWRMS), by CH2MHill, 2001, and provided by Agriculture and Agri-Food Canada.

Chapman and Putnam, D.F., the Physiography of Southern Ontario, 3^d Edition, Ontario Ministry of Natural Resources, 1984, 270p.

Chin, V.I., K.T. Wang and Vallery, D.J., 1980 Water Resources of the South Nation River Basin. Water Resources Report 13 Ontario Ministry of the Environment.

Department of Planning and Development, Napanee Valley Conservation Report, 1957.

Department of Planning and Development, Moira Valley Conservation Report, 1950.

Department of Energy and Resources Management, Conservation Authorities Branch, Prince Edward Region Conservation Report 1968.

Department of Energy and Resources Management, Conservation Authorities Branch, Napanee Region Conservation Report, Salmon River Section, 1967.

Dillon, 2001, The United Counties of Leeds and Grenville Groundwater Management Study, 179 p.

District Health Units and Health Branch (City of Ottawa) lists of known and potential O.Reg 459 and O.Reg 505 wells

Finamore, P.F., and Courtney, S.J., 1982. Quaternary Geology of the Coe Hill Area, Southern Ontario: Ontario Geological Survey, Map P. 2536. Geological Series-Preliminary Map. Scale 1:50,000, Geology 1980.

Freeze, R.A, and Cherry, J.A., 1979. Groundwater. Prentice-Hall Inc. Englewood Cliffs, New Jersey, U.S.A.. 604p.

Gold, A. J., DeRagon W. R., Sullivan W.M. and Lemunyon J.L., 1990. Nitrate-Nitrogen Losses to Groundwater from Rural and Suburban Land Users, Journ. Of Soil and Water Conservation, March-April, 305-310p.

- Golder and Dillon, 2003, The Renfrew County-Rideau-Mississippi Valley Groundwater Study, 2003
- Goss, M.J., Rollins, K.S., McEwan, K., Shaw, J.R. and Lammers-Helps, H. 2001. The Management of Manure in Ontario with Respect to Water Quality. Report prepared for the Walkerton Inquiry by the University of Guelph. 272 pp.
- Goss, M.J., Barry, D.A.J. and Rudolph, D.L. 1998. Contamination in Ontario Farmstead Domestic Wells and its Association with Agriculture: I. Results from Drinking Water Wells. *Journal of Contaminant Hydrology*, 32:267-293.
- Henderson. P.J., and Kettles, I.M. 1992. Surficial Geology, Sharbot Lake, Ontario, Geological Survey of Canada, Map 1799A, Scale 1:50,000.
- Hem, J.D., 1992. Study and Interpretation of the Chemical Characteristics of Natural Water. U.S. Geological Survey. Water-Supply Paper 2254, 264p.
- Leyland. J.G. 1982. Quaternary Geology of the Wellington Area, Southern Ontario: Ontario Geological Survey, Map P. 2541. Geological Series-Preliminary Map. Scale 1:50,000, Geology 1981.
- Leyland. J.G. 1982. Quaternary Geology of the Belleville Area, Southern Ontario: Ontario Geological Survey, Map P. 2540. Geological Series-Preliminary Map. Scale 1:50,000, Geology 1981.
- Leyland. J.G., and Mihychuk. M. 1984. Quaternary Geology of the Trenton-Consecon Area, Southern Ontario: Ontario Geological Survey, Map P. 2586. Geological Series-Preliminary Map. Scale 1:50,000, Geology 1980.
- Leyland. J.G., and Mihychuk, M, 1984. Quaternary Geology of the Campbellford Area, Southern Ontario: Ontario Geological Survey, Map P. 2532. Geological Series-Preliminary Map. Scale 1:50,000, Geology 1980.
- Leyland. J.G., and Mihychuk, M, 1983. Quaternary Geology of the Tweed Area, Southern Ontario: Ontario Geological Survey, Map P. 2615. Geological Series-Preliminary Map. Scale 1:50,000, Geology 1981.

- Leyland, J.G., and Russell, T.S., 1984. Quaternary Geology of the Sydenham Area, Southern Ontario: Ontario Geological Survey, Map P. 2587. Geological Series-Preliminary Map. Scale 1:50,000, Geology 1982.
- Leyland, J.G., and Russell, T.S. 1983. Quaternary Geology of the Bath-Yorkshire Island Area, Southern Ontario: Ontario Geological Survey, Map P. 2588. Geological Series-Preliminary Map. Scale 1:50,000, Geology 1982.
- MacDonald, K.B. and Gleig, D.B. 1996. Indicator of Risk of Water Contamination: Nitrogen Component. Progress Report (Ontario), Agri-Environmental Indicators Project, Agriculture and Agri-Food Canada, Guelph, ON. 39 pp.
- Mazor, E., 1991. Applied Chemical and Isotopic Groundwater Hydrology. Open University Press Buchingham, England, 274p.
- New Brunswick Department of Agriculture, Fisheries and Aquaculture. 1997. Manure Management Guidelines; <http://www.gnb.ca/0173/10/0173010002-e.asp>.
- Ontario Geological Survey, 2003., Surficial Geology of Southern Ontario, Ontario Geological Survey Miscellaneous Release-Data 128, CD pack, Scale 1:50,000.
- Ontario Geological Survey, 2003., Bedrock Geology of Ontario, Ontario Geological Survey Miscellaneous Release-Data 126, 1:250,000 scale, CD pack.
- Ontario Ministry of the Environment, 2002, Permit To Take Water Database, updated as of January, 2003.
- Ontario Ministry of the Environment, 2001, A Kit for Water Works Owners, Ontario Regulation 505/01”.
- Ontario Ministry of the Environment, list of approved water works.
- Ontario Ministry of the Environment, list of Ontario Regulation 459 systems.
- Ontario Ministry of the Environment and Energy, 2002; Groundwater Studies, 2001/2002, Technical Terms of Reference with Database Field References, March 2002”.

- Ontario Ministry of the Environment and Energy, 2002 ; Groundwater Studies, 2001/2002, Clarification for TOR sections 2.2.2 and 2.2.3 – GwIS calculation. July 12, 2002.
- Ontario Ministry of the Environment, “Ontario Drinking Water Standards”. August 2000.
- Ontario Ministry of the Environment, “Wells – R.R.O. 1990, Reg. 905.
- Ontario Ministry of Natural Resources, 2002, undated letter from Scott Christilaw to MVCA.
- Ontario Ministry of Natural Resources. Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2. 1992. R.M. Easton, Chapter 19, *The Grenville Province and the Proterozoic History of Central and Southern Ontario*.
- Ontario Ministry of Natural Resources. 1983., Structure Top Trenton Group (P2629), Structure Top Black River Group, Isopach Trenton Group (P2640), Isopach Black River Group (P2647), various maps, 1:250,000 scale, Petroleum Resources Section, 1983.
- Ontario Ministry of Natural Resources, Oil and Gas Library, Various Oil and Gas well logs, Hastings County, Lennox and Addington County, Northumberland County and Prince Edward County.
- Ostrey, R.C., and Singer, S.N., 1981. The Hydrogeology of the IFYGL Moira River, Wilton Creek and Thousand Islands Study Areas, Ministry of the Environment, Water Resources Branch, Water Resources Report 5e.
- Rob de Loe, 2002, Agricultural Water Use in Ontario by Watershed: Estimates for 2001, Report prepared for the Ontario Ministry of Natural Resources, August 15, 2002, 14p.
- Robertson W.D., and Cherry, J.A., 1991. Subsurface Behaviour of Nitrogen at a Large-Flux Septic System on an Unconfined Sand Aquifer, *Int. J. of Applied Hydrogeology*
- Russell, H.A.J., Brennand, T.A., Logan, C., and Sharpe, D.R., 1998, Standardization and assessment of geological descriptions from water well records: Greater Toronto and Oak Ridges Moraine Areas, southern Ontario, Current Research 1998-E: Ottawa, Geological Survey of Canada, p. 89-102.

Sharpe, D.R., 1979, Quaternary geology of the Merrickville area; Ontario Geological Survey, Report 180, 54 p.

Sibul, U., Goff, K., and Choo-Ying., A.V., 1974., Water Resources of the Moira River Drainage Basin, Ontario Ministry of the Environment, Water Quantity Management Branch, 1974.

Statistics Canada, 2001 federal population statistics.

Thurston, P.C., Williams, H.R., Sutcliffe, R.H., and Stott, G.M., 1992, Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1 and 2, 1992.

Water and Earth Science Associates, 1985, Preliminary Hydrogeological Investigation of Prince Edward County, March, 1985.

Watt, W.E., Gorman, W.A., Ambrose, J.W., 1973, Groundwater Resources of Prince Edward County. Queen's University, April, 1973.

Wilhelm, S.R., 1991. The Geochemical Evolution of Domestic Wastewater in Septic Systems, University of Waterloo, M.Sc. Thesis.

10.1 Glossary

Advection — The process by which dissolved chemicals are transported by flowing groundwater.

Alkalinity — Refers to the extent to which water or soil contains soluble mineral salts, and its ability to neutralize acids. Waters with a pH greater than 7.4 are considered alkaline. Alkalinity of natural waters is due primarily to the presence of hydroxides, bicarbonates, carbonates.

Alluvial — Referring to soil or earth material that has been deposited by running water, as in a riverbed, flood plain, or delta.

Alluvial Fan — A fan-shaped deposit of generally coarse material created where a stream flows out onto a gentle plain; a geomorphologic feature characterized by a cone or fan-shaped deposit of clay, silt sand, gravel, and boulders that have been eroded from mountain slopes, transported by flood flows, and deposited on the valley floor.

Alluvial Plain — A level or gently sloping tract or a slightly undulating land surface produced by extensive deposition of alluvium, usually adjacent to a river that periodically overflows its banks; it may be situated on a flood plain, a delta, or an alluvial fan.

Anisotropy — The condition of having different properties in different directions; the condition under which one or more of the hydraulic properties of an aquifer vary according to the direction of the flow.

Annual Runoff — The total quantity of water in runoff for a drainage area for the year.

Anthropogenic — Involving the impact of man on nature; induced, caused, or altered by the presence and activities of man, as in water and air pollution.

Aquifer — An underground layer of porous rock, sand, or gravel containing large amounts of water. Use of the term is usually restricted to those water-bearing structures capable of yielding water in sufficient quantity to constitute a usable supply.

Aquifer, Confined — An aquifer that is bounded above and below by formations of impermeable or relatively impermeable material. An aquifer in which groundwater is under pressure significantly greater than atmospheric and its upper limit is the bottom of a bed of distinctly lower hydraulic conductivity than that of the aquifer itself.

Aquifer, Fractured Bedrock — An aquifer composed of solid rock, but where most water flows through cracks and fractures in the rock instead of through pore spaces. Flow through fractured rock is typically relatively fast.

Aquifer, Leaky (Semi-Confined) — An aquifer overlaid and/or underlaid by a thin semipervious layer through which flow into or out of the aquifer can take place.

Aquifer, Perched — A groundwater unit, generally of moderate dimensions, that occurs whenever a groundwater body is separated from the main groundwater supply by a relatively impermeable stratum and by unsaturated conditions above the main water aquifer.

Aquifer, Unconfined — An aquifer where the upper boundary is the water table and no overlying saturated confining unit is present.

Aquitard — A saturated but poorly permeable bed that impedes groundwater movement and does not yield water freely to wells, but which may transmit appreciable water to or from adjacent aquifers and, where sufficiently thick, may constitute an important ground-water storage unit.

Arable Land — Land capable of being cultivated and suitable for the production of crops.

Artesian Aquifer — A commonly used expression, generally synonymous with (but a generally less favoured term than) confined aquifer. An artesian aquifer is an aquifer that is bounded above and below by formations of impermeable or relatively impermeable material. An aquifer in which groundwater is under pressure significantly greater than atmospheric and its upper limit is the bottom of a bed of distinctly lower hydraulic conductivity than that of the aquifer itself.

Artesian Pressure — The pressure under which artesian water in an artesian aquifer is subjected, generally significantly greater than atmospheric.

Artesian Well — A well tapping a confined or artesian aquifer in which the static water level stands above the top of the aquifer. The term is sometimes used to include all wells tapping confined water. Wells with water levels above the unconfined water table are said to have positive artesian head (pressure) and those with water level below the unconfined water table, negative artesian head. If the water level in an artesian well stands above the land surface, the well is a flowing artesian well. If the water level in the well stands above the water table, it indicates that the artesian water can and probably does discharge to the unconfined water body.

Attenuation — The process of diminishing contaminant concentrations in groundwater, due to filtration, biodegradation, dilution, sorption, volatilization, and other processes.

Basin — A geographic area drained by a single major stream; consists of a drainage system comprised of streams and often natural or man-made lakes. Also referred to as drainage basin, watershed, or hydrographic region.

Braided Stream — A stream that divides into a network of channels branching and reuniting, separated by islands.

Discharge — The flow of surface water in a stream or the flow of groundwater from a spring, ditch, or flowing artesian well.

Discharge Area — An area in which groundwater is discharged to the land surface, surface water, or atmosphere; an area in which there are upward components of hydraulic head in the aquifer. Groundwater is flowing toward the surface in a discharge area and may escape as a spring, seep, or base flow, or by evaporation and transpiration.

Dispersion — The change in concentration of chemicals within the aquifer as a result of mechanical mixing and molecular diffusion. Dispersion causes dilution and spreading of dissolved chemicals within the aquifer

Downgradient — The direction that groundwater flows; similar to “downstream” for surface water flows.

Drawdown — The lowering of the elevation of the groundwater table, usually from pumping wells, but can occur naturally during periods of prolonged drought. At the well, it is the vertical distance between the static and the pumping level.

Eolian — Pertaining to the wind; especially said of rocks, soils, and deposits (such as loess, dune sand, sand from volcanic tuffs) whose constituents were transported (blown) and laid down by atmospheric currents, or of landforms produced or eroded by the wind, or of sedimentary structures (such as ripple marks) made by the wind, or of geologic processes (such as erosion and deposition) accomplished by the wind.

Ephemeral (Stream) — A stream that flows only in direct response to precipitation and thus discontinues its flow during dry seasons. Such flow is usually of short duration.

Evaporation — The physical process by which a liquid (or a solid) is transformed to the gaseous state.

Evapotranspiration (ET) — The process by which plants take in water through their roots and then give it off through the leaves as a by-product of respiration; the loss of water to the atmosphere from the earth’s surface by evaporation and by transpiration through plants.

Fluvial — Of or pertaining to rivers and streams; growing or living in streams or ponds; produced by the action of a river, stream or flood flow, as in a fluvial plain.

Glacial — Characterized or dominated by the existence of glaciers.

Glacial Outwash — Stratified material, chiefly sand and gravel deposited by meltwater streams in front of the margin of a glacier.

Glacial Till — Till is the mixture of rocks, boulders, and soil picked up by a moving glacier and carried along the path of the ice advance. The glacier deposits this till along its path — on the sides of the ice sheet, at the toe of the glacier when it recedes, and across valley floors when the ice sheet melts. These till deposits can be good sources of groundwater if they do not contain significant amounts of impermeable clays.

Glaciofluvial Deposits — Material moved by glaciers and subsequently sorted and deposited by streams flowing from the melting ice. The deposits are stratified and may occur in the form of outwash plains, deltas, kames, eskers, and kame terraces.

Glaciolacustrine — Pertaining to or characterized by glacial and lacustrine processes or conditions; applied especially to deposits made in lakes.

Groundwater — Water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper level of the saturate zone is called the water table.

Groundwater Divide — A line on a water table on either side of which the water table slopes downward. It is analogous to a drainage divide between two drainage basins on a land surface. It is also the line of highest hydraulic head in the water table or the potentiometric surface.

Groundwater Flow — The movement of water through openings in sediment and rock that occurs in the zone of saturation.

Groundwater Flow Model — A digital computer model that calculates a hydraulic head field for the modeling domain using numerical methods to arrive at an approximate solution to the differential equation of groundwater flow.

Groundwater Recharge — The infiltration of water into the earth. It may increase the total amount of water stored underground or only replenish the groundwater supply depleted through pumping or natural discharge.

Hydraulic Conductivity — A coefficient describing the rate at which water can move through an aquifer or other permeable medium.

Hydraulic Gradient — The gradient or slope of a water table or piezometric surface in the direction of the greatest slope.

Hydraulic Head — The height of the free surface of a body of water above a given point beneath the surface.

Hydrologic Cycle — The circuit of water movement from the atmosphere to the earth and return to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transportation. Also referred to as the water cycle and hydrogeologic cycle.

Infiltration — The flow of fluid into a substance through pores or small openings. The word is commonly used to denote the flow of water into soil.

Interflow — Runoff due to that part of the precipitation that infiltrates the surface soil (but not to the water table) and moves laterally through the upper soil horizons toward stream channels. The interflow is included in direct runoff.

Karst — Limestone and dolomite areas with topography peculiar to and dependent on underground solution and the diversion of surface waters to underground routes. Characteristic of an area of irregular limestone in which erosion has produced fissures, sinkholes, underground streams, and caverns.

Outwash — A deposit of sand and gravel formed by streams of meltwater flowing from a glacier and laid down in stratified deposits.

Perched Water Table — The top of the zone of saturation that bottoms on an impermeable horizon above the level of the general water table in the area. Is generally near the surface and frequently supplies a hillside spring.

Porosity — Most generally, porosity is the property of containing openings or interstices. In rock or soil, it is the ratio (usually expressed as a percentage) of the volume of openings in the material to the bulk volume of the material.

Potentiometric Surface — A surface that represents the static head of groundwater in tightly cased wells that tap a water-bearing rock unit (i.e., aquifer). In relation to an aquifer, the potentiometric surface is defined by the levels to which water will rise in tightly cased wells. The water table is a particular potentiometric surface for an unconfined aquifer.

Recharge Area -- The land area over which precipitation infiltrates soil and percolates downward to replenish an aquifer.

Runoff — That portion of precipitation that is not intercepted by vegetation, absorbed by the land surface or evaporated, and thus flows overland into depressions, streams, lakes or the ocean (runoff called “immediate subsurface runoff” also takes place in the upper layers of the soil).

Saturated Thickness (Aquifer) — The thickness of the portion of the aquifer in which all pores or voids are filled with water. In a Confined Aquifer, this is generally the aquifer thickness. In an Unconfined Aquifer, this is the distance between the water table and the base of the aquifer.

Saturated Zone — The part of a water-bearing layer of rock or soil in which all spaces, large or small, are filled with water.

Specific Yield (of an Aquifer) — The volume of water that can be pumped from an aquifer per unit drawdown in the watertable.

Specific Capacity (of a Well) – The productivity of a well expressed as the volume of water that can be pumped per unit drawdown in the well.

Spring (Water) — A concentrated discharge of groundwater coming out at the surface as flowing water; a place where the water table crops out at the surface of the ground and where water flows out more or less continuously.

Static Water Level — The elevation or level of the water table in a well when the pump is not operating.

Transmissivity — A measurement of the intrinsic ability of a geological unit or layer to transmit water in the horizontal direction. It is calculated by multiplying the hydraulic conductivity of an aquifer with its thickness.

Unsaturated Zone — The portion of the soil profile that contains both air and water. Water in this zone cannot enter a well.