AquaResource
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BARRIE TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

APPENDIX A: CONCEPTUAL UNDERSTANDING MEMORANDUM (COMPANION REPORT)

AquaResource
A Division of Matrix Solutions Inc.

TIER THREE WATER BUDGET AND
LOCAL AREA RISK ASSESSMENT
CONCEPTUAL UNDERSTANDING MEMORANDUM

Report Prepared for:

LAKE SIMCOE REGION CONSERVATION AUTHORITY

Prepared by:

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July 2013
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AQUARESOURCE
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MATRIX SOLUTIONS INC.

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1.0 INTRODUCTION

The Province of Ontario introduced the Clean Water Act (Bill 43) (Ontario Ministry of Environment 2006) to ensure that every Ontarian has access to safe drinking water. Under the requirements of Bill 43, communities are required to create and carry out a Source Protection Plan to protect the sources of their municipal drinking water supplies. As part of their Source Protection Plans, communities will inventory the existing and potential threats to the quality and quantity of their water sources, and begin to implement the actions necessary to reduce or eliminate the greatest of those threats.

Linking the Source Protection Plans with the inventory of water quality and water quantity threats, the Ministry of Environment released the Technical Rules: Assessment Report (Ontario Ministry of Environment 2009) that describes the technical work required by municipalities to inventory the threats posed on their water supplies. The quantity aspects are assessed using a tiered water budget framework that is briefly summarized below;

- Complete a Tier One Water Budget and Subwatershed Stress Assessment to identify subwatersheds that have a moderate or significant potential for stress,

- Complete a Tier Two Water Budget and Subwatershed Stress Assessment to confirm the stress classification for the subwatersheds classified in the Tier One Stress Assessment as having a moderate or significant potential for stress, and

- Conduct a Tier Three Water Budget and Local Area Risk Assessment for any municipal water supply systems present within subwatersheds classified as having a moderate or significant potential for stress in the Tier Two Assessment. As part this assessment, delineate water quantity vulnerable areas for the drinking water systems, estimate the water quantity risk associated with these areas, and identify moderate or significant drinking water threats within these areas.

1.1 South Georgian Bay-Lake Simcoe (SGBLS) Source Protection Region Water Budget Studies

For the purposes of Source Water Protection Planning, the Lake Simcoe Basin, Nottawasaga River, Severn Sound and Black River watersheds were combined to form the South Georgian Bay-Lake Simcoe (SGBLS) Source Protection Region. The Source Protection Region is administered by the Lake Simcoe Region Conservation Authority (LSRCA), the Nottawasaga Valley Conservation Authority (NVCA), the Severn Sound Environmental Association (SSEA) and the Black-Severn River municipalities, with LSRCA as the lead managing authority. The SGBLS Source Protection Region, which extends from the Oak Ridges Moraine in the south to the Canadian Shield and Georgian Bay in the north, has developed the required materials for their Technical Assessment report, as per the Clean Water Act.

A number of studies have been completed within the SGBLS Source Protection Region in support of the Clean Water Act. These include vulnerable area delineation, threat identification/classification, and subwatershed-based water budgets. As outlined above in Section 1.0, the Clean Water Act (2006) requires the completion of a Water Quantity Stress Assessment to determine potential hydrologic stress at the subwatershed scale. The objective of the Water Quantity Stress Assessment is to evaluate the sustainability of municipal water supplies from a water quantity perspective. The potential stress is estimated using the Percent Water Demand calculation, which compares the consumptive water demands to the available water supply for each subwatershed. As outlined above, the Stress Assessment is a three-tiered process whereby subwatersheds identified as having a higher Percent Water Demand are studied in greater detail than those that have a lower Percent Water Demand.

With the completion of a Tier One Water Budget and Stress Assessment in the Nottawasaga Valley, Severn Sound and Lakes Simcoe Region Watersheds (LSRCA, 2009a, 2009b, 2009c), and one for the Black-Severn Watershed (Earthfx, 2010a), the SGBLS Source Protection Region proceeded with a Tier Two Water Budget and Stress Assessment in 2008/2009. For the Tier Two Water Budget and Stress Assessment, the SGBLS Source Protection Region was divided into two separate study areas; namely, the South Georgian Bay - West Lake Simcoe Study Area and the East Lake Simcoe - Black-Severn River Study Area. The following text focuses on the South-Georgian Bay – West Lake Simcoe (SGBWLS) Tier 2 Study as the City of Barrie lies within that study area.

The methodology followed in the SGBWLS Tier Two Water Budget and Stress Assessment was consistent with the Technical Rules prepared by the Ministry of Environment (MOE 2009) for the preparation of Assessment Reports under the Clean Water Act. In addition, the Province (MOE 2006) developed the Provincial Guidance Module 7 Water Budget and Water Quantity Risk Assessment (Guidance Document) which provides further instruction on how to complete a subwatershed stress assessment. As outlined in the Guidance Document, the stress assessment determines the potential for stress in each subwatershed by using the Percent Water Demand calculations and the established stress thresholds for both surface water and groundwater. As the Tier One Stress Assessment for the SGBWLS determined only municipal systems using groundwater sources to be potentially stressed, the Tier Two Stress Assessment was only carried out for groundwater, not surface water.

The SGBWLS Tier Two Stress Assessment (Golder and AquaResource 2010) was completed using a set of water budget tools including a regional numerical groundwater flow model and a pair of concurrently developed surface water models. The developed surface water models provided recharge estimates to the groundwater flow model required to complete the stress assessment, while the groundwater flow model provided the interbasin transfers to the surface water model to complete an iterative approach to the overall modelling of the water budget system. To complete the stress assessment for existing, planned and future conditions, significant efforts were undertaken to quantify and characterize the consumptive water demand. An uncertainty assessment was also performed and a drought conditions assessment was completed to identify any municipal well that might be adversely impacted by naturally occurring reduced water levels for any subwatershed not identified as potentially stressed under existing, planned or future conditions.

The results of the Tier Two Stress Assessment classified the Midland Area subwatershed as having a moderate potential for stress and the Barrie Creeks subwatershed as having a significant potential for stress. The municipal systems within these two subwatersheds are required under the Clean Water Act to undergo a more detailed study within a Tier Three Water Quantity Risk Assessment to characterize the risk associated with sustaining groundwater pumping within these urban well fields. Whereas the Tier Two Stress Assessment was focused on the subwatershed scale and evaluated the total consumptive water demand and water supply for the subwatershed, Tier Three Local Area Water Budget and Risk Assessments are focused on the area where competing water uses may impact the water level at a municipal well/intake. For groundwater wells, this area includes the lands contributing water to the wells as well as sensitive features near the wells. The methodology followed for this analysis is consistent with the Technical Rules prepared by the Ministry of Environment (MOE 2009) for the preparation of Assessment Reports under the Clean Water Act and the *Guidance Document*

*(MOE2006)***.** The relevant section in the Technical Rules (MOE 2009) can be found in *Part IX – Local Area Risk Level and in Section 5 of the Guidance Document (MOE 2006).*

As part of the Tier Three analysis, characterization is being initially undertaken for municipal systems within the Barrie Creeks subwatershed. As part of the Tier Three Water Budget and Local Area Risk Assessment, both a surface water model and a groundwater model will be used for the local areas, drawing upon the vast amount of data and experience acquired to date. This document outlines the hydrogeologic and hydrological conceptual understanding of the Barrie Study Area, and also the steps undertaken in refining the characterization in the well field areas in preparation for the Barrie Water Quantity Risk Assessment. While the municipal systems for the Cities of Midland and Penetanguishene were also identified as requiring Tier Three analyses, study of those areas has been deferred and will be completed as a separate study.

1.2 Project Team

The Project Team is directed by a technical team comprised of staff from the Lake Simcoe Region Conservation Authority (LSRCA), the Nottawasaga Valley Conversation Authority (NVCA), the City of Barrie, the Ontario Ministry of Natural Resources (MNR), and the Ontario Ministry of the Environment (MOE).

The Consultant Project Team responsible for the completion of the Tier Three Assessment included several representatives from the following consulting companies;

- AquaResource, a Division of Matrix Solutions Inc. (Primary Consultant);
- Golder Associates Ltd.; and
- International Water Consultants (IWC) Ltd.

1.3 Purpose and Scope of Work

The purpose of the study is to conduct a Tier Three Water Quantity Risk Assessment in accordance with provincial guidance (Ontario Ministry of Environment 2006). The Tier Three includes the following components:

- Complete a three-dimensional conceptual geologic / hydrogeologic model;
- Develop a three-dimensional groundwater flow model of the Study Area;
- Develop a surface water model;
- Incorporate local knowledge of the area into the model and risk criteria;
- Identify Local Area Risks; and
- Develop a water budget and Tier Three Local Area Risk Assessment.

As listed above, the development of a regional groundwater model to complete water budget calculations is instrumental in the completion of the Tier Three Assessment. This report covers the conceptualization work done in preparation for the above applications. The scope of work for the conceptualization portion of the study consists of the following key components:

Background Review and Initial Data Gap Assessment: The first stage of this study involved a general review of background information and an initial data gap assessment. References were compiled and reviewed. New field data (recent drilling by the Ontario Geological Survey (OGS) and the City of Barrie, as well as monitoring well installations and pumping test programs) have improved the current understanding of local geology and regional hydrogeology. Well construction data, as well as historical pumping and water levels were compiled.

Data Compilation: This study included updates to the Simcoe Study database (and therefore the Barrie Tier Three database which links to it) to include more recent borehole data including those drilled in Kempenfelt Bay, which were obtained during investigations for a new surface water supply. Information for all included boreholes including well construction, geophysical testing, water level monitoring, municipal pumping and borehole geology was compiled in the database. Multilevel water levels, as well as historical and transient pumping and related water level data from the pumping wells were also added to the database.

Hydrogeological Characterization and Conceptual Model Refinement**:** Based on the compilation of existing data and the new data collected as part of this study, the hydrogeological conceptual model surfaces of the municipal aquifer system were revised as part of this study. Conceptual model surfaces were developed based on geologic picks made at higher quality boreholes, with efforts focused on including new data, as well as local refinement around the areas of interest. An analysis of municipal pumping and water level data was completed and key aquifer tests summarized. A characterization of the groundwater flow system is provided including discussion of groundwater flow directions, vertical gradients, aquifer parameters and flow producing zones.

These components will also be discussed, from a characterization framework, within this interim memorandum. The information provided herein is intended to communicate our understanding with the peer review members and study team such that data gaps can be identified and potentially filled with any previously unknown data sources, experience or knowledge. The goal of this effort is to ensure that all of the correct information is being applied toward developing realistic numerical tools for the Tier Three scenario assessment and risk evaluation.

1.4 Previous and Concurrent studies

1.4.1 Report References – Electronic Library

Numerous local and regional groundwater studies have been carried out within the vicinity of this Study Area. This Conceptual Understanding Report was drafted in a consultation with this wealth of pre-existing geologic, hydrogeologic and hydrologic reports which have been completed at various scales in various portions of the area. Over 170 publications that were scanned or collected are stored in a Tier Three Web Portal for the Project Team to query, download and review. These references are listed in Appendix A1 and were reviewed for this conceptual understanding study. In many cases, information such as well completion information, well field history, hydrogeological properties and hydrological information, amongst others, were extracted and compiled for inclusion in this report. Map 1.2 shows the locations where reports exist and are considered relevant to this study. These reports have been indexed with a unique key and organized such that they can be accessed by the Project Team, Peer Review Team and City staff; they represent a significant repository of data regarding the surface and subsurface conditions within the area.

1.4.2 Key Water Resources and Modelling Studies

In addition to the knowledge gained from local well field and other studies mentioned in Section 1.4.1, data, knowledge and understanding gained through other groundwater modelling studies on a regional scale have also been incorporated into the current work in order to achieve continuity in geological interpretation and properties, where possible. Because these studies represent at large portion of the data obtained for this study and serve as a foundation for the characterization of the Study Area, they are described below.

- ***South Simcoe Groundwater Study*** (Golder 2004). This study, completed as part of the provincial groundwater protection studies, provided a large-scale overview of pertinent conceptual features before focusing on municipal wellhead protection area (WHPA) delineation and groundwater vulnerability assessments.

- ***South Georgian Bay-Lake Simcoe Watershed Preliminary Conceptual Water Budget Report*** (SGBLS 2007). This report provides a detailed review of available data and knowledge regarding the surface and groundwater flow systems as well as water use.

- ***Lake Simcoe Watershed, Nottawasaga Valley Watershed, and Severn Sound Watershed Tier One Water Budget and Water Quantity Stress Assessment Reports*** (SGBLS, 2009; EarthFx, 2010a). These reports provide the preliminary Water Quantity Stress Assessment for the Study Area.

- ***South Georgian Bay - West Lake Simcoe Hydrostratigraphic Model Report*** (Golder and AquaResource 2009). This report documents the regional hydrostratigraphic surfaces throughout the entire watershed-scale study area.

- ***South Georgian Bay - West Lake Simcoe Tier Two Water Budget and Water Quantity Stress Assessment Report*** (Golder and AquaResource 2010). This report documents the Tier Two Water Quantity Stress Assessment for the study area.

1.5 Report Organization

As described above, this report focuses on the characterization and conceptual model development components of the Tier Three Assessment.

The report is organized into seven sections including this introduction (Section 1.0).

- **Section 2.0: Study Area Background** – describes the physical features of the study area, including topography, surface water features, as well as the geologic setting, which contains descriptions of bedrock and Quaternary overburden deposits.
- **Section 3.0: Groundwater Demands** - is a compilation of the municipal and non-municipal permitted and non-permitted water takers within the Study Area.
- **Section 4.0: Hydrogeological Characterization** - provides discussion of the groundwater level monitoring undertaken within the Study Area, as well as water level mapping, hydrogeological characterization and conceptual model refinement.
- **Section 5.0: Hydrological Characterization** - provides discussion of the hydrological characterization and the selection of a surface water model.
- **Section 6.0: Summary and Next Steps** – provides a summary of the report and outlines the next steps in the overall study, including a preview of the construction groundwater model.
- **Section 7.0**: **References**

Appendices A1 through A7 include background review information compiled throughout the conceptual understanding study (Appendix A1); detailed well construction data (Appendix A2); municipal pumping and water level hydrographs, as well as supporting tables for consumptive water use estimates (Appendix A3); regional and local cross sections developed for the hydrogeologic surface refinement (Appendix A4); conceptual model surface elevation and isopach (thickness) mapping (Appendix A5); streamflow monitoring gauge summaries (Appendix A6), and Site Photographs (Appendix A7).

2.0 STUDY AREA BACKGROUND

This section provides a general overview of the Study Area, including the boundary, topography, drainage, climate, land use, surface water features, ecologically sensitive areas, physiography, and bedrock and quaternary geology.

2.1 Study Area Boundary

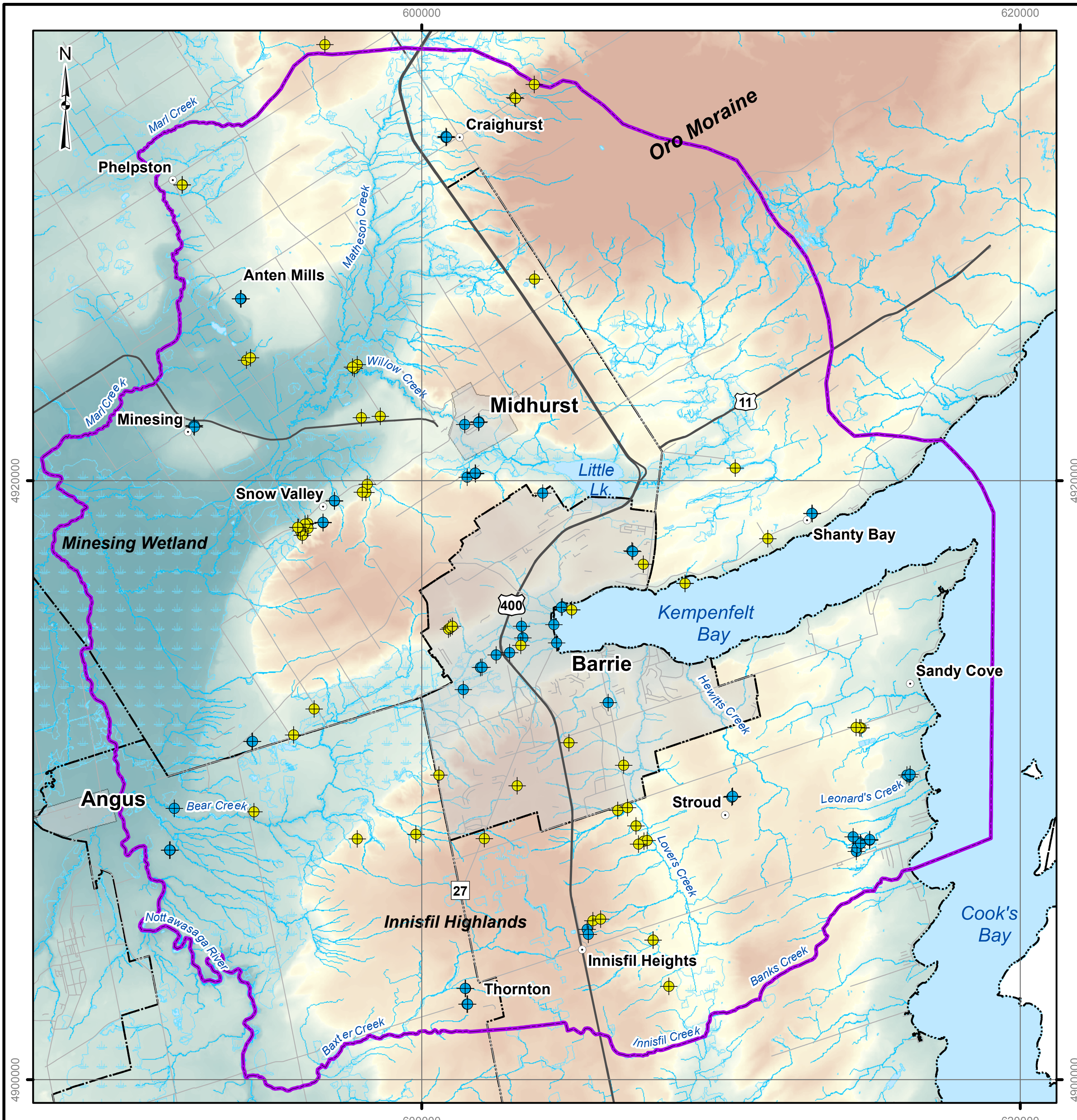
The City of Barrie is located at the western end of Kempenfelt Bay of Lake Simcoe, in the center of the Study Area (Map 1.1). The current (2010) population is approximately 135,000 persons (City of Barrie Planning Services), almost all of whom are serviced by the municipal water supply. The municipal water supply has traditionally been based on groundwater supplies; however, a surface water source has been added (Aug 2011) to service the City of Barrie on the south shore of Kempenfelt Bay (Lake Simcoe). The majority of the water supply wells lie with the Barrie Creeks subwatershed, which was identified in the Tier Two Water Budget and Stress Assessment (Golder and AquaResource 2010) as having a significant potential for stress; and therefore the municipal system is required to undergo a more rigorous Tier Three analysis.

The Study Area boundary was delineated for the Tier Three analysis to contain the urban well fields within the City of Barrie, as well as the municipal systems in Midhurst, Innisfil Heights and Stroud (given their proximity to the City of Barrie). This boundary encompasses the modelled capture zones of these well fields, and further extends to the natural surface water and groundwater subwatershed boundaries, as determined by equipotential and surface water feature maps. The complete Study Area covers an area of 800 km^2 and occupies both the Nottawasaga Valley watershed and the Lake Simcoe watershed within Simcoe County; however the primary focus of the characterization study is on the City of Barrie and the immediate surrounding area. The Focus Area, which centers on the City of Barrie well field, is presented on Map 1.1.

2.2 Topography and Drainage

The City of Barrie is located within the Simcoe Lowlands physiographic region, as defined by Chapman and Putman (1984). The Simcoe Lowlands are subdivided into two physiographic areas: the Nottawasaga Basin (Nottawasaga Valley Watershed) and the Simcoe Basin (Lake Simcoe Watershed). The Simcoe Basin is located in the lowlands surrounding Lake Simcoe including the area of the City; the Nottawasaga Basin includes the lands drained by the Nottawasaga River (Map 2.1).

Regionally, ground surface elevation in the Study Area reaches a high of 375 metres above sea level (masl) in the north east along the Oro Moraine, a high of 300 masl in the Innisfil Heights area in the south, and a low of 180 masl within the Minesing Wetlands/Nottawasaga River complex. In contrast, the elevation of Kempenfelt Bay (Lake Simcoe) is approximately 220 masl. Topography in the Study Area is influenced by the present-day stream network, as well as the drainage network from the last glaciation



LEGEND

- Towns/Villages
- Private Permits
- Municipal Water Supply
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary

REFERENCES
Base Data - NVCA, 2009
Produced using information provided by the Ministry of Natural Resources, Copyright © Queen's Printer, 2010.
Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 07-Jun-2012; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

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Map 1.1

Study Area

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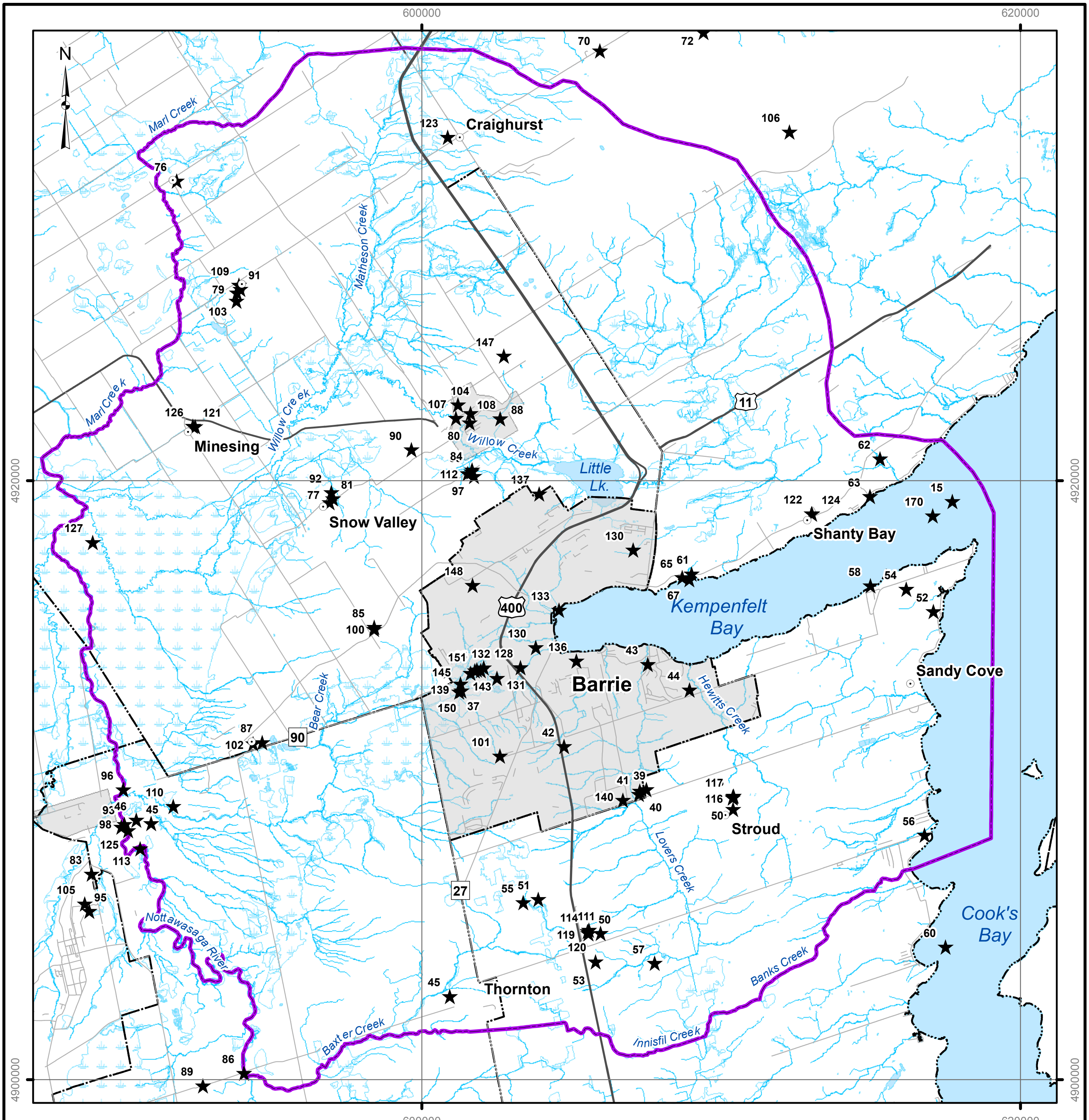
Project: 2010007 BarrieTier3



Index Map

LEGEND

- Towns/Villages
- Project References
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary

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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 07-Jun-2012; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

Map 1.2

References By Location

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Project: 2010007 BarrieTier3

(Wisconsinan) which ended in this area approximately 14,000 years ago. The main surface water drainage systems include Willow Creek, which includes Little Lake to the north of Barrie, Matheson Creek to the north of Midhurst and the Nottawasaga River. All of these are within the Nottawasaga drainage basin. The Nottawasaga River forms a topographic depression along the Western boundary of the Study area. The Nottawasaga River valley was blocked by the Edenvale Moraine during the recession of the Wisconsinan ice, which backed up surface water outflow in the Nottawasaga River valley and resulted in the formation of the Minesing Wetlands.

Land elevations within the City of Barrie range from a high of 305 masl at Highway 400 and Mapleview Drive in the south, and Ferndale Drive and Livingstone Street in the north, to a low of approximately 220 masl at the shore of Kempenfelt Bay. Drainage within the immediate Barrie area is primarily through small streams, some of which have been channelized, leading to Kempenfelt Bay, including Dyment and Jacob Creeks from the west and Lovers and Hotchkiss Creeks from the south. Bear Creek drains westward from Barrie to the Nottawasaga River drainage basin.

A prominent topographic feature is a southwest-northeast trending valley through the City core. Within this valley, there are numerous small wetland complexes; most notably is the Bear Creek Wetland within the City of Barrie.

2.3 Climate

The climate within the Study Area is characterized by moderate winters, warm summers, and a long growing season with usually reliable precipitation and is influenced by the proximity to Georgian Bay and Lake Simcoe. The variations in topography, proximity to large water bodies and prevailing winds, lead to local differences in climate. This is evident by the variability in mean annual precipitation at five meteorological stations (Map 2.1) across the Study Area in Figure 2.1. The mean annual precipitation varies from approximately 820 mm/year at Cookstown to approximately 920 mm/year at Barrie. The City of Barrie lies within the Georgian Bay climatic region as defined by Brown et al. (1980). Much of the surface water catchment area and interpreted regional recharge zone of the municipal water supply aquifer is located in the Lake Simcoe and Kawartha Lakes climatic region.

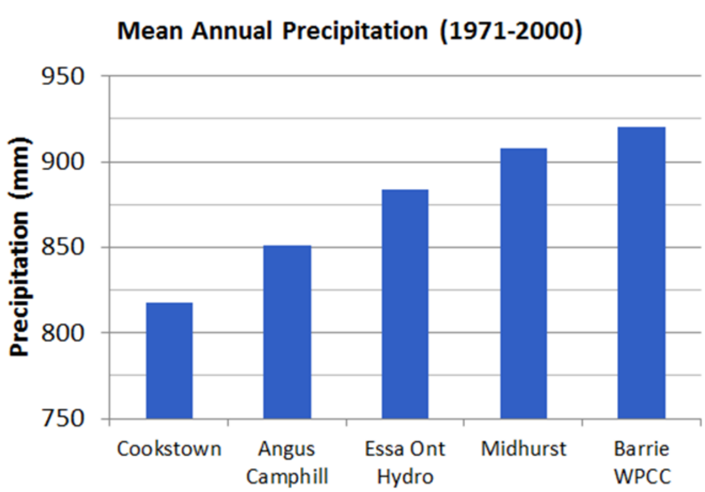
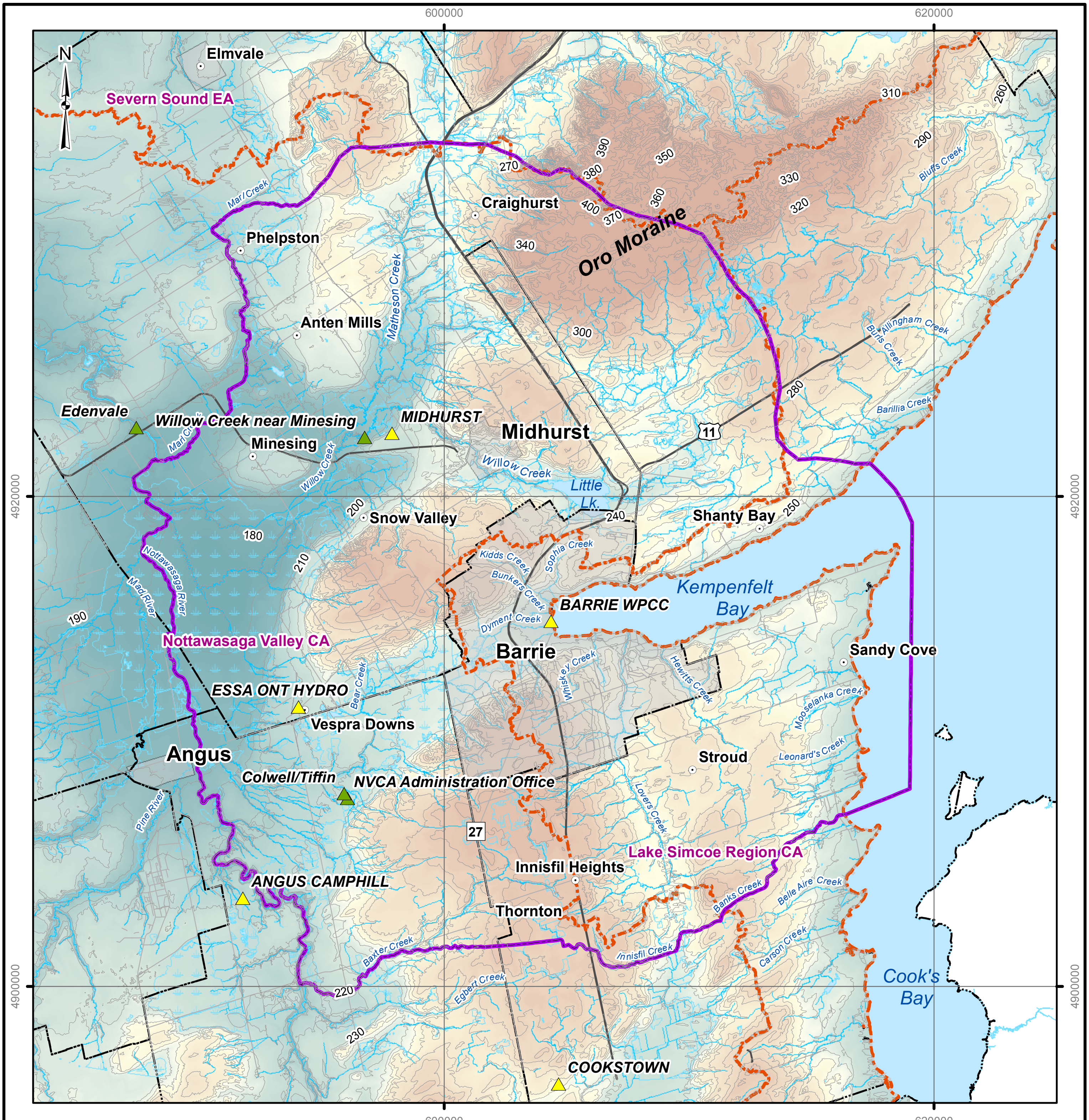


FIGURE 2.1 Mean Annual Precipitation for Five Meteorological Stations in the Study Area (Land Information Ontario 2008)



LEGEND

- Towns/Villages
- Environment Caanada Climate Stations
- NVCA Climate Stations
- Ground Surface Contours - Interval 10m
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Watershed Boundary
- Urban Centres
- Township Boundary

Ground Surface Elevation (m)

High : 411.797

Low : 173.093

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Map 2.1

Topography, Drainage and Climate Stations

REFERENCES

Base Data - NVCA, 2009; DEM - LSRCA, 2010

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Projection: UTM Zone 17N, NAD 83

Map Version: 1; Map Date: 07-Jun-2012; Created By: ccurry

Scale 1:220,000

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Kilometres

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Project: 2010007 BarrieTier3

Continuous in-filled climatic data are available for five Environment Canada meteorological stations within or near the Study Area (Map 2.1) (Land Information Ontario 2008). They consist of Cookstown to the south, Angus Camphill to the South, Essa Ont Hydro to the west, Midhurst to the northwest, and Barrie WPCC (Water Pollution Control Centre) in the centre. These climate stations have complete data records required for surface water modelling. They are summarized in Table 2.1. Barrie WPCC station has the highest average annual precipitation (920 mm/year) and Cookstown station has the lowest (820 mm/year).

TABLE 2.1 Summary of Climate Normals (1971 to 2000) for the Study Area

Station Name	AES Station Number	Elevation (masl)	Mean Annual Temperature (°C)			Mean Annual Precipitation		
			Avg.	Min.	Max.	Rainfall (mm)	Snowfall (cm)	Total (mm)
Angus Camphill	6110275	212	6.2	0.4	12.1	636	215	851
Barrie WPCC	6110557	221	6.7	1.7	11.7	683	237	921
Cookstown	6111859	244	6.3	1.1	11.4	657	161	818
Essa Ont Hydro	6112340	216	6.6	1.5	11.8	670	213	884
Midhurst	6115099	226	6.6	1.3	11.9	687	222	908

The seasonal variation in climate within the Study Area is typical of southern Ontario, with winter precipitation consisting mainly of snowfall and summer of rainfall. The mean monthly precipitation as snow and rain is shown in Figure 2.2 for the Barrie climate station and in Figure 2.3 for the Cookstown climate station. Evidently, Barrie receives more winter snowfall due to lake effects than Cookstown.

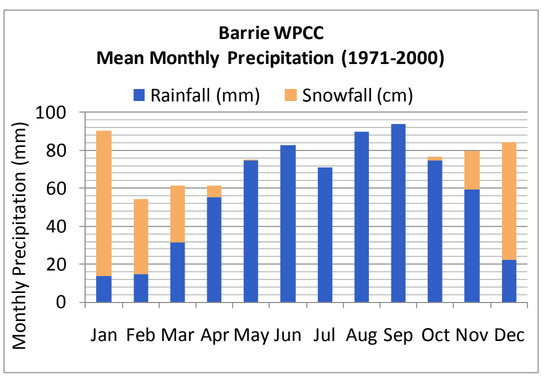


FIGURE 2.2 Mean Monthly Precipitation as Snowfall and Rainfall for Barrie WPCC Station

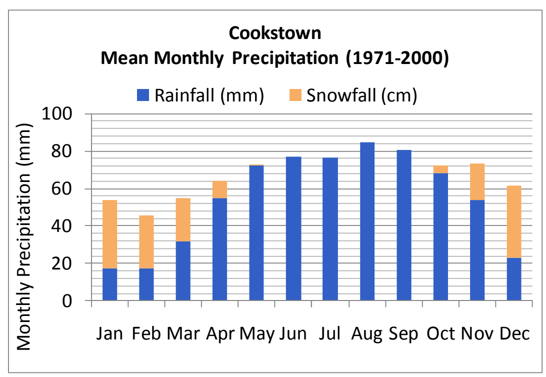
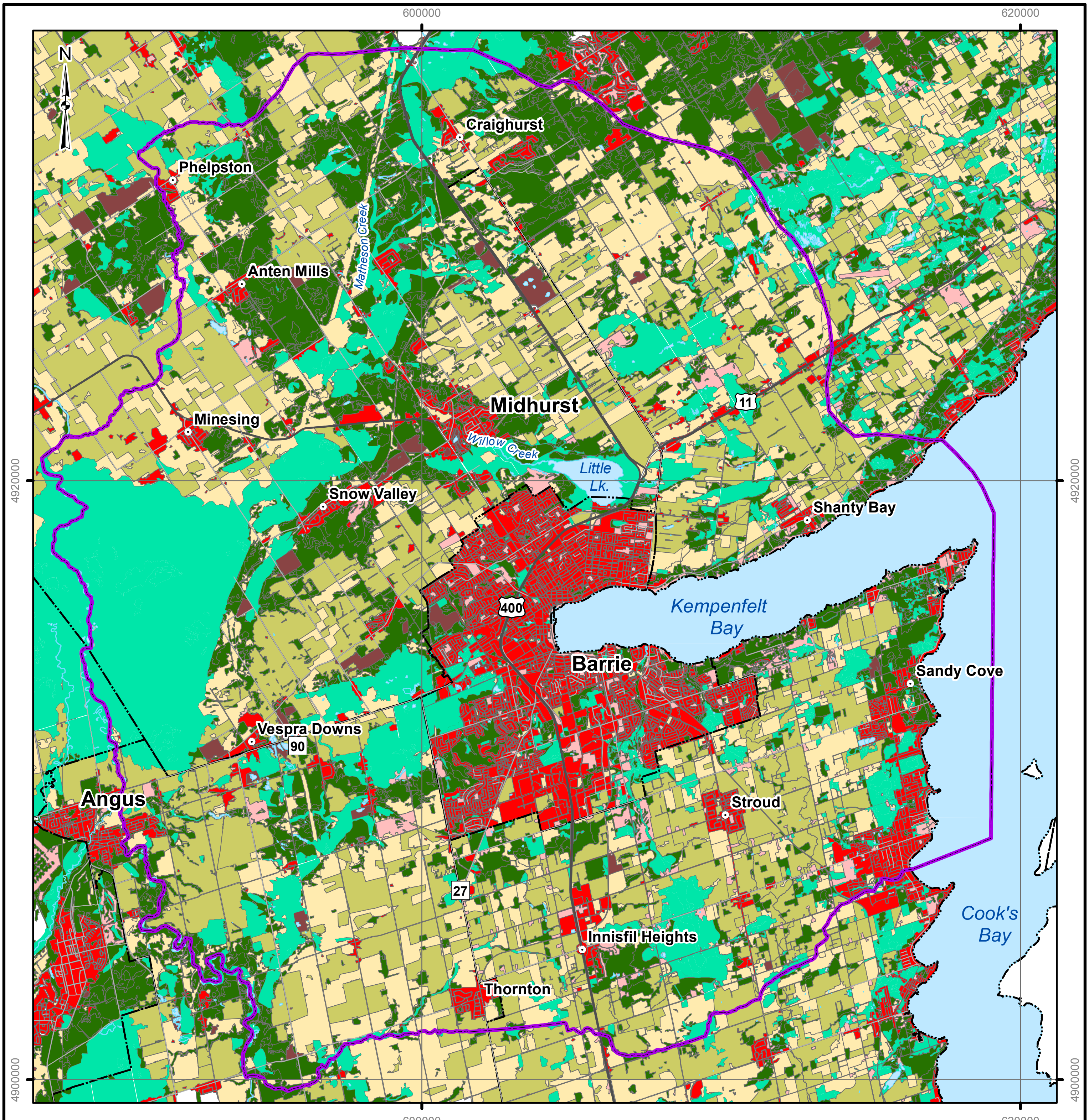


FIGURE 2.3 Mean Monthly Precipitation as Snowfall and Rainfall for Cookstown Station

Also included on Map 2.1 are climate stations operated by the NVCA. These include the snow survey station at Colwell/Tiffin and rainfall and temperature stations at The NVCA administration office and at Midhurst.

2.4 Land Use

The land use within the Study Area includes a mix of agriculture, forest and built up areas (residential/commercial/industrial) as shown in Map 2.2. The largest built up urban areas include the City of Barrie at the centre of the Study Area, Midhurst located directly north of Barrie, and Stroud and



LEGEND

- Towns/Villages
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Township Boundary

Current Landuse

- Water
- Low Intensity Developed
- High Intensity Developed
- Hay / Pasture
- Row Crop
- Coniferous Woodland
- Woody Wetland
- Quarries

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IWC
International Water Consultants Ltd.

Map 2.2

Present Landuse

REFERENCES
Base Data - NVCA, 2009; Landuse - LSRCA and NVCA, 2010
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Innisfil located in the south. The second largest urban area within the study boundary is Alcona, in the southeast of the Study Area. The town of Angus is also partially within the Study Area in the west. The surrounding smaller towns, villages and hamlets include Snow Valley, Vespra Downs, Minesing, Craighurst, Anten Mills, Shanty Bay, and Thornton. Most of these small urban areas are surrounded by a rural setting consisting mainly of agricultural land use.

In general, the land use outside of the built up areas is either agricultural or wetland. Agricultural lands are predominately consisting of row crops and pastures. In addition to the Minesing Wetlands, other woody wetlands are prominent throughout this area and are often surrounded with coniferous woodlands. These woodlands, especially in the north of Barrie, are connected by fragmented wooded areas associated with stream valley corridors and designated greenspace. The wetland areas associated with them are therefore valley bottom lands and poorly drained areas adjacent to the highlands. Numerous aggregate extraction sites in the north and various golf courses in the south are also situated throughout the Study Area.

Economic development is an important issue to many communities within the Study Area. Under the political current system, economic development and land use planning is largely the responsibility of City, Township and County governments. The plans identify the land use designations to be allowed into the future. Future land use within the Study Area is shown in Map 2.3. The future land use mapping was provided by the Lake Simcoe Region Conservation Authority (LSRCA) for both the Nottawasaga River watershed and the Lake Simcoe watershed. The future land use data were created in 2005-2006 for an assimilative capacity study (Greenland 2006) and represents the future land use according the committed future growth specified in the Official Plans for each municipality (i.e., approved development plans).

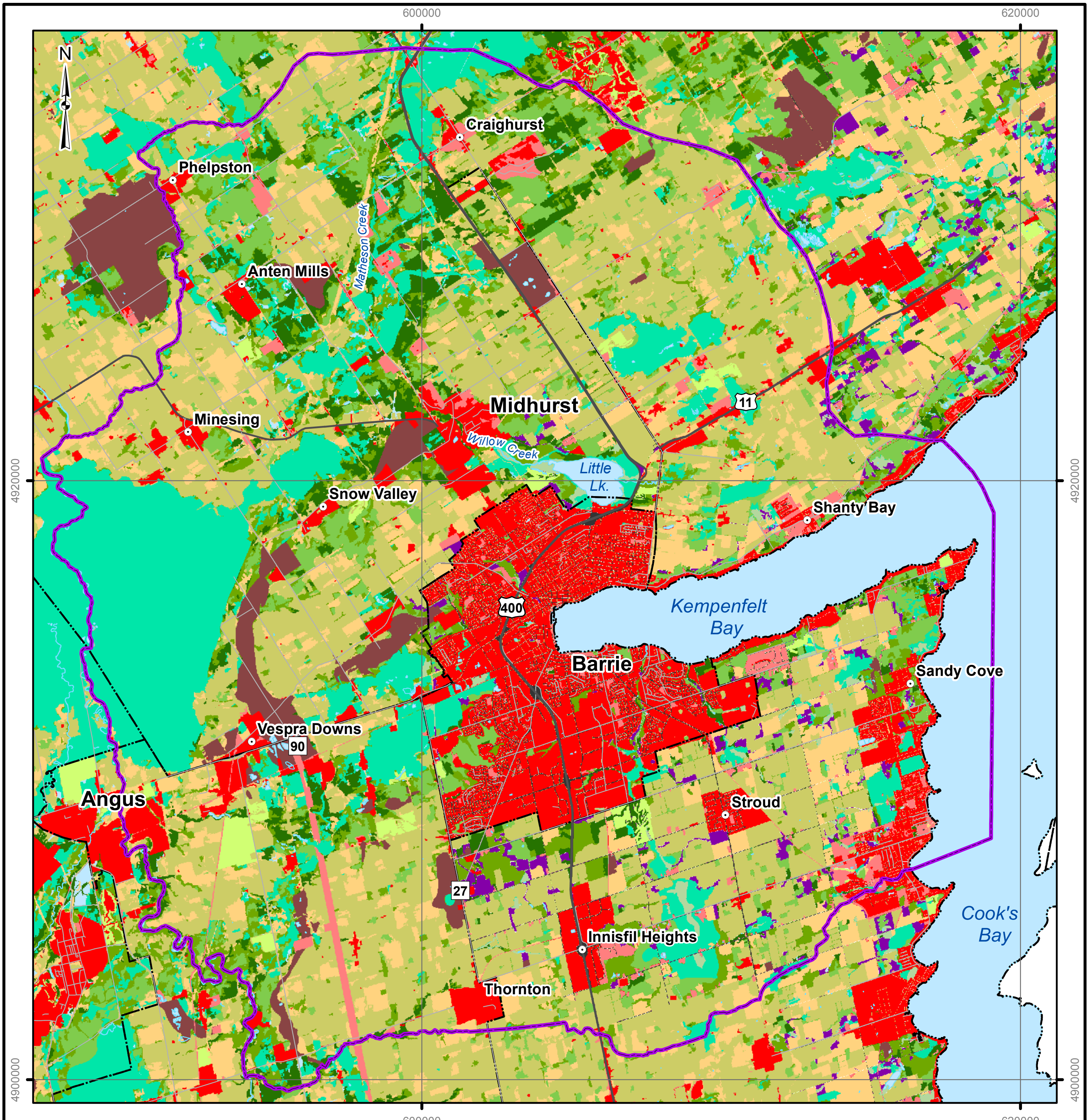
2.5 Surface Water

2.5.1 <u>Overview</u>

The Study Area lies south of Georgian Bay and immediately west of Lake Simcoe, encompassing Kempenfelt Bay. The Study Area is within two major watersheds: the Nottawasaga River watershed and the Lake Simcoe watershed, as seen on Map 2.4. The Nottawasaga River drains an area of approximately 3,100 km^2. It originates above the Niagara Escarpment at an elevation of approximately 490 masl and has a total change in elevation of 310 m to its outlet into Georgian Bay, with an average gradient of 2.6 m/km (www.nvca.on.ca). The Lake Simcoe watershed is 3,300 km^2, with the Lake covering approximately 20% of the total area.

Approximately 70% of the Study Area is within the Nottawasaga River watershed. The remaining 30% of the Study Area is within the Lake Simcoe watershed. The Study Area was delineated to include known natural drainage boundaries and therefore is coincident with several subwatershed boundaries. The subwatersheds within the Study Area are listed in Table 2.2. Willow Creek is a major tributary of the Minesing Wetlands and the Nottawasaga River, which discharges to Georgian Bay. In the southeast quadrant of the Study Area, the Barrie Creeks, South Oro, Lover’s Creek, Innisfil Creeks and Hewitt’s Creek subwatersheds all discharge to Lake Simcoe by numerous small streams. The major streams in the Study Area are described below within their respective subwatersheds. Many of the streams in the Study Area are classified as cold water streams as shown on Map 2.4. Map 2.1 shows stream names.

There are very few inland lakes in the Study Area; Little Lake is 2.3 km^2 on the northern border of the City of Barrie. It is situated along Willow Creek and is surrounded by a provincially significant wetland, as



LEGEND

- Towns/Villages
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Township Boundary

Future Landuse

- Water
- Low Intensity Developed
- High Intensity Developed
- Hay / Pasture
- Row Crop
- Coniferous Woodland
- Mixed Woodland
- Deciduous Woodland
- Woody Wetland
- Emergent Wetland
- Quarries
- Transitional
- Sod Farm / Golf Course
- Road

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Map 2.3

Future Landuse

REFERENCES

Base Data - NVCA, 2009; Future Landuse - LSRCA and NVCA, 2010
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Project: 2010007 BarrieTier3

LEGEND

- Towns/Villages
- Warm Water Streams
- Cool Water Streams
- Cold Water Streams
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Subwatersheds
- Urban Centres
- Township Boundary

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Map 2.4

Surface Water Hydrology

REFERENCES
Base Data - NVCA, 2009; Thermal Regime - NVCA 2009, LSRCA 2010.
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Project: 2010007 BarrieTier3

discussed in below. Aside from receiving inflows from Willow Creek, the lake is within a topographic depression, and as such, receives water primarily through groundwater discharge from adjacent slopes. There are several wetland features within the Study Area. The Minesing Wetland Complex is a major surface water feature which lies along the path of the Nottawasaga River; approximately 85% of the river basin drains through this wetland. It is also known to be underlain by upward gradients from the underlying aquifer units, as evidenced by flowing artesian conditions encountered in deep wells that have been drilled along the margin with the Oro Moraine adjacent to the wetland. It is the largest undisturbed wetland in southern Ontario and one of the largest and most diverse in Canada (Friends of Minesing 2010). Wetlands are discussed in further detail in Section 2.5.4.

2.5.2 Kempenfelt Bay

The most significant surface water feature in the Study Area is Kempenfelt Bay, a 14.5 km long bay that extends in a south-westerly direction from Lake Simcoe (see Map 2.4). A number of mapping studies have been conducted throughout Lake Simcoe to better understand the lake bathymetry as well as the lake-bottom sediments and structures (Canadian Hydrographic Service, 1957; Todd and Lewis, 1993; Todd et al., 2008; Boyce et al. 2002; Boyce and Pozza 2004). Based on these studies, Kempenfelt Bay has an average depth of approximately 20 m (a maximum depth of 42 m south of Shanty Bay), and is underlain by a series of strata. The Bay itself is thought to have been carved through glacial processes consistent with tunnel-channel erosion. The base of the overburden deposits beneath Kempenfelt Bay are considered to be comprised of coarse-grained sand and gravels and to be an extension of tunnel-channel deposits associated along the Barrie-Borden corridor (Golder 2004). Overlying those coarse grained deposits, the floor of the Bay is thought to be primarily comprised of finer-grained silt and clay deposits with a highly variable thickness. Where it is thin, there is enhanced potential for interaction between the deep aquifer deposits associated with the tunnel channel and the Bay. Recent mapping suggest areas where such interaction may occur (e.g., groundwater seeps) (Slattery 2009).

2.5.3 Streams and Creeks

TABLE 2.2 Subwatersheds within the Study Area

Major Watershed	Subwatershed	Area (km^2)	% in Study Area	Tier 1 Stress	Tier2 Stress	Streams	Municipal Systems
LAKE SIMCOE	Barrie Creeks	37.5	100%	Yes	Yes	Hotchkiss Creek Dyment's Creek Whiskey Creek Bunker's Creek Kidd's Creek Sophia Creek	Barrie Wells 3A, 4 (to be replaced by 4A), 5, 7, 11, 12, 14, 15, 17, 18
	Hewitts Creek	17.5	100%	Yes	No	Hewitt's Creek	Stroud
	Innisfil Creeks	55.3	52%	No	No	Sandy Cove Creek Bank's Creek Mooselanka Creek Leonard's Creek Bon Secour Creek	Alcona
	Lovers Creek	59.9	100%	Yes	No	Lover's Creek	Innisfil Heights
	Oro Creeks South	11.6	20%	No	No	Shanty Bay Creek Orolea Creek Pemberton Creek	Shanty Bay

Major Watershed	Subwatershed	Area (km^2)	% in Study Area	Tier 1 Stress	Tier2 Stress	Streams	Municipal Systems
NOTTAWASAGA	Middle Nottawasaga	141.7	48%	Yes	No	Baxter Creek Bear Creek	Angus Thornton Barrie Well 19
	Willow Creek	306.5	99%	No	No	Willow Creek Matheson Creek	Midhurst Craighurst Snow Valley Barrie Wells 9, 13 and 16
	Lower Nottawasaga	92	20%	No	No	Nottawasaga River Bear Creek	Vespra Downs Minesing Anten Mills
	Innisfil Creek	12	2%	Yes	No	Innisfil Creek	N/A

2.5.3.1 *Lake Simcoe – Barrie Creeks Subwatershed*

The Barrie Creeks Subwatershed (38 km^2) is comprised of a series of small streams and creeks that drain the central portion of the City of Barrie. These creeks include Whiskey Creek on the south end of the City; Hotchkiss Creek, Dyment's Creek, Bunker's Creek, Kidd's Creek in the City centre; and Sophia Creek in the north end of the City. Whiskey Creek is in close proximity to Well 10, which is being decommissioned. Kidd's Creek is in close proximity to Wells 4 and 15. Dyment's Creek originates near the Sandy Hollow Landfill and is in close proximity to Well 3. Hotchkiss Creek is in close proximity to Well 6 and 12. Wells 17, 7, 5, and 12 are situated between Hotchkiss and Dyment's Creek. Within the City core, some watercourse have been either piped or conveyed in channels to the outlet at Kempenfelt Bay. These include Kidd's Creek, Sophia Creek and Hotchkiss Creek.
(http://www.barrie.ca/CDocs/2010/CLR-100419.pdf)

The majority of the creeks in this subwatershed are coldwater streams, with the exception of Sophia Creek, which is a warmwater stream along its entirety, and Bunkers and Dyment's Creek, which transition from coldwater to warmwater east of Highway 400 until their discharge at Kempenfelt Bay.

2.5.3.2 *Lake Simcoe – Hewitts Creek Subwatershed*

Hewitts Creek Subwatershed is the smallest subwatershed (18 km^2) in the Study Area and drains the south east portion of the City of Barrie. It originates near Innisfil Beach road and flows north to discharge into Kempenfelt Bay. The subwatershed is located within a low lying area, comprised mainly of drumlinized till plains. The Stroud municipal wells are located along the western edge of the Hewitts Creek subwatershed. Hewitts Creek is classified as a coldwater stream.

2.5.3.3 *Lake Simcoe – Innisfil Creeks Subwatershed*

Innisfil Creeks subwatershed is a lowland area draining the shores of Lake Simcoe to the southeast of Barrie. It is comprised of numerous small creeks draining an area of 107 km^2 stretching from Kempenfelt Bay to Cooks Bay. The northern half of the subwatershed (55 km^2) until Banks Creek is within the Study Area. The area includes the following creeks (listed from north to south): Strathallan Creek, Sandy Cove Creek, Mouselanka Creek, Leonard's Creek, Bon Secours Creek, and Banks Creek. The municipal wells for Alcona are located within the subwatershed along Leonard's Creek. Sandy Cove Creek, Leonard Creek, Banks Creek, and Strathallan Creek are coldwater streams. Bon Secours Creek and Mooselanka Creek are warmwater streams.

2.5.3.4 *Lake Simcoe – Lovers Creek Subwatershed*

Lovers Creek is located in the southern portion of the Study Area and flows north from Innisfil Heights to Kempenfelt Bay. The subwatershed drains an area approximately 60 km^2 in size, with the lower portion (15 km^2) within the City of Barrie. The municipal wells for Innisfil Heights are located in the headwaters of the subwatershed.

Lovers Creek is a deeply incised watercourse flowing north through valleys approximately 8-10 m deep and discharging to Kempenfelt Bay. The Creek is generally situated in a till plain physiographic region, with some surficial deposits of kame or outwash sand and gravel overlying the till in the adjacent topographically higher areas. West of Lover's Creek, the predominant direction of vertical groundwater flow is upwards which is evident in the extensive seepage zones found on that side of the Creek. Groundwater discharges from the seeps and through the bottom of the Creek, and results in a coldwater stream classification and the presence of Trout spawning. On the east side, the gentle topographic slopes and the geologic setting (i.e., sand over fine-grained soils) results in a relatively small contribution of base flow.

2.5.3.5 *Lake Simcoe – Oro Creeks South Subwatershed*

Oro Creeks South subwatershed is located northeast of the City of Barrie and is comprised of mainly small creeks flowing south to Kempenfelt Bay and Lake Simcoe. The western tip of the subwatershed (12 km^2 or 20%) is within the Study Area, including Orolea Creek, Pemberton Creek and Shanty Bay Creek. The municipal wells for Shanty Bay are within the subwatershed. Lakeview Creek, just outside the Study Area is classified as a coldwater stream; however none of the creeks within the Study Area have been classified.

2.5.3.6 *Nottawasaga River – Middle Nottawasaga Subwatershed*

The Middle Nottawasaga subwatershed (300 km^2) comprises the area draining directly to the Nottawasaga River downstream of Innisfil Creek and upstream of the Minesing Wetlands. Approximately half of this subwatershed is within the Study Area and drains the area southwest of Barrie. The Study Area boundary follows the Nottawasaga River from the Minesing Wetlands to Baxter and then follows Baxter Creek through Essa Township. This area includes Baxter Creek, Bear Creek and small direct tributaries to the Nottawasaga River. This area also has a large proportion of wetland, including Bear Creek wetlands near Barrie Well 19. The municipal wells for Angus (Centre Street and Brownley) and Thornton are also within the Middle Nottawasaga subwatershed.

This subwatershed is within the Simcoe lowlands and is mainly sand plains and till plains. It collects runoff and infiltration from the surrounding upland areas.

2.5.3.7 *Nottawasaga River – Willow Creek Subwatershed*

Willow Creek subwatershed drains the largest portion of the Study Area (340 km^2). Willow Creek headwaters are in the north-eastern corner of the Study Area and flow south through Little Lake at the northern edge of Barrie. Willow Creek continues west to the Minesing Wetlands. Matheson Creek drains the northwest corner of the Willow Creek subwatershed and joins Willow Creek just above Minesing

Wetlands. Willow Creek meanders through the Wetland before discharging into the Nottawasaga River. The municipal wells for Barrie (Well 9, Well 13 and Well 16), Midhurst, Snow Valley, and Craighurst are within the Willow Creek subwatershed.

The Willow Creek subwatershed drains part of the Oro Moraine in the headwaters, drumlinized till plains around Midhurst and sand plains along Matheson Creek. Willow Creek above Little Lake is a warmwater stream. Parts of Matheson Creek and parts of Willow Creek below Little Lake are classified as coldwater streams.

2.5.3.8 *Nottawasaga River – Lower Nottawasaga Subwatershed*

The Lower Nottawasaga subwatershed (455 km^2) includes the Nottawasaga River from the Minesing Wetlands to the outlet at Georgian Bay. The Study Area boundary follows the Nottawasaga River through the Minesing Wetlands and along Marl Creek. The contributing areas east of these watercourses are within the Study Area and make up 20% of the subwatershed. This area includes the municipal wells for Vespra Downs, Minesing and Anten Mills.

2.5.3.9 *Nottawasaga River – Innisfil Creek Subwatershed*

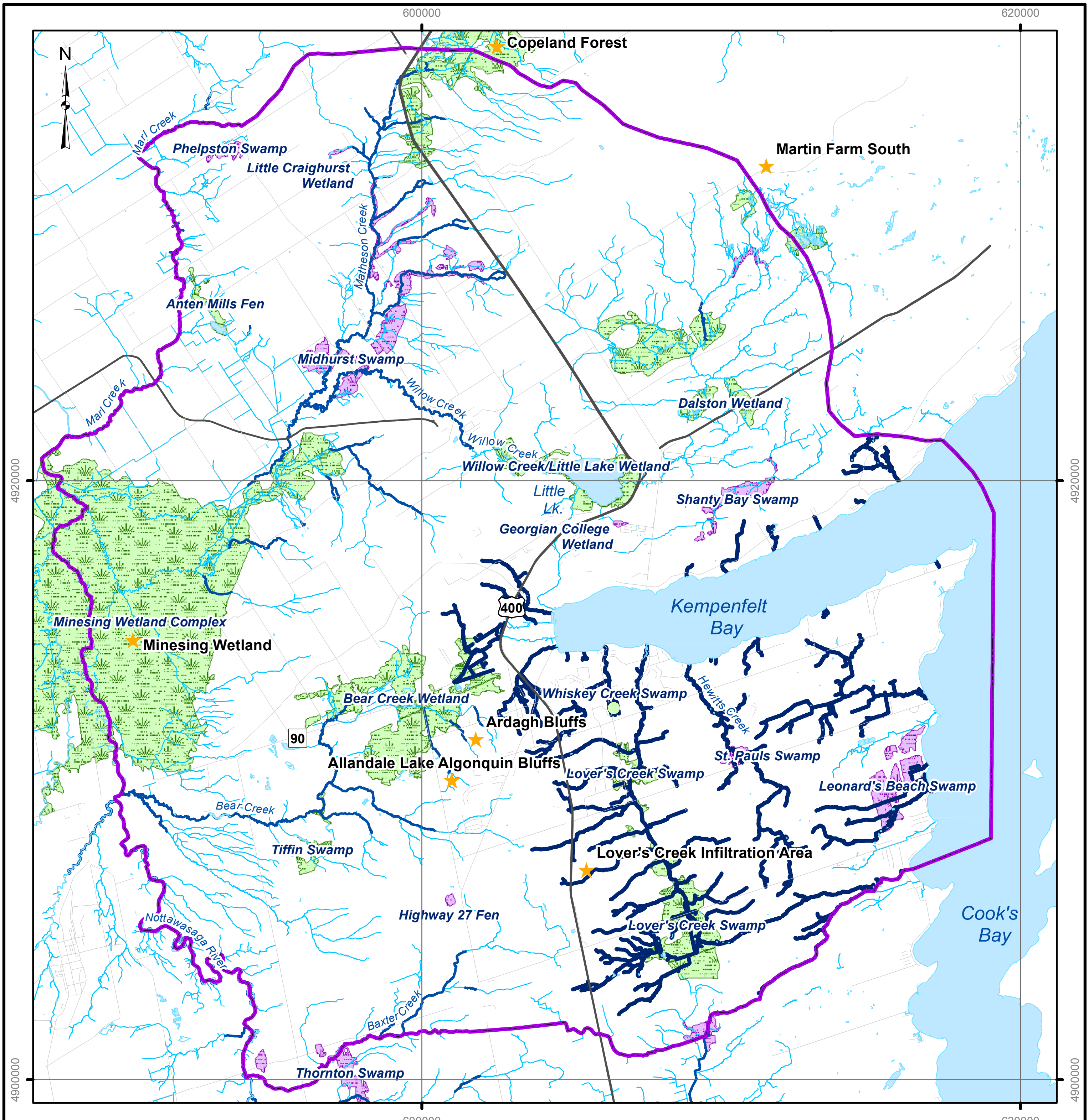
The Innisfil Creek subwatershed (490 km^2) consists of four major creeks – Innisfil Creek, Bailey Creek, Beeton Creek and Penville Creek - that drain the headwaters of the Nottawasaga River watershed. Only 2% of this subwatershed, namely a small portion of the headwaters of Innisfil Creek, is within the Study Area. Innisfil Creek arises on the rolling sand-silt plains of the Simcoe Uplands south of Barrie. Emerging from headwater forests and wetlands, it quickly flows south into intensive agricultural lowlands which extend through Cookstown to Innisfil Creek's confluence with the Nottawasaga River east of Thompsonville. Innisfil Creek headwaters are classified as coldwater streams.

2.5.4 Significant Wetland Complexes

There are five types of wetlands: fens, bogs, swamps, marshes and open water marshes. Wetland type classifications inherently describe the nature of the groundwater flow processes occurring beneath a wetland. For example, fens and swamps will occur at locations of net local or regional groundwater discharge and bogs and marshes will occur at locations of net local or regional groundwater recharge (Ontario Ministry of Natural Resources 2010). The reproduction of these local / regional behaviours with appropriate hydraulic conductivity and recharge is an important component in the calibration of a groundwater model.

Wetlands in Ontario are protected under the Planning Act, R.S.O, 1990 and the Provincial Policy Statement 2005 (PPS). The PPS states that development and site alteration will not be permitted in significant wetlands south and east of the Canadian Shield. A 'significant' wetland is any "area identified as 'provincially significant' by the Ministry of Natural Resources (MNR) using evaluation procedures established by the Province, as amended from time to time." Wetlands which are not 'provincially significant' can be classified as 'locally significant' or 'other'.

Wetlands provide vital habitat for rare and endangered species; maintain and improve water quality; function as areas for groundwater recharge and discharge; provide spawning grounds for fish, as well as help to stabilize shorelines and control flooding and erosion (Ontario Ministry of Natural Resources 2010). Wetland descriptions for the Study Area have been separated into two sections: Provincially Significant Wetlands (PSW) and Locally Significant Wetlands (LSW). Both are presented on Map 2.5**.**



LEGEND

- Towns/Villages
- Provincially Significant Wetland
- Area of Natural & Scientific Interest (ANSI)
- Cold Water Streams
- Highways
- Roads
- River / Stream
- Open Water
- Provincially Significant Wetland
- Locally Significant Wetland
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary

REFERENCES
Base Data - NVCA, 2009
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Scale 1:180,000
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Map 2.5
Environmentally Significant Areas

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Project: 2010007 BarrieTier3

2.5.4.1 *Provincially Significant Wetlands*

Provincially Significant Wetlands (PSWs) are identified by the Ontario Ministry of Natural Resources using the Ontario Wetland Evaluation System and are recognized as having ecological significance. There are eight 8 PWSs within the Study Area, three of which are in close proximity to the City of Barrie wells and therefore summarized below. The fourth, the Minesing Wetlands, is also summarized because of its strong influence on regional flow.

<u>Minesing Wetlands</u>

The Minesing Wetlands is one of the largest and most diverse undisturbed wetland tracts in Canada. Located 20 kilometres west of Barrie, it is recognized as an Internationally Significant Ramsar wetland, a Provincially Significant Wetland and a Provincially Significant Life Science Area of Natural and Scientific Interest (ANSI). It contains large areas of all wetland types found in Ontario. The unique hydrology provides for an interconnected network of swamps, fens, bogs and marshes, permanent rivers and creeks, including some with waterfalls (Frazier 1999). There are three major vegetation complexes in the Minesing Wetlands that arise from differences in topography and landform: Glacial Lake Shoreline, Boreal Wetland and Deciduous Bottomland. Minesing also has one of the most extensive (over 26 km^2) silver maple bottomland forests in Southern Ontario which reportedly has highest productivity in eastern Canada. Some of the largest stands of tamarack swamp in Southern Ontario are found on the Minesing peat plain. The largest open fens in Southern Ontario, over 2 km^2 acres in extent, occur at Minesing with a pattern of string islands. The fens are extremely ecologically rich.

The Minesing Wetland Complex is the result of glacial and postglacial processes that have been occurring in the area over the past 20 millennia. These processes have resulted in the convergence of the drainage basins of Nottawasaga River, Mad River, Willow Creek and Coates Creek. When water levels in these areas are high, they spill over natural levees in the wetland, flooding up to 70 km^2 of land. Water is stored in this large "reservoir" and slowly released to the Nottawasaga River at the north end of the wetland, hence moderating the severity of flooding in the town of Wasaga Beach, and augmenting base flow over the summer months. Although primarily a regional discharge area for ground water, large portions of the wetland are thought to be an important recharge area for groundwater (Frazier 1999). Water can be up to 1 m deep in summer.

The Mad River and Nottawasaga River which transverse through the wetland are the sole migratory routes for Georgian Bay rainbow trout and Pacific salmon, seeking spawning beds in the upper Nottawasaga river basin. The wetland is also an important spawning habitat for northern pike and walleye.

<u>Lover's Creek Swamp</u>

This area forms a north-south corridor from Innisfil Creek north to Kempenfelt Bay and is primarily located between Sixth and Tenth Concessions just west of Yonge Street. This wetland complex covers an area of 6.8km^2 and is comprised of a diverse wetland complex containing two wetland types with approximately 99% of the area covered in swamp and 1% made up of marsh (Black et al. 1985).

<u>Bear Creek Wetland</u>

This complex of 10 individual wetlands forms the headwaters of Bear Creek within the city of Barrie, which discharges to the Nottawasaga River. Within the city core, water is around 0.5-1 m deep. The Bear

Creek Wetland complex is approximately 9 km^2 in total area and is composed of two wetland types (96% swamp and 4% marsh) (Natural Heritage Information Centre 2012). It is a palustrine wetland with permanent or intermittent outlflow and a combination of soil types: 21% clay/ loam, 24% sand, 42% humic/ mesic, and 13% fibric. It is locally significant for waterfowl, as well as for fish spawning with a nursery habitat (<0.05km^2) (Natural Heritage Information Centre 2012). This wetland is suspected to be supplied by groundwater discharging from the surrounding upland areas (South and North) that results from relatively shallow groundwater flow (I.W.S, 1999; I.W.S. 2009).

Willow Creek/Little Lake Wetland

The Little Lake Wetland is approximately 2.4 km^2 in size and surrounds Little Lake, northeast of Barrie. The wetland is documented as 100% lacustrine, although riverine wetland communities occur at the northwestern end of the lake at the junction of Willow Creek) (Simkin and Gillespie 1984). The reach of Willow Creek that crosses under St. Vincent Street is hydrologically connected to this wetland. It is composed of three wetland types (1% fen, 52% swamp and 47% marsh) (Simkin and Gillespie 1984) and has significance as a fish spawning and rearing (Yellow Pickerel) (Simkin and Gillespie 1984). Viable fish habitat is present for walleye, pike, large mouth bass and other species of forage fish.

Other provincially significant wetlands within the Study Area but outside of the Focus Area, include: *Dalston Wetland, Anten Mills Fen, Copeland Craighurst Guthrie Complex, and the Tiffin Swamp.*

2.5.4.2 *Locally Significant Wetlands*

Locally Significant Wetlands are identified by the governing Conservation Authority according to its own set of criteria (Gartner Lee Limited 1996). There are eight (8) Locally Significant Wetlands in the Study area, two of these are within the Focus Area and could be potentially impacted by pumping, i.e., the Whiskey Creek Swamp and the Georgian College Wetland. *The Whiskey Creek Swamp* lies at the headwaters of a small unnamed tributary of Whiskey Creek along Huronia Road, north of Big Bay Point Road. The Barrie Huronia Rd Well (no.10) is also at this location. On the north side of Barrie, the *Georgian College Wetland* is approximately 0.1 km^2 and is located 1 km from Barrie's Johnson Street Wells (Nos. 9 and 13). Other locally significant wetlands in the Study Area include: *Leonard's Beach Swamp, Highway 27 Fen, Thornton Swamp, Shanty Bay Swamp, Phelpston Swamp, Little Craighurst Wetland, Midhurst Swamp and St. Pauls Swamp.*

2.6 Other Ecologically Sensitive Areas

2.6.1 Environmentally Significant Areas (ESAs)

ESAs are categorized into three types: biological, hydrogeological, and physical significant areas (Ecologistics 1982). Environmentally significant areas (ESA) were delineated by the LSRCA to evaluate and protect environmental features, their functions and attributes, and as such, are considered representative of Ontario's diversity. ESAs are provided with different levels of protection which depends upon the nature of the ESA (e.g., shoal, biological, recharge/discharge) (LSRCA 2012). There are numerous ESAs identified in the Study Area. The ESAs are identified on Map 2.5. Specifically, within or immediately around the City of Barrie, the following key environmentally sensitive features are present:

Biologically Significant Areas

- Tenth Concession Tributary to Lover's Creek

- South Headwaters, Lover's Creek

Hydrogeologically Significant Areas

- Lover's Creek Infiltration Area

Physically Significant Areas

- Hewitt's Creek

2.6.2 Areas of Natural and Scientific Interest (ANSIs)

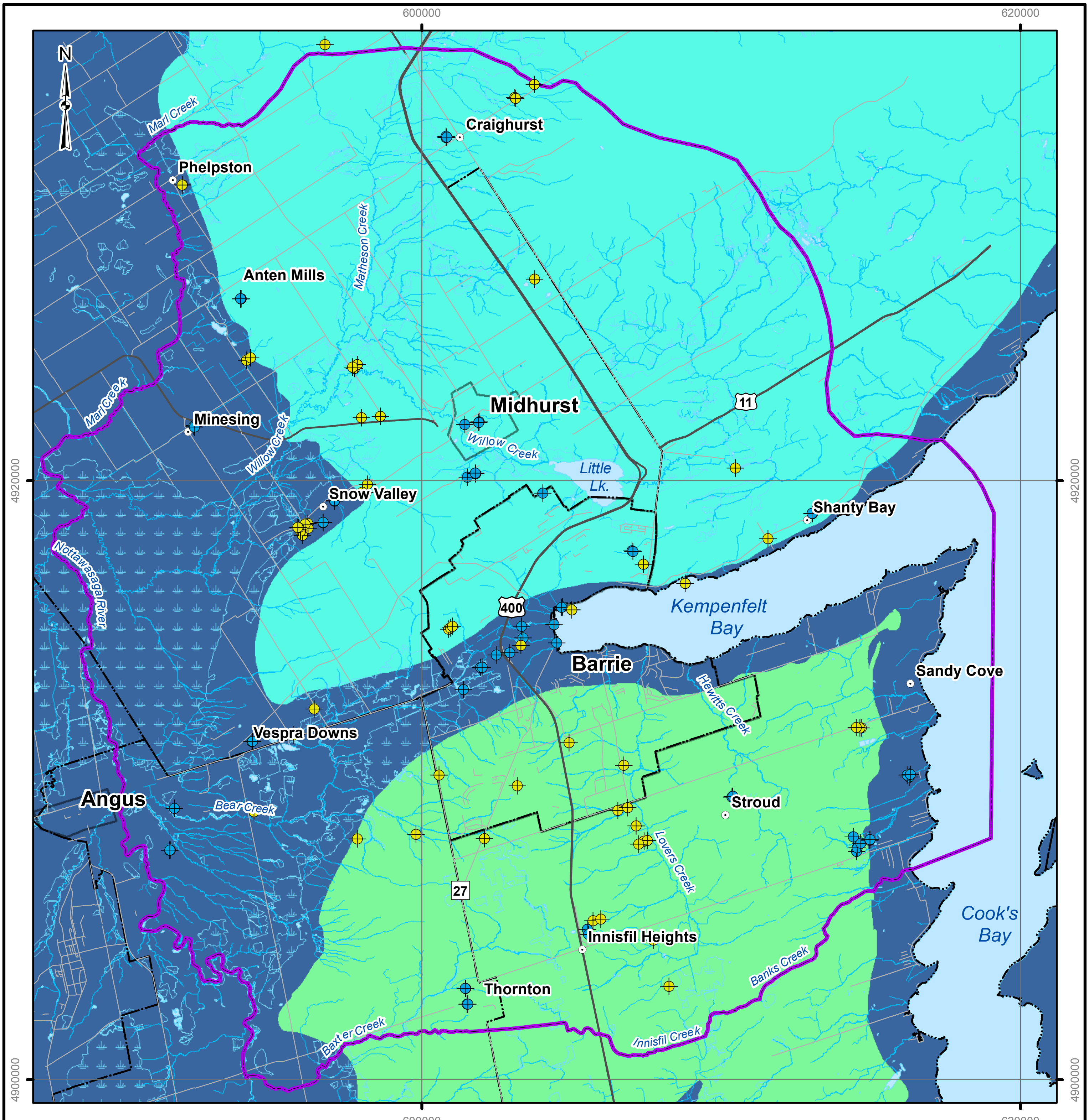
Areas of Natural and Scientific Interest (ANSI) are defined by the OMNR (2010) as "areas of land and water containing natural landscapes or features which have been identified as having values related to protection, natural heritage appreciation, scientific study or education"(Hanna 1984). ANSIs found in the Study Area are described below and are identified on Map 2.5. These areas, as identified by the Ontario Ministry of Natural Resources, are broken down as earth science (having provincially or regionally significant representative geological features) or life science (having provincially or regionally significant representative ecological features).

There are various ANSIs that have been identified in the Study Area. Some of the key ANSIs in the area include *Minesing Wetlands, Allandale Lake Algonquin Bluffs, Martin Farm South, Fergusonvale North, Copeland Forest, Ardagh Bluffs. The Ardagh Bluffs* is partially situated on the Allandale Lake Algonquin Bluffs ANSI, and both features are within the Focus Area, particularly close to Barrie Municipal Well 19. The major physical attribute of the Bluffs is a 7 km long, 50 to 70 m high Erosion Bluff (City of Barrie, 2007). The Bluffs are dissected by eight valley stream systems and includes an area of the Simcoe lowlands; previously part of the postglacial Algonquin Lake Bed. The gradient of the area slopes rapidly into the eight surrounding waterways which feed into the Bear Creek Wetland. The gentle slope north toward sandy soils is where water infiltration takes place. In addition, there are locations exhibiting a perched water table that is within one meter of the surface as a result of localized horizontal seams of clay. Within the Ardagh Bluffs area, groundwater was found to occur at a variety of depths, from as shallow as 15 cm in the north end (adjacent to the Bear Creek Wetland) to 100 metres below the surface at the extreme East end of the Study Area. Upland aquifers discharge from the north facing slopes of the Bluffs, serving to recharge surface waters and lower aquifers. The area within the Ardagh Bluffs requires Environmental Protection zoning based on its geography, geology, and natural features (City of Barrie 2007).

2.7 Physiography

The physiography of the Study Area is a relic of Quaternary glacigenic depositional and erosional systems. Quaternary sediment is mainly defined by glacially-derived diamict, ice-contact and outwash stratified sands and gravels, and glaciolacustrine silts and clays that form a complex modern landscape. Three regional-scale physiographic regions, reflecting upland, lowland, or drumlinized areas, are defined by Chapman and Putnam (1984) to span the Study Area (Map 2.6): Simcoe Uplands, Simcoe Lowlands, and Peterborough Drumlin Field. A description of these areas is outlined below.

The Simcoe Uplands physiographic region is characterized by rolling till plains that have been dissected into discrete upland areas by steep-sided, flat-floored valleys. Upland areas span the north-eastern part of the Study Area, and rise up to 100 m above the neighbouring low-lying areas. The Newmarket Till persists along the surface of many upland landforms, occasionally overlain by local deposits of



LEGEND

- Towns/Villages
- Private Permits
- Municipal Water Supply
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary

Physiographic Region

- 31, Peterborough Drumlin Field
- 35, Simcoe Lowlands
- 36, Simcoe Uplands

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Map 2.6

Physiography

REFERENCES
Base Data - NVCA, 2009
Physiography Regions-Chapman, L.J. and Putnam, D.F. 1984. Physiography of Southern Ontario; Ontario Geological Survey, Miscellaneous Release--Data 228 ISBN 978-1-4249-5158-1

Projection: UTM Zone 17N, NAD 83; Map Version: 1; Map Date: 07-Jun-2012; Created By: ccurry

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Kilometres

glaciolacustrine or outwash sediment (Burt 2006). Most upland areas are predominantly composed of till and fine-grained sediment; however, some upland areas, including the Oro Moraine, consist of stratified sands and gravels with minor fine-grained sediment components (Barnett, 1991; Burt, 2006; Burt and Russell, 2006; Burt, 2007a). The upland areas near Innisfil tend to be till-cored, and are blanketed by a drumlinized till plain associated with the Peterborough Drumlin Field physiographic region. Shoreline features, including wave-cut terraces and beaches, are observed along the flanks of the upland areas (Slattery 2003; Burt, 2004 2006), and are relicts of nearshore processes acting in the various proglacial lakes that inundated the Study Area during the latter stages of the last glaciation.

The Simcoe Lowlands encompasses narrow stretches of land along the shores of Lake Simcoe, extending along the landward extension of Kempenfelt Bay to the low-lying area west of Barrie (Map 2.6). The lowland areas are defined by flat, low-lying plains, some occupying large valley floors. Glaciolacustrine sand, silt and clay deposited in Glacial Lake Algonquin are documented at surface (OGS 2010). Glacial Lake Algonquin inundated the Study Area approximately 12,500 years before present (ybp) when glacial meltwaters ponded in front the receding Simcoe, Huron, and Georgian Bay ice lobes (Barnett 1992). Further evidence of Glacial Lake Algonquin, as well as its predecessors and successors, in the Simcoe Lowlands region is recorded as remnant landforms along lowland margins, including shore cliffs such as the Algonquin Bluffs slightly east of the Minesing Wetlands, wave-cut terraces, and beach ridges (Chapman and Putnam 1984).

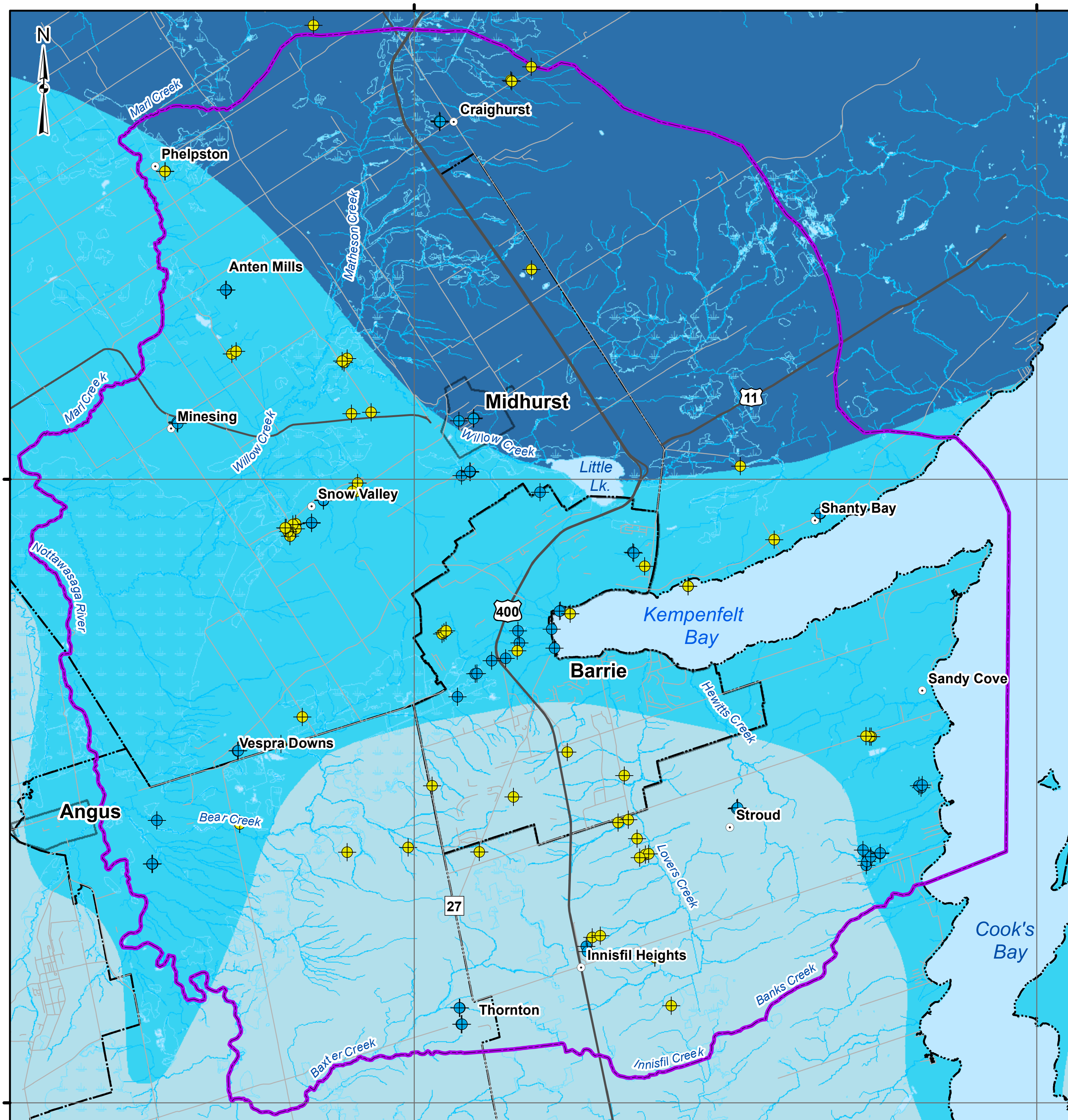
The Peterborough Drumlin Field encompasses the upland areas of Innisfil Heights south of Kempenfelt Bay in the Study Area (Map 2.6), and is characterized by drumlins and drumlinoid hills that rise from the surrounding Newmarket Till plain. Drumlin axes are aligned southwest-northeast (Chapman and Putnam 1984), indicating that Newmarket Till glacial ice encroached from the northeast through the Study Area. Sediment composing the Peterborough Drumlin Field is texturally similar to deposits found in the Simcoe Uplands; however, the upper till unit is notably more continuous.

2.8 Bedrock Geology

The Ordovician-aged carbonates and shales of the Simcoe Group underlay the Study Area. These rocks were deposited in a gradually deepening shelf system in a shallow subtropical sea approximately 460 million years ago (Brookfield and Brett 1988). As the overburden groundwater flow system is used to supply groundwater to the Barrie area, only the bedrock formations in direct contact with overburden sediments are the focus of this discussion.

The Simcoe Group can be sub-divided into four formations that dip gently toward the southwest: Gull River Formation, Bobcaygeon Formation, Verulam Formation, and Lindsay Formation, from oldest to youngest. However, the Gull River Formation does not subcrop in the Study Area (Map 2.7), and therefore will be excluded from this discussion.

The Bobcaygeon Formation is composed of interbedded muddy and coarse-grained limestones with variable argillaceous content that were deposited by shallow subtidal processes (Johnston et al. 1992). It ranges in thickness from 7 to over 87 m, and subcrops throughout the northern extent of the Study Area. The overlying Verulam Formation was deposited in a deeper marine environment than the Bobcaygeon Formation, where sedimentation was controlled by open marine shelf and shoal processes. As such, the Verulam Formation is composed of 32 to 65 m of muddy to coarse-grained limestone with shale interbeds (Johnston et al. 1992). It subcrops across the middle of the Study Area. Bedrock in the southern portion of the Study Area is characterized by the Lindsay Formation (Map 2.7). The limestone



Index Map

LEGEND

- Private Permits
- Municipal Water Supply
- Towns/Villages
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary

Bedrock Geology

- 9: Bobcaygeon
- 10: Verulam
- 11: Lindsay

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Map 2.7

Bedrock Geology

REFERENCES
Base Data - NVCA, 2009
Bedrock Geology - Armstrong, D.K. and Dodge, J.E.P. 2007. Paleozoic geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release--Data 219. ISBN 978-1-4249-4526-9
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Project: 2010007 BarrieTier3

and shale of the Lindsay Formation record deposition in a shallow shelf and shoal environment (Johnston et al. 1992). The Lindsay Formation tends to be less than 67 m thick.

A major, regional unconformity separates the Paleozoic bedrock from the overlying Quaternary sediment throughout southern Ontario, including the Study Area. Bedrock was exposed and extensively eroded between the deposition of the Paleozoic rock formations and Quaternary sediment, as recorded by the unconformity (Johnston et al. 1992). Exposure to the elements (wind, rain, etc.) and repeated glacial advances likely caused intense fracturing of the upper portions of the bedrock surface prior to glacial deposition (Armstrong and Carter 2006).

2.9 Quaternary Geology

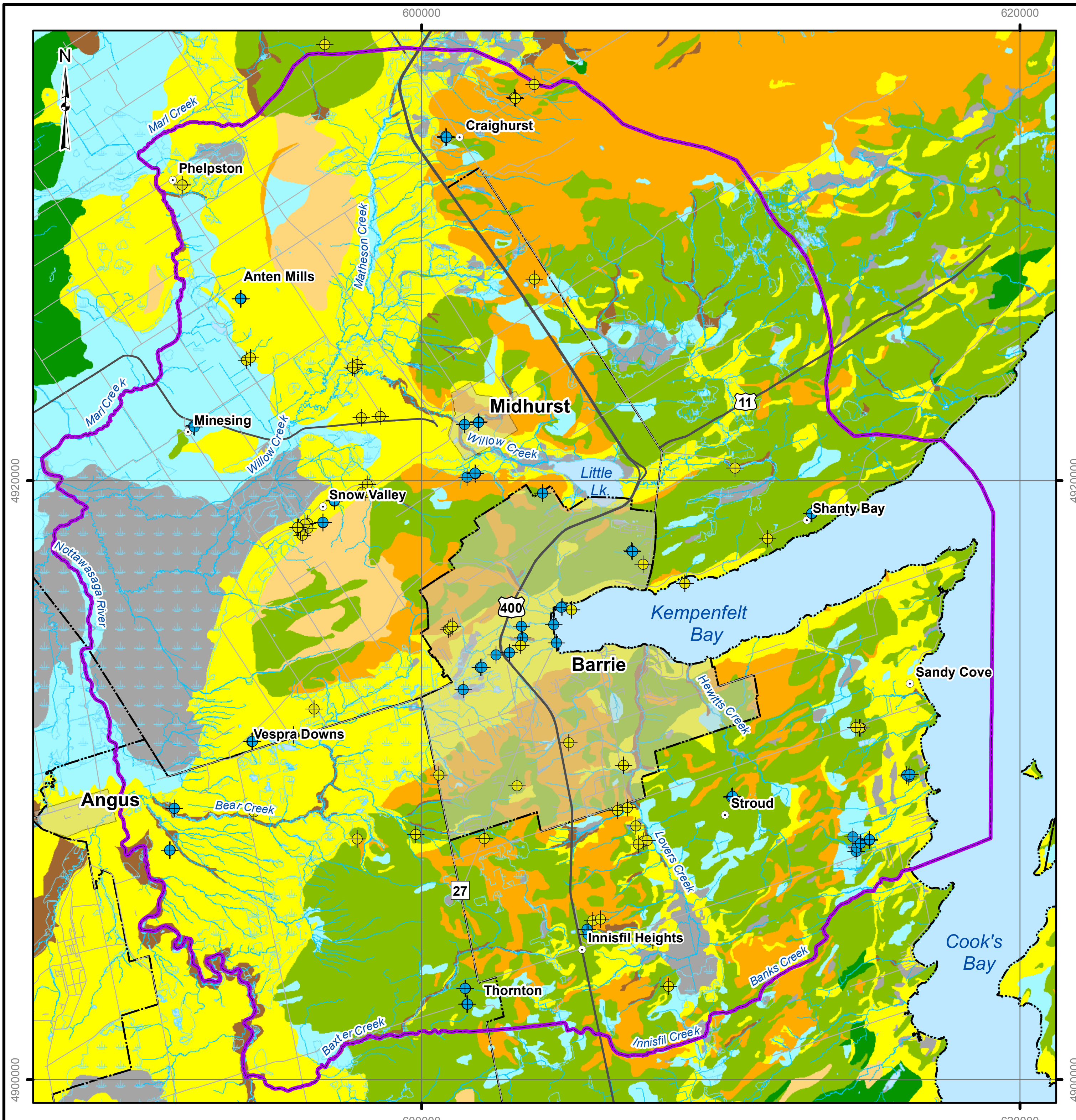
Overburden sediment in the Study Area detail a record of repeated ice advance and retreat of the Simcoe Lobe, which originated from the neighbouring Lake Simcoe basin (Chapman and Putnam, 1984; Barnett 1992). At surface, sediment is characterized by laterally discontinuous till sheets, stratified sand and gravel units, and interbedded finer-grained silt and clay bodies (Map 2.8). Lesser amounts of recent organic and floodplain deposits are observed in the Minesing Wetlands and Bear, Willow, and Lovers Creek valleys, as well as along the Nottawasaga River. The Study area is marked by raised uplands areas surrounded by channelized lowlands. Generally, sediment in the Barrie area documents glacial, glaciolacustrine, and glaciofluvial sedimentation (upland areas), followed by large-scale catastrophic erosional events, which formed steep-sided valleys that are seen to dissect upland features.

2.9.1 Overview of the Regional Glacial History

The Laurentide Ice Sheet advanced into southern Ontario twice during the Illinoian and later Wisconsinan glaciations (Clark, 1992; Goldthwait 1992). The Wisconsinan Glacial Stage (25,000 to 10,000 ybp) is the most recent glacial episode to occur in the Study Area. Although some older deposits may be present at depth (Barnett 1991), the Late Wisconsinan sedimentological record in the Barrie area is much better preserved than previous glacial advances. As such, the deposits of the Late Wisconsin are the focus of the following discussion.

As the Laurentide Ice Sheet advanced into southern Ontario during the Wisconsinan glaciation, the contential-scale ice mass broke into a series of smaller, discrete ice lobes. These smaller ice lobes developed in the broad topographic depressions of the Great Lakes and lesser large lakes (i.e. Lake Simcoe) (Barnett 1992). The flow of ice was largely controlled by local ice-bed conditions, rather than, or in addition to, climatic variations, which permitted the various ice lobes to act independently from one another. The individual ice lobes assume the name of the lake basin that they occupied (e.g. Simcoe Lobe).

Four distinct till units have been identified within, and neighbouring, the Study Area (Table 2.3): Bogarttown Till, an unnamed sandy till, Newmarket Till, and Kettleby Till, from oldest to youngest (Gwyn 1972; Barnett 1986, 1988). In general, the till units record periods of ice advance by the Simcoe Lobe; whereas, the intervening silt and clay, and stratified sand and gravel units record variable depositional conditions during ice retreat and stagnation.



LEGEND

- Private Permits
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Quaternary Geology

- 1,2: Precambrian bedrock
- 3,4: Paleozoic bedrock
- 5b: Stone-poor, carbonate -derived silty to sandy till
- 5d: Glaciolacustrine-derived silty to clayey till
- 6: Ice-contact stratified deposits
- 7: Glaciofluvial deposits
- 8: Fine-textured glaciolacustrine deposits
- 9: Coarse-textured glaciolacustrine deposits
- 12: Older alluvial deposits
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- 14: Coarse-textured lacustrine deposits
- 17: Eolian deposits
- 19: Modern alluvial deposits
- 20: Organic deposits
- 21: Man-made deposits

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Map 2.8

Quaternary Geology

REFERENCES
Base Data - NVCA, 2009
Ontario Geological Survey 2003. Surficial geology of Southern Ontario; Ontario Geological Survey, Miscellaneous Release-Data 128
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Project: 2010007 BarrieTier3

TABLE 2.3 Generalized schematic of the major stratigraphic units and geologic event identified in the Study Area.

		Generalized Regional Stratigraphy	Major Geologic Event
Late Wisconsin	Two Creeks Interstade (~12,000 ybp)	Glacial Lake Algonquin Deposits (sand, silt, clay)	
	Port Huron Stade (~13,000 ybp)	Glacial Lake Schomberg Deposits (Schomberg Clay Plain)	Catastrophic Flooding Events; Tunnel Valley Genesis
		Kettleby Till (Simcoe Lobe)	
	Mackinaw Interstade (~13,400 ybp)	Glaciolacustrine / Glaciofluvial Deposits	Formation of Oak Ridges Moraine (Simcoe / Ontario Interlobate Area)
	Port Bruce Stade (~14,800 ybp)	Newmarket Till (Simcoe Lobe)	
		Unnamed Sandy Till (Simcoe Lobe)	
		Bogarttown Till (Simcoe Lobe)	
	Erie Interstade (~15,500 ybp)	Ice Covered	
	Nissouri Stade (~20,000 ybp)		

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Ice covered the Barrie area throughout the Nissouri Stade and Erie Interstade of the Late Wisconsinan glaciation. The Simcoe Lobe advanced in the Barrie area and deposited several tills during the Port Bruce Stade (Table 2.3): Bogarttown Till, an unnamed sandy till, and the Newmarket Till. The distinct till units were deposited by the fluctuating ice margin of the Simcoe Lobe. Periods of smaller-scale ice retreat separating glacial ice advance have been interpreted from thick units of coarse-grained glaciofluvial and fine-grained glaciolacustrine deposits amid the tills (Burt 2006). The ice retreated, ushering in the Mackinaw Interstade, which was characterized by the deposition of glaciolacustrine and glaciofluvial sediments, and the continued deposition of the Newmarket Till (Barnett 1992). During this warmer period, the Oak Ridges Moraine formed south of the Study Area in the interlobate zone between the Simcoe and Ontario ice lobes (Barnett et al. 1998). As the climate cooled at the end of the Mackinaw Interstade, the Simcoe Lobe advanced, triggering the end of the Mackinaw Interstade, and the beginning of the Port Huron Stade.

During the Port Huron Stade, the Simcoe Lobe advanced for the last time and deposited the Kettleby Till observed at surface south and northeast of the Study Area. It has been suggested that following the deposition of the Kettleby Till, large-scale catastrophic releases of subglacially stored meltwater scoured the landscape, and eroded the steep-sided valleys seen in the Study Area (Barnett 1986; Slattery 2003; Burt 2006). Approximately four pulses have been interpreted from fining-upwards sequences in valley-fill successions (Slattery 2009).

The ice margin retreated toward the Lake Simcoe basin after the deposition of the Kettleby Till, and glacial meltwater ponded in front of the receding Simcoe Lobe between the Oak Ridges Moraine and the Niagara Escarpment, forming Glacial Lake Schomberg (Barnett 1992). The Schomberg Clay Plains extend at surface south of the Study Area, north of the Oak Ridges Moraine. The waters of Glacial Lake

Schomberg coalesced with Early Lake Algonquin during the Two Creeks Interstade approximately 12,000 ybp (Barnett, 1992; Burt and Russell, 2005; Burt, 2004, 2006, 2007b). Glaciolacustrine sand, silt and clay were deposited in the low-lying areas of the Study Area inundated by Glacial Lake Algonquin, and shoreline features associated with Glacial Lake Algonquin were eroded and / or deposited along the flanks of the upland areas. Glacial Lake Algonquin eventually drained eastward through the Ottawa River valley via outlets across what is now Algonquin Provincial Park; these outlets opened in response to continued northward glacial retreat (Barnett 1992).

One predominant upland feature located north of the City of Barrie, the Oro Moraine, is distinct from other upland areas. The Oro Moraine is a depositional landform consisting of stratified sand and gravel with minor fine-grained units (Beckers and Frind, 2000; Slattery, 2003; Burt, 2004, 2006, 2007b). It has not been overridden by glacial ice (Burt 2006), and has been observed to overlie the lower drift packages and upper till units (i.e. Newmarket Till, Kettleby Till) found in the upland areas (Burt 2006), suggesting a moraine of mid-Port Huron age or younger.

Following the retreat of glacial ice and meltwater from the Study Area, fluvial processes continued to shape the landscape with ongoing erosion and deposition along the Nottawasaga River and its various tributaries. Extensive gullying is also observed along the flanks of the Innisfil Heights upland areas (Chapman and Putnam 1984).

2.9.2 <u>Stratigraphic Sequences</u>

Drilling programs conducted in 1990, and 2004-2006 by the Ontario Geological Survey (Barnett, 1991; Burt and Russell, 2006; Burt, 2007a) that encompass the Study Area have greatly improved the sedimentologic and stratigraphic understanding of the various subsurface deposits in the Study Area. Two sedimentary sequences emerge that can be attributed to either upland or lowland areas (Figure 2.4).

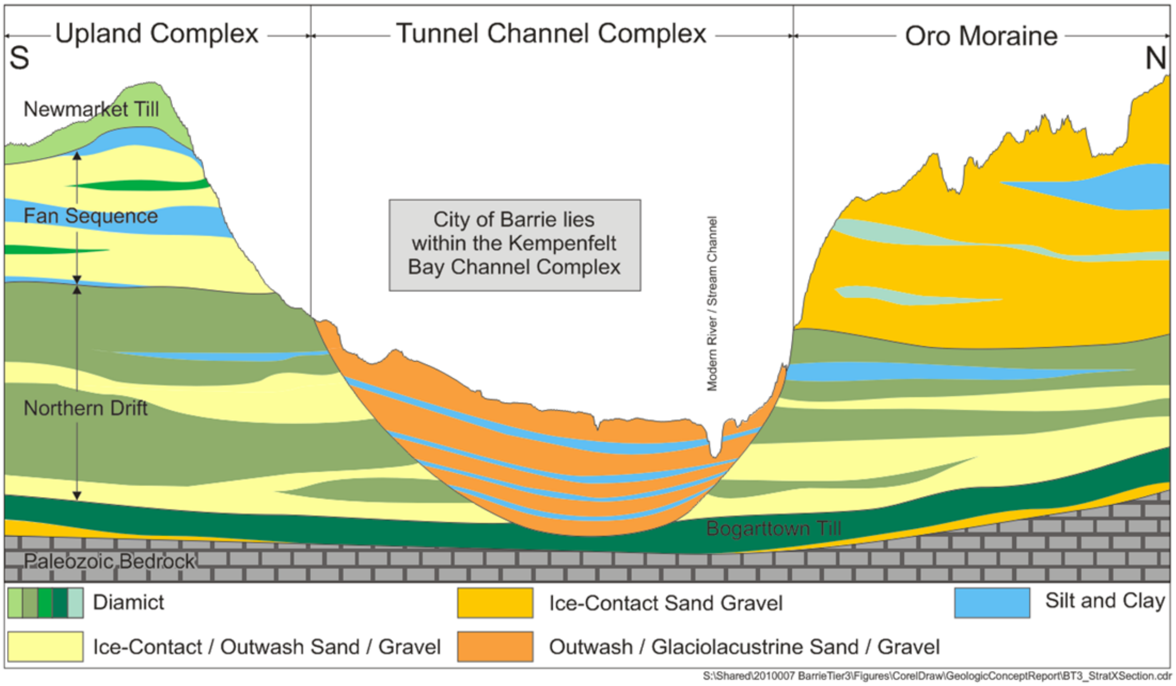


FIGURE 2.4 Generalized conceptual stratigraphy of upland complexes, lowland tunnel channel complexes, and the Oro Moraine.

2.9.2.1 *Simcoe Uplands Sedimentology*

Three distinct till packages can be observed in the subsurface of upland areas (Figure 2.4). The Bogarttown Till is found at depth overlying ice-contact sand and gravel that rests on bedrock. The Bogarttown Till is a massive sandy silt till, which is 2 to 4 m thick (Gwyn 1972). The Bogarttown Till is overlain by an unnamed clast-rich, sandy till, which has been informally named the Northern Till by Burt and Russell (2005). The Northern Till is observed in a drift sequence that includes diamict, coarse-grained subaqueous fan and / or outwash sands and glaciolacustrine silts and clays (Burt 2006; Slattery 2009). This sequence is approximately 50 m thick (Burt and Russell, 2006; Burt, 2007a). A subaquatic fan sedimentary sequence overlies the Northern Drift sequence. Sand and gravel fan facies are interbedded with fine-grained glaciolacustrine sediment recording quiet water sedimentation, as well as diamicton, reflecting periodic debris flow events (Burt 2006). The uplands are capped by a discontinuous unit of Newmarket Till, which has been locally streamlined, and drumlinized in some areas (e.g. Innisfil Heights uplands). The Newmarket Till is a pebbly sand to silty sand till (Gwyn 1972), and is the most prominent till at surface in the Study Area. It tends to be up to 10 m thick (Burt 2006).

2.9.2.2 *Oro Moraine*

The Oro Moraine, alternatively termed the Bass Lake Kame Moraine or Oro sandhills, is an ice-contact feature that rises from the surrounding landscape north of the City of Barrie (Figure 2.4). Oro Moraine sediments are characterized by several thick fining-upwards sequences of cobble gravel to silt, which is indicative of multiple phases of fan deposition (Burt 2006). Interbedded in the stratified sands and gravels are discontinuous beds of diamict, which are approximately 10 m thick.

Many paleoenvironmental interpretations have been proposed for the Oro Moraine. Deane (1950) originally interpreted the moraine as an end moraine formed during a standstill of the Simcoe Lobe. An interlobate origin followed by glacial overriding was later proposed by Gravenor (1957), and modified by Chapman and Putnam (1984) who describe the Oro Moraine as a sandy moraine deposited by the Georgian Bay Lobe that was subsequently overridden by glacial ice from the northeast. Barnett (1986, 1989) interpreted the Oro Moraine as a series of coalescing subaquatic fans deposited in an interlobate position; whereas, a series of stacked subaquatic fans has been proposed by Slattery (2003). After intensive investigation of continuously cored boreholes and outcrops in aggregate mines, Burt (2006) has interpreted the Oro Moraine as coalescing subaquatic fans fed by a subglacial conduit located on the eastern end of the moraine. Recent research by Barnett (1986, 1989), Slattery (2003), and Burt (2006) generally agree on a subaquatic fan depositional model for the Oro Moraine.

2.9.2.3 *Simcoe Lowlands Sedimentology*

Low-lying channels in the Study Area are hypothesized to have formed through the erosion of sediment by catastrophic releases of subglacially stored meltwater (Barnett, 1988, 1989; Slattery, 2003; Burt and Russell, 2005; Burt, 2006, 2007b). Pulses of meltwater carved away the sediment preserved in the upland areas and infilled the resultant valley with a succession of fining-upwards sequences of gravels and sands, capped by silt (Barnett, 1991; Burt and Russell, 2006; Burt, 2007a). Later inundation of the lowlands by Glacial Lake Algonquin water allowed suspended sediment to be deposited as shallow water sands with minor gravel content. These glaciolacustrine sediments are exposed at surface in the valley forms.

2.10 Regional Hydrogeologic Setting

The regional hydrogeologic setting of the Study Area is largely controlled by the Quaternary geologic deposits as discussed above. Overburden aquifers in the Study Area include aquifers associated with ice contact deposits, kame moraines, and similar coarse-grained sediments described in the section above. These deposits create a regionally extensive and complex aquifer system. Till plains in the Study Area (i.e., Innisfil area) represent localized and regional aquitards that act to impede the vertical movement of groundwater (and potential contaminants) to underlying aquifers.

The aquifer system is generally described as containing four major sand and gravel aquifer units (from shallowest to deepest: A1, A2, A3, and A4). These four aquifer units are defined based on their relative stratigraphic position (e.g., Mackinaw Interstade) and are commonly identified based on elevation ranges that have been refined through decades of characterization efforts. The shallowest of these aquifers (i.e., A1 and A2) are commonly unconfined in the Study Area (e.g., Borden Sands and Oro Moraine deposits), with A1 deposits generally constrained to upland areas. The deeper units (i.e., A3 and A4) are locally confined by overlying till sheets or finer-grained bedding (e.g., Barrie-Borden aquifer), and are most prevalent within the tunnel-channel, lowland deposits. Despite the distinction between upland and lowland sedimentology, stratigraphically equivalent units from both the upland and lowland areas are lumped together within the hydrostratigraphic units.

A deep, highly-transmissive aquifer is found under the central portion of the City of Barrie within the tunnel-channel deposits associated with the lowland area. This aquifer extends in an east-west direction from Kempenfelt Bay west towards the Angus-Borden area (referred to as the Barrie-Borden aquifer). The fining-upwards sequence of this deposit generally results in this aquifer being confined from shallow aquifers by overlying silt and clay aquitard deposits. This has historically resulted in flowing artesian conditions, particularly along the banks of Kempenfelt Bay. The aquifer system in the Study Area is described in greater detail within the context of the hydrostratigraphic conceptual model in Section 4.0.

3.0 GROUNDWATER DEMAND

Estimating water demands is a critical component in the developing a water budget. In the Tier Three Water Budget and Local Area Risk Assessment, the water demands focus on the large municipal and non-municipal permitted water takers. Water demand is estimated based on the following components:

- Municipal water demand: Municipal water demand estimates were based on pumping rates reported by municipalities;

- Permitted water demand: The Province of Ontario issues Permits to Take Water (PTTW) for water takings greater than 50,000 L/d. Permitted water demand was estimated using reported pumping rates from the 2009 Water Taking Reporting System (WTRS) or by combining the permitted rate with the months of expected active pumping. Consumptive factors were then applied to determine the amount of pumped water that is not returned to the original source in a reasonable amount of time; and

- Non-permitted water demand: water takings less than 50,000 L/d, or for firefighting, livestock watering or rural domestic purposes are exempt from the PTTW program.

3.1 Consumptive Water Use

Records of permitted or reported water taking/pumping do not reflect the amount of water that is removed from the hydrologic system. For example, a water user may pump large quantities of water from a pond, use the water (e.g., aggregate washing) and return the majority of it back to the pond. In this example, only the quantity of used water absorbed by the aggregate is lost from the pond (e.g. consumed). Water that is ***not*** returned back to the original source is referred to as “Consumptive Water Use”, and this value may be much less than the total quantity of water pumped.

Consumptive water demands are not reported and consequently need to be estimated through the use of consumptive water use coefficients, which are based on the purpose of water use. Estimating consumptive water demand requires consideration of the point of discharge for wastewater and consideration of the physical water taking operation. While some water takers have large extraction rates associated with their permits, they consume very little of that water. For example, aggregate washing operations are permitted to pump large volumes of water between washing and settling ponds, and a relatively small percentage is lost to evaporation, or is removed offsite within the washed material. Conversely, uses such as golf course irrigation, or snow making are not expected to return much of the water pumped to the aquifer system (used water is assumed to evaporate or run-off as surface water) and as such are considered highly consumptive uses during their active seasons. Such takings are considered to have a low consumptive water use at both the local scale (the ponds) and at the subwatershed scale. Other water users may consume very little water at the subwatershed scale, but may have significant impacts locally at the water source. Dewatering operations, where groundwater is pumped to lower the water table then discharged to a nearby creek, can impact the aquifer, but have a negligible impact on the water balance of the subwatershed as a whole. In this case, while the taking is not consumptive with respect to the subwatershed, it is 100% consumptive with respect to the aquifer.

Estimating consumptive water use depends on the scale of the assessment. For the Tier Three Water Budget, all water takings were considered on the well field or source scale. In other words, if water is removed from a water source and not returned to the same water source as it was withdrawn, the taking is assumed to be 100% consumptive with respect to the source. Commonly, groundwater takings fall into this category; where water is extracted from a deep aquifer and returned to a surface water feature. In all instances, the Tier Three Water Budget Study considered the consumptive demands, rather than the permitted rates. The process of estimating the consumptive water use for the Tier Three using the various data sources is included in Figure 3.1. These sources and processes are discussed further in the following sections.

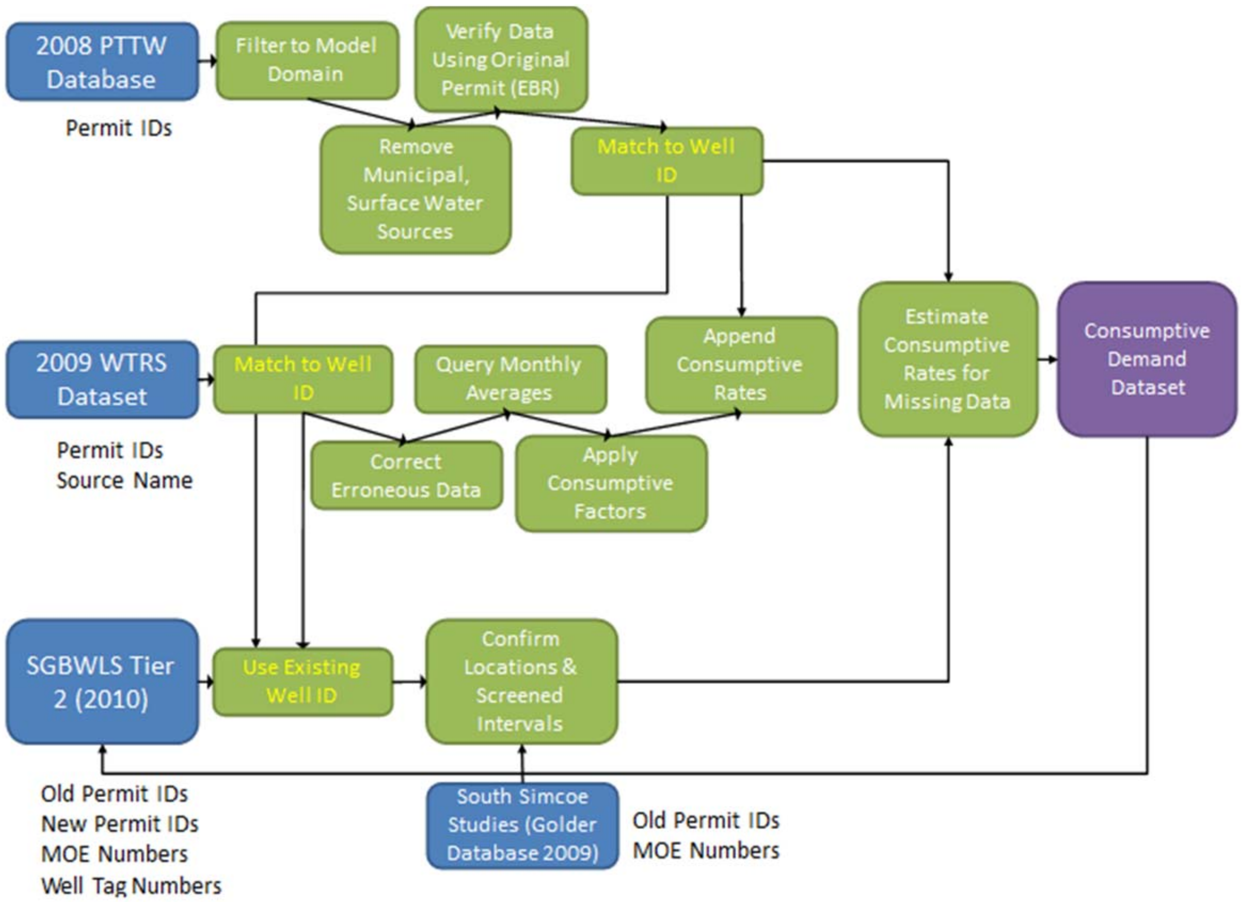


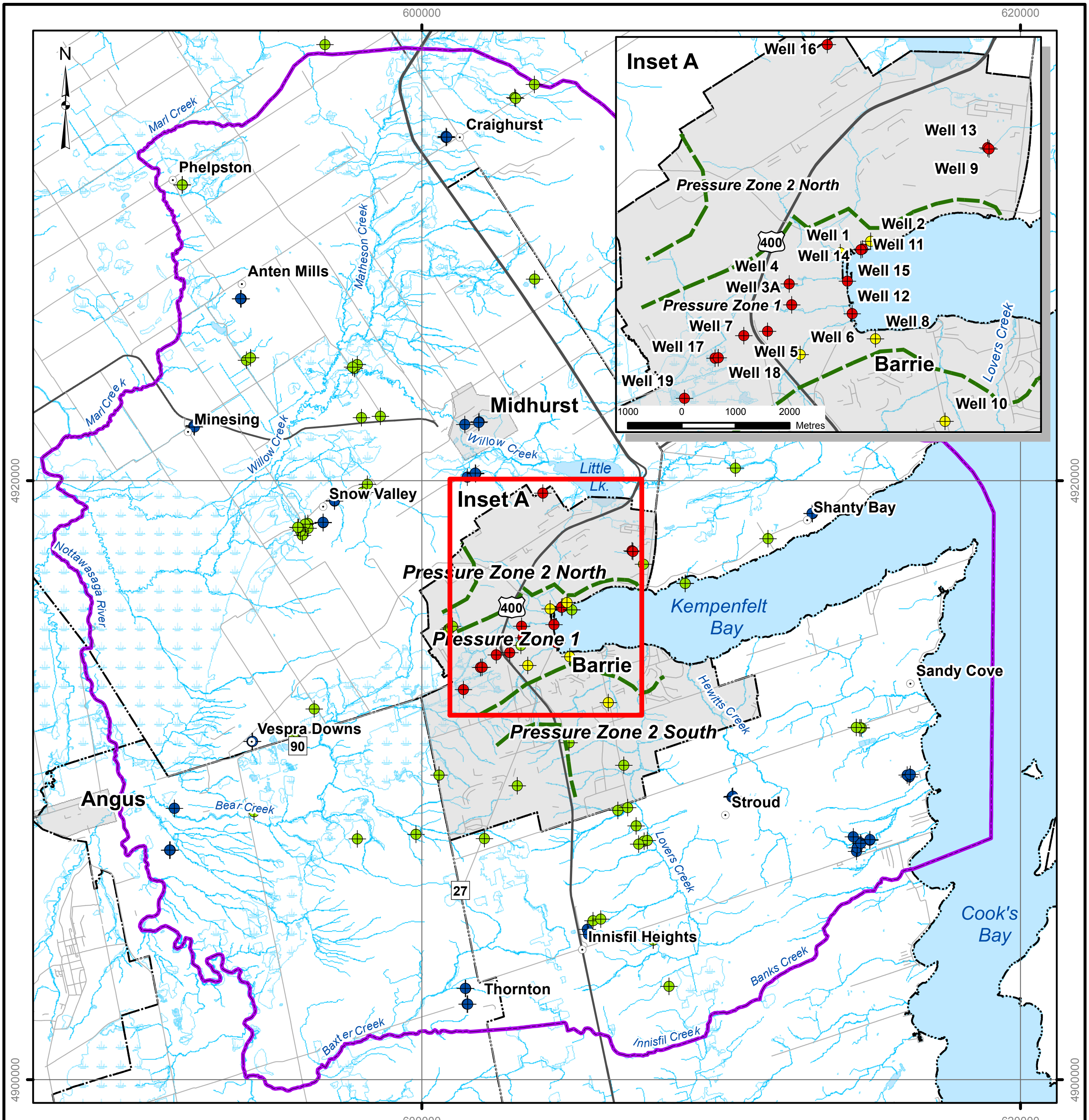
FIGURE 3.1 Establishing Consumptive Demand Dataset Workflow

3.2 City of Barrie Water Takings

Particular focus was given to the water takings within the City of Barrie. The following sections describe the well fields and their hydrogeologic setting to provide greater understanding of the municipal water takings for the City of Barrie.

3.2.1 <u>Well Field Description</u>

Until recently, the City obtained its water supply entirely from groundwater. The municipal system, which has been in operation since 1937, currently consists of a total of 15 wells, 13 of which are operational, and constructed into deep overburden aquifer systems. The aquifer systems are capable of producing significant yields to meet the present water demands of the community. The total average daily yield of the groundwater supply wells is over 45,000 m^3. Map 3.1 illustrates the locations of



LEGEND

- Barrie Municipal Wells
- Other Municipal Wells
- Private PTTWs
- Muncipal Supply Wells No Longer in Operation
- Towns/Villages
- Pressure Zone Extents (Approximate)
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary

REFERENCES
Base Data - NVCA, 2009
Produced using information provided by the Ministry of Natural Resources, Copyright © Queen's Printer, 2010.
Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 07-Jun-2012; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

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Map 3.1

Municipal and Private Pumping Wells

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Project: 2010007 BarrieTier3

municipal wells in the Study Area. Due to the topographic relief of the area, the distribution system is divided into pressure zones. Zone 1, includes the core City area and the lowlands flanking Kempenfelt Bay. The surrounding uplands to the North and South of the core area are divided into two pressure zones known as Zone 2 North and Zone 2 South.

The majority (13) of the 19 original municipal wells are located within the central and lakeshore Barrie area, in Pressure Zone 1 and consist of Wells 3A, 4, 5, 7, 11, 12, 14, 15, 17, 18 and 19. Three wells, Wells 9, 13 and 16, are located in the north part of the City in Pressure Zone 2 North, and one (Well 10) is located in the south part of the City in Pressure Zone 2 South. With the exceptions of Wells 9 & 13 and 11 & 14, all wells are constructed at separate locations. These wells are all fitted with line-shaft vertical turbine pumps and are located within individual well houses. Details regarding well operation are provided in the Quarterly Reports prepared by the City as required under Ontario Regulation 459. Well 3 has been replaced by offset Well 3A, and Well 4 is being replaced by offset Well 4A. Well 19 is a permitted municipal well but is not connected to the municipal system at this time. Wells historically part of the municipal system include Wells 1 and 8 that have been sealed/plugged and abandoned and Wells 2 and 6 still in place, but are nonoperational because of water quality concerns. There are no plans to operate these wells in the future. Appendix A2 provides a summary of the wells and further information pertaining to well construction. The well fields are typically referred to by street location as well as by number.

Two other wells, located in Springwater Township and referred to as Wonder Valley Wells 1 and 2, are decommissioned wells owned by the City. These wells, which are approximately 2.5 km northeast of Wells 9 and 13, have been capped and the pumping equipment removed. The Tollendal wells, located on the south shore area of Kempenfelt Bay, were abandoned in 2001. Other former municipal/communal water supply wells in the outlying subdivisions (e.g. Holly, Big Bay Point) have also been recently abandoned.

The City of Barrie is expected to experience continued population and economic growth throughout the next planning period. The ability of water resources to meet future demands will be a key factor relating to this expected growth. It has been recognized for some time that the aquifer used by the City as its sole source for municipal water supply is limited, and as a result, the City of Barrie has added a surface water intake in the summer 2011 to facilitate growth in the south end of the City. The current maximum day capacity listed in the Permit to Take Water is 148,000 m^3/day; 83,000 m^3/day from groundwater and 65,000 m^3/day from the surface water plant. The surface water plant will service pressure zones in the south end of the City, where the largest growth in residential housing and commercial use is anticipated. Groundwater will continue to be used to supply water to the central and north pressure zones. The most recent study of aquifer yield (Golder, 2009a) indicates a total aquifer capacity ranging from 80,000 m^3/day to 100,000 m^3/day, including the recently constructed Well 19 (Golder, 2009a).

As noted above, the City of Barrie is planning to commence operation of their surface water treatment plant in 2011. As a result, the water supply for the south pressure zone of the City will be essentially entirely supplied from this surface water plant and the remaining two pressure zones (central and north) will be supplied by the existing wells. The surface water source that is currently being developed to service the City of Barrie will be located on the south shore of Kempenfelt Bay (Lake Simcoe). It is anticipated that Well 10, which has not been operating at the efficiency desired by the City, will be shut down and eventually abandoned. At this time, only one additional well, Well 20 located in the west end of Barrie, is planned for construction.

3.2.2 Well Field Hydrogeology

The aquifers underlying the proposed Tier Three Study Area are part of a regionally extensive and complex aquifer system, within which four major sand and gravel aquifer units have been identified. In previous studies, the units in the Study Area and surrounding region have been assigned nomenclature that are used to identify the units in reverse order of deposit, for example: A1 (shallow) – A4 (deep) for aquifers, and C1 (Shallow, immediately below A1) to C4 (deep) for aquitards. A thin confining layer over A1 is identified as UC. A deep, highly transmissive channelized aquifer extends under the central portion of Barrie, generally corresponding to the lowland area. It runs in an east-west direction and extends west towards the Angus-Borden area and east under Kempenfelt Bay. This aquifer corresponds with the regionally identified A3 aquifer and with Pressure Zone 1.

Thinner, less transmissive aquifers extend out regionally from this central core area and are separated by relatively continuous confining layers. However, the confining layer between A3 and A4 is discontinuous within the central part of the aquifer in Barrie, and as a result, the aquifers are often directly interconnected. The A3 and A4 aquifers form the source of the majority of Barrie's groundwater supply, as well as that of the surrounding communities of Midhurst, and Stroud. Locally within Barrie, it is noted that Aquifer A2 is in contact with the lower aquifer in the vicinity of Well 6, where impacts from an organic solvent plume have resulted in the shutdown of that well. Additionally, based on the elevation of the bottom of Kempenfelt Bay and the known elevation of the upper surface of Aquifer A3, it is interpreted that the aquifer is in contact with Kempenfelt Bay in areas to the east.

The City of Barrie Wells 3A, 5 and 12 are all constructed in the deeper aquifer A4. Wells 7, 9, 11, 13, 14, 15, 17 and 18 are located approximately in the centre of the combined A3/A4 aquifer, whereas the remaining wells (Wells 4, 10 and 16) are located in the upper part of aquifer A3. Groundwater flow to the City's aquifers converges from the recharge areas located in the surrounding uplands north and south of the City to Kempenfelt Bay, which is a regional discharge area. Wells in the northern portion of the City (Wells 9, 13 and 16) are recharged within the upland areas in the Township of Oro-Medonte. Conversely, the remaining Barrie wells, located to the south (Well 10) and in the core area of the City, are recharged by flow originating from the west towards the Minesing Wetlands and from the south (Township of Innisfil).

Groundwaters under the direct influence of surface water (GUDI) investigations have been completed for each municipal well within the City of Barrie; none of the municipal wells have been classified as GUDI wells. This lack of interaction with nearby surface water features within the City suggests that the municipal production aquifers (A3 and A4) are well isolated from surface water features by the intervening aquitard units (i.e., C2, C3).

3.2.3 Municipal Demand

Municipal water supplies represent the largest water use within the Study Area. As such, accurate estimates of municipal water use are a critical component of the water demand estimate. For this study, reported municipal pumping rates were obtained from the City of Barrie. Table 3.1 lists the municipal wells within the City of Barrie, broken down by pressure zone. Pumping rates were obtained for the year 2008, as required in the Technical Rules (MOE 2009) for a Tier Three Risk Assessment, as well as for 2010 (January to September) as these represent the most up-to-date pumping rates. Note Well 19 is not active at this time.

TABLE 3.1 Municipal Wells within the City of Barrie and Reported Pumping Rates

Well Name	MOE Number	Pumped Aquifer	Reported Average Pumping Rate in 2008 (m^3/day)	Reported Average Pumping Rate in 2010 (m^3/day)
Pressure Zone 1 – Core Area				
3A (Anne Street)	32108	A4	2,397	2,182
4 (Perry Street)	No record	A3	1,698	N/A
5 (John Street)	271	A4	2,898	2,741
7 (Tiffin Street)	9125	A3/A4	4,746	5,462
11 (Heritage Park)	19246	A3/A4	3,252	0
12 (Centennial Park)	17393	A4	2,972	4,400
14 (Heritage Park)	27877	A3/A4	1,625	4,307
15 (Centennial Park)	28705	A3/A4	2,824	4,595
17 (Cross Street)	37406	A3/A4	3,164	2,589
18 (Cross Street)	39442	A3/A4	3,225	2,904
19 (Boulton Court)	A011235	A3/A4	0	N/A
Pressure Zone 2 - North				
9 (Johnson Street)	12496	A3/A4	3,436	3,997
13 (Johnson Street)	24686	A3/A4	1,985	4,266
16 (Brownwood)	33545	A3	4,809	4,642
Pressure Zone 2 - South				
10 (Huronia Road)	14078	A3	645	0
Total			39,675	42,085

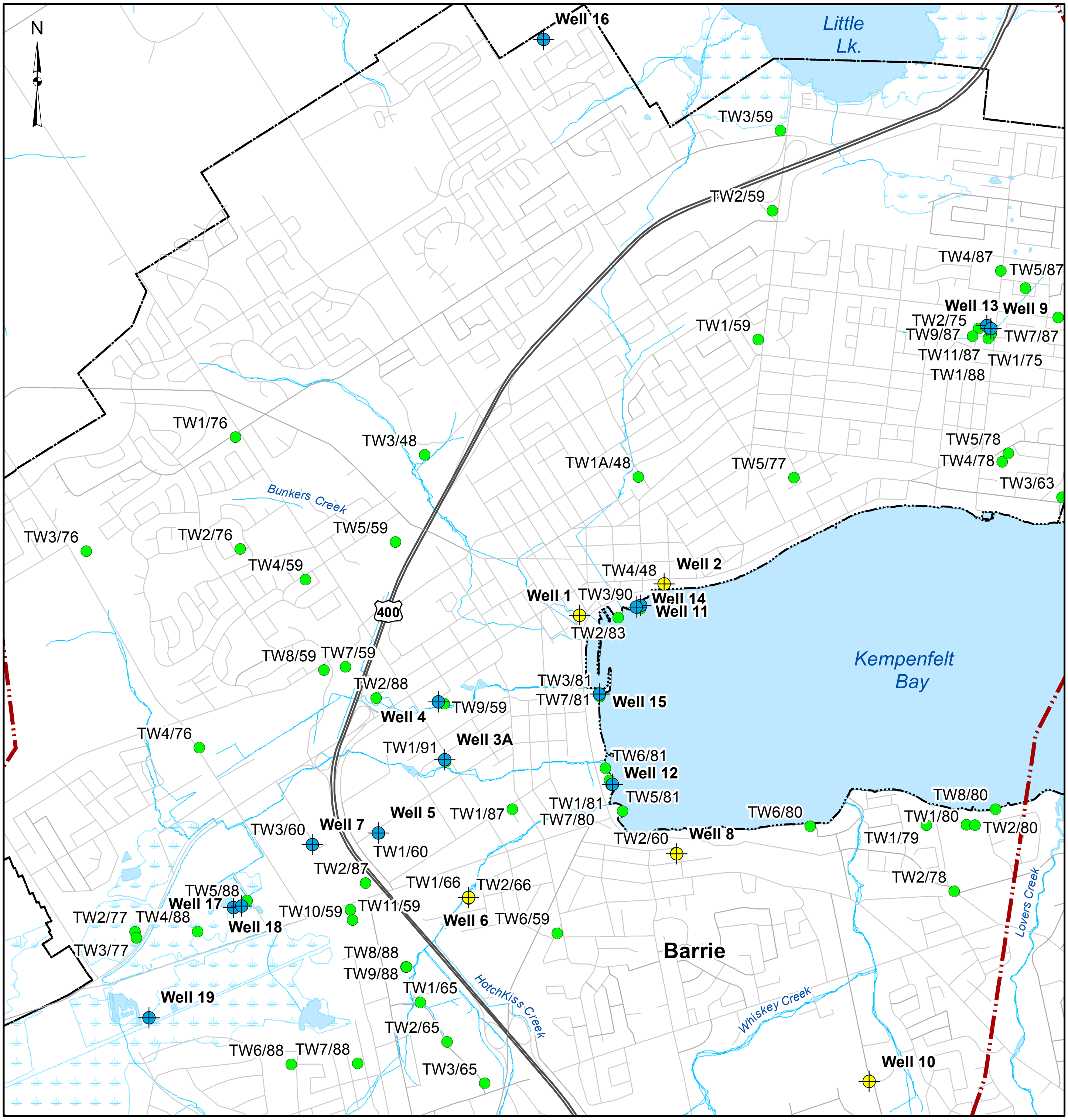
*Note: Average pumping rates for 2010 are based on data from January through September.

3.2.4 Municipal Groundwater Production Trends (Historical Pumping and Water Levels)

Pumping data for the production wells in Barrie were compiled by the City of Barrie and have been added to the project database. Since 1997, daily pumping totals and pump run-times are available from the City's SCADA system and are considered to be the most accurate data available. Water withdrawals for each municipal well from 1997 to 2010, together with water levels monitored in the production well and adjacent monitoring well, if available, are shown in Appendix A3. These graphs of average day per month and average day per year are plotted, using data available from the City of Barrie's SCADA and WaterTRAX systems. The pumping data represents the average instantaneous pumping rates over the month based on the total volume of water pumped and the pump run times. The location of the pumping wells and city monitoring network is shown on Map 3.2.

Water level trends in both the production wells and nearby monitoring wells, together with production rates, are often reviewed to determine periods of well performance decline. Evidence of performance decline would be a decline in pumping level in the production well without an increase in withdrawals, and no corresponding decline in the water levels in the adjacent monitoring well. When this occurs, wells are often taken offline (shut down) for rehabilitation. Both shut down and pumping conditions are useful for the purpose of groundwater model calibration, as local responses to these conditions can be used to test the aquifer response to changes in pumping stress. This information will be used in selecting a calibration period for the groundwater model, evaluating representative pumping rates, developing transient pumping rates for calibration scenarios, and evaluating aquifer continuity by evaluating responses in neighbouring water level data to pumping changes.

Each municipal pumping well, along with their associated hydrographs, is summarized below, and separated by Pressure Zone for discussion purposes.



LEGEND

- Muncipal Supply Wells No Longer in Operation
- Municipal Water Supply
- City of Barrie Monitoring Network
- Towns/Villages
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary
- Focus Areas

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Map 3.2
Barrie Pumping and Monitoring Network

REFERENCES
Base Data - NVCA, 2009
Produced using information provided by the Ministry of Natural Resources, Copyright © Queen's Printer, 2010.
Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 07-Jun-2012; Created By: ccurry

Scale 1:37,500
0.5 0 0.5 1
Kilometres

3.2.4.1 *Pressure Zone 1 – Core Area*

Anne Street Well No. 3A

Well 3A is a replacement well that was constructed in 1991. The hydrograph shows aquifer levels (TW1/91) have remained relatively stable with aquifer levels ranging between elevations of 212 to 222 masl. This reflects the range with Well 3A both in pumping and non-pumping periods. There is no evidence of overall declines or over-pumping. The hydrograph shows, however, that well performance declined between late 2000 and 2002. This was due to well plug-in issues and a rehabilitation program undertaken in 2005 restored the well performance, as shown by the recovered pumping levels in 2006. Well performance declined once again in late 2007.

Average annual and maximum day production was highest in 2000 and 2007 with average annual withdrawals of 4,100 m^3/day and a maximum of 6,100 m^3/day. There have been no long term shut-down periods with this well, the longest two periods were both 2 months in duration: March-April 1999 and March-April 2009.

Perry Street Well No. 4

The hydrograph shows aquifer levels (TW 9/59) have remained relatively stable over the 13 year hydrograph span, ranging between about 212 to 223 masl, reflecting both pumping and non-pumping conditions. Comparison with the original 1959 static water level of 227 masl indicates only a 4 m decline in static level over the last 48 years. This confirms excellent aquifer performance. Water levels in Well 4 are consistent with the observation well and confirm good well performance with no evidence of well plugging.

Average annual withdrawals were the greatest in 2000, at 3,300 m^3/day. Highest maximum day withdrawal was 6,200 m^3/day in 1997. Since 2005, average annual withdrawal has remained less than 2,000 m^3/day with a maximum of 3,100 m^3/day. There has been one major shutdown period from June-August 2003. Water levels during this period stabilized at 215 masl in Well 4, and 218 masl in TW9/59. Well 4 is currently being replaced by a new offset Well 4A due to increased turbidity resulting from sand/silt production in Well 4 and therefore did not pump in 2010.

John Street Well No. 5

Aquifer levels at John Street are stable ranging from between 217 to 225 masl, reflecting the operating range with Well 5 during pumping and non-pumping operation modes. Comparison with the original static level at TW1/60 of 230 indicates a decline of only 5 m over the last 47 years, again confirming excellent aquifer performance with no over-pumping. Well 5 pumping levels are only nominally lower than the TW1/60 aquifer levels demonstrating good well performance. However, since 2004, there are several metres of additional spread between the pumping levels and TW1/60 aquifer levels.

Average annual withdrawals were greatest in 2006 at 3,500 m^3/day. Maximum day withdrawals were highest in 2001 at 6,400 m^3/day. Since 2007, maximum day withdrawals have been below 4,000 m^3/day. There have been several periods of shutdown with this well. The largest one occurs from October 2003 to March 2004.

Wood Street Well No. 6

This well was taken out of service in 2000 as a result of water quality issues. The ongoing monitoring, however, has demonstrated that aquifer levels in the pressure zone remain stable, with no evidence of over-pumping.

Tiffin Street Well No. 7

The hydrograph at TW3/60 at Well 7 shows aquifer levels have remained consistent between 217 and 227 masl. This is compared to the original TW3/60 static level of 230 masl, a decline of only 3 m over the last 47 years, indicating excellent aquifer performance. The Well 7 hydrograph closely follows TW3/60, with no evidence of well performance decline.

Highest average annual withdrawal was in 2008 at 4,700 m^3/day with highest maximum day of 5,800 m^3/day in 2002/2003. Maximum days in 2009/2010 have been about 5000 m^3/day. The longest shutdown period for this well occurred from October 2003 to March 2004.

Heritage Well No. 11

Aquifer levels at TW1/83 have fluctuated between about 202 and 219 masl. This fluctuation range reflects the range in monthly productions during 2000 and 2001. There is no overall declining trend of evidence of over pumping. Pumping levels in Well 11 appeared to decline in 2002 and 2003. A well rehabilitation program in 2005 restored well performance.

The highest annual extraction was 4,400 m^3/day in 2003. Highest maximum day withdrawals were in 1999 and 2003 at about 8,600 m^3/day. There has been no long term shutdown periods; however, this well is offline currently due to well rehabilitation and has been since late 2009.

Heritage Well No. 14

This well is located adjacent to Well 11. As predicted, aquifer performance is similar to the Well 11 site. Pumping levels in Well 14 were consistently above elevation of 200 masl in 1997 and 1998 and then declined somewhat in 1999 and 2000 to below 200 m. Well rehabilitation work was eventually undertaken in 2005 and early 2007 to restore well performance.

The highest average annual withdrawal was near 5,000 m^3/day in 2000 and 2004. The highest maximum day withdrawal was 8,100 m^3/day in 2000. This well has one significant shutdown period from November 2002 to February 2003.

Centennial Well No. 12

Aquifer levels at TW1/81 have shown stable conditions with water levels ranging between about 211 to 220 masl. The original TW1/81 level was 224 masl, which indicates a decline in water level of about 4 m in 26 years. Pumping levels in Well 12 have indicated generally satisfactory performance, although there was a modest decline in 2003. Subsequently well rehabilitations work in 2005 restored performance and pumping levels.

The highest average annual withdrawal was 6,700 m^3/day in 2003 with highest maximum day of 8,700 m^3/day in 1999. This well has had no significant shutdown periods.

Centennial Well No. 15

Aquifer levels as monitored in TW3/81 at this site show stable and consistent aquifer levels ranging between 207 and 220 masl with no evidence of declining levels. Pumping levels in Well 15 mirror the TW3/81 aquifer levels and show excellent well performance with no evidence of well plugging or performance decline.

The highest average annual withdrawal was about 6,500 m^3/day in 1997 and 1999. The highest maximum day withdrawal was 10,600 m^3/day in 1999. This well has had no significant shutdown periods.

Cross Street Well No.17

Well 17 began production in mid 2005. Aquifer levels as monitored in TW1/02 are relatively stable ranging from between 214 to 223 masl. There is no evidence of over-pumping or aquifer performance declines. The Well 17 levels correspond to the TW1/02 levels. Levels in 2006 appear higher than the TW 1/02 levels, which suggests the possibility of measurement errors.

The highest average annual withdrawal was about 6,000 m^3/day in 2005 and a maximum day withdrawal of 8,000 m^3/day. Production declined in the spring of 2006, when Well 18 began production.

Cross Street Well No. 18

This well began production in Spring 2006 and is adjacent to Well 17. The limited available monitoring data shows excellent well and aquifer performance.

3.2.4.2 *Pressure Zone 2 North*

Johnson Street Wells No. 9 and 13

Aquifer levels at this site were essentially stable through to 2000 at about 228 to 230 masl, and then declined modestly through the remaining period to between 225 to 228 masl. This slight decline was likely related to Well 16 coming online in 2001. Compared to the original static level at TW1/75 of 238 masl, there is only about 10 m of water level lowering at this site since 1975, due to operation of the Zone 2 North Wells 9, 13 and 16. It is noted that TW 1/75 was abandoned in 2003 during expansion of the pumphouse facility at this location to provide chlorine contact. TW3/88 remains at this site. Pumping levels show a similar trend to the aquifer levels at TW3/88 and there is no evidence of well performance decline.

Highest average annual extraction was 4,000 m^3/day in 2006 at Well 9 and 5,000 m^3/day at Well 13 in 2003. Highest maximum day was about 7,100 m^3/day in 1997 at Well 9 and 6,900 m^3/day in 1997 and 2000 at Well 13. There has been one major shutdown period for Well 9 from June 2003 to January 2004, and only minor intervals of shutdown for Well 13.

Brownwood Well No. 16

Aquifer levels declined from a preconstruction level of about 235 masl to a range between about 226 to 232 masl after production began. Water levels have remained stable with no evidence of over-pumping.

Pumping levels in Well 16 mirror the aquifer levels in TW2/95 with only a few additional metres of separation and demonstrate excellent well performance.

The highest average annual withdrawal was in 2003 at 6,000 m^3/day and the highest maximum day withdrawal was in 2001 and 2003 at 7,500 m^3/day. The longest shutdown period for this well was one month in duration and occurred in December 2006.

3.2.4.3 *Pressure Zone 2 South*

Huronia Road Well No. 10

Aquifer levels at the Well 10 site (TW1/74) have remained stable ranging between about 219 and 227 masl. The original static water level at TW1/74 was 227 masl, and therefore there has been essentially no decline in static level at this site, demonstrating satisfactory aquifer performance.

Pumping levels in Well 10 have fluctuated considerably and there have been a number of quick rehabilitations performed on this well, which tend to provide a relatively short term improvement. This well provides only a modest supply. The highest average day withdrawal was 2,000 m^3/day in 2004 with the highest maximum day of nearly 4,000 m^3/day. There was a significant shutdown period from June 2003 to March 2004. It is anticipated that Well 10, which has not been operating at the efficiency desired by the City, will be shut down and eventually abandoned.

3.3 Other Groundwater Demands

3.3.1 Other Municipal Water Use

The other communities within the Study Area also obtain potable water from groundwater sources. The locations of other municipal wells are shown on Map 3.1. The main adjacent municipalities that use groundwater for supply include Midhurst, Angus, Stroud, and Innisfil Heights. These systems are included in Table 3.2. The Midhurst wells are within the same vicinity as Barrie's Well 16.

TABLE 3.2 Municipal Wells within the remainder of the Study Area

Municipal System	Well Name	Moe Number	Aquifer	Reported Average Pumping Rate for 2009 (m^3/day)
		Stroud		
Stroud	Well 1	5708340	A3	3.5
Stroud	Well 2 Standby	5711982	A3	0.8
Stroud	Well 3	5720924	A3	489.5
		Angus		
Centre Street (McGeorge)	Well 1	No Record	A3/A4	194.6
Centre Street (McGeorge)	Well 2	No Record	A3/A4	377.9
Brownley	Well 4	5739698	A3/A4	3.9
Brownley	Well 5	5730542	A3/A4	15.4
Brownley	Well 6	5730543	A3/A4	97.5

Municipal System	Well Name	Moe Number	Aquifer	Reported Average Pumping Rate for 2009 (m^3/day)
Midhurst				
Idlewood	Well 2	5711983	A3	110.8
Idlewood	Well 3	5718775	A3	386.4
Greenpine	Well 4	DHL0194	A3	217.5
Carson Road	Well 5*	5725264	A3	280.8
Del Trend	Well 1 (Paddy Dunn's Circle)	5728243	A3	11.07
Del Trend	Well 2 (Paddy Dunn's Circle)	5728671	A3	4.1
Del Trend	Well 3 (Paddy Dunn's Circle)	5733452	A3	120.9
Vespra Downs				
Vespra Downs	Well 1 (1-93)	5729945	A3	38.9
Vespra Downs	Well 2 (1-91)	5728338	A3	0.2
Craighurst				
Craighurst	Well 1	5728783	A1	0
Craighurst	Well 2	5728784	A1	11.1
Craighurst	Well 3	5728785	A2	19.8
Minesing				
Minesing	Well 2	5710801	A3	73.7
Minesing	Well 3	5724869	A2	1.4
Minesing	Well 4	5729291	A2	1.6
Thornton				
Glen Avenue	Well 1	5723177	A2	106.6
Glen Avenue	Well 2	5730575	A2	121.6
Thornton Estates	Well TW1-69	5706712	A1/A2	83.3
Thornton Estates	Well TW2-69	5706711	A1/A2	61.7
Anten Mills				
Anten Mills	Well 1	5712365	A3	0.4
Anten Mills	Well 2	5710898	A3	0.4
Anten Mills	Well 3	5737379	A3	158.6
Shanty Bay				
Shanty Bay	Well 1	5712374	A3	34.6
Shanty Bay	Well 2	5716548	A2	47.1
Shanty Bay	Well 3	DHL0193	A3	68.7
Snow Valley				
Snow Valley	Well 3	5738227	A3	43.2
Snow Valley	Well 4	A011213	A3	134.9
Snow Valley	Well 1	5723284	A3	55.6
Snow Valley	Well 2	5724900	A3	58.1

Municipal System	Well Name	Moe Number	Aquifer	Reported Average Pumping Rate for 2009 (m^3/day)
		Innisfil Heights		
Innisfil Heights	Well 2	5711853	A2	219.2
Innisfil Heights	Well 3	5727320	A2	184.1

*Formerly Well 4

3.3.2 Permitted Non-Municipal Groundwater Users

In addition to the municipal water takers within the Study Area, there are also a number of private permitted water takers within the Study Area (Map 3.1). Estimating the consumptive demand of these water takers involved additional steps to ensure the consumptive use of the water taking as well as the seasonality of the taking were taken into account. The steps below briefly outline the process undertaken to estimate the consumptive use based on the Permit To Take Water (PTTW) database and the Water Taking Reporting System (WTRS).

- Estimate the pumping rate based on the reported water use in the WTRS for 2008; or where this data was not available, combine the maximum permitted rate with the estimated months of active pumping based on the purpose of the water taking (Table A3.1 in Appendix A3).

- Adjust the pumping rate to account for the consumptive use using a consumptive use factor (Table A3.2 in Appendix A3).

The PTTW database used for this analysis was provided by the LSRCA in May 2010, and is considered up to date to January 2009. For additional information, please refer to the SGBWLS Tier Two Water Budget Report (Golder and AquaResource 2010). This data has been built upon for this study with the following goals in mind:

- Confirm Permit Exists (either by site visit or personal communications);
- Confirm that the Estimated Pumping Rate is valid for the permit; and
- Update Well Screens with new data obtained from background review.

The consumptive water use estimates for non-municipal water takings, include water takings for agriculture, commercial, dewatering, industrial and groundwater remediation purposes within the Study Area. A summary of these permits is shown in Table 3.3.

TABLE 3.3 Private Permitted Groundwater Takings

Category	Purpose	Well Name	Pumping Rate (m^3/day)		Permit Number
			Average for 2008	Maximum Permitted	
Agricultural	Field and Pasture Crops	Dugout Pond	*161	982	03-P-1069
Agricultural	Field and Pasture Crops	Well 1	*681	2,589	1664-6W3MCU
Agricultural	Other - Agricultural	Dugout Pond	5	681	00-P-1210
Commercial	Bottled Water	Well 1	0	354	5524-6PEK3Q
Commercial	Bottled Water	Well 2	0	792	5524-6PEK3Q
Commercial	Bottled Water	Well 2	*200	400	8141-7BYRP2
Commercial	Bottled Water	Well 3	*200	400	8141-7BYRP2

Category	Purpose	Well Name	Pumping Rate (m^3/day)		Permit Number
			Average for 2008	Maximum Permitted	
Commercial	Golf Course Irrigation	Clubhouse Well	1	65	0040-733RE2
Commercial	Golf Course Irrigation	Clubhouse Well	3	7	4755-73RHNU
Commercial	Golf Course Irrigation	Dugout Pond	27	1,091	4755-73RHNU
Commercial	Golf Course Irrigation	Dugout Pond	66	1,818	7455-6QPLB5
Commercial	Golf Course Irrigation	Heritage Pond	42	2,000	3474-759GY9
Commercial	Golf Course Irrigation	Heritage Well	10	200	3474-759GY9
Commercial	Golf Course Irrigation	Irrigation Pond	*753	2,619	0386-7AMLUY
Commercial	Golf Course Irrigation	Irrigation Pond	139	2,946	0040-733RE2
Commercial	Golf Course Irrigation	Irrigation Pond	62	1,137	5813-6U2S3J
Commercial	Golf Course Irrigation	Irrigation Pond	102	2,561	5447-6QWR7W
Commercial	Golf Course Irrigation	Irrigation Well	*339	982	0040-733RE2
Commercial	Golf Course Irrigation	Main Irrigation Pd	*50	218	6824-68XPUW
Commercial	Golf Course Irrigation	Pump House	*130	564	3124-6J5T9M
Commercial	Golf Course Irrigation	Well 1	3	32	5813-6U2S3J
Commercial	Golf Course Irrigation	Well 1	*249	720	8531-6ASQXU
Commercial	Golf Course Irrigation	Well 1/94	*113	327	7542-6P8M92
Commercial	Golf Course Irrigation	Well 1-4/93	*1146	1,637	0386-7AMLUY
Commercial	Golf Course Irrigation	Well 2	0	262	5813-6U2S3J
Commercial	Golf Course Irrigation	Well 2-1/93	*687	982	0386-7AMLUY
Commercial	Golf Course Irrigation	Well 3	0	1,570	5813-6U2S3J
Commercial	Mall / Business	Well 1/06	*39	716	5372-6SYPRA
Commercial	Snowmaking	Berry Hill Pond	*915	5,564	6845-6D7NUT
Commercial	Snowmaking	Pond 1 Winter	32	982	6845-6D7NUT
Commercial	Snowmaking	Pond 2 Winter	27	982	6845-6D7NUT
Commercial	Snowmaking	Pond 3 Winter	32	2,618	6845-6D7NUT
Commercial	Snowmaking	Pond Summer	*143	1,309	6845-6D7NUT
Commercial	Snowmaking	Pond Summer	*323	524	6845-6D7NUT
Commercial	Snowmaking	Pond Winter	348	13,092	6845-6D7NUT
Industrial	Aggregate Washing	Source Pond	20	7,980	4105-7EENGW
Industrial	Cooling Water	Private Well	*181	300	6313-5Z4NC5
Miscellaneous	Heat Pumps	Injection Well 3	*0	0	2677-63PK84
Miscellaneous	Heat Pumps	Well 2	*0	98	92-P-3093
Miscellaneous	Heat Pumps	Well 2	*0	0	2677-63PK84
Miscellaneous	Heat Pumps	Well 2	*0	260	2677-63PK84
Miscellaneous	Heat Pumps	Well 4	*0	0	2677-63PK84
Recreational	Other - Recreational	Artesian Well	119	357	5353-5W4LB8
Recreational	Other - Recreational	Pond	126	1,890	5353-5W4LB8
Remediation	Groundwater	Pump Station 1	0	131	5006-7CVGHZ
Remediation	Groundwater	Pump Station 2	23	589	5006-7CVGHZ

Category	Purpose	Well Name	Pumping Rate (m^3/day)		Permit Number
			Average for 2008	Maximum Permitted	
Remediation	Groundwater	Well 1	164	262	1315-6W3QAS
Remediation	Groundwater	Well 2	308	458	1315-6W3QAS
Remediation	Groundwater	Well 3	172	360	1315-6W3QAS
Water Supply	Campgrounds	Well	*12	106	96-P-5022
Water Supply	Campgrounds	Well 1	*4	39	3772-6EQGSY
Water Supply	Campgrounds	Well 3	*7	68	3772-6EQGSY
Water Supply	Campgrounds	Well 4	*5	46	3772-6EQGSY
Water Supply	Communal	House Well	*16	81	1586-62FLP2
Water Supply	Communal	Well 1	*109	547	6334-72JP7N
Water Supply	Communal	Well 1	*371	1,114	87-P-3008
Water Supply	Communal	Well 1	6	327	02-P-1193
Water Supply	Communal	Well 2	*131	655	6334-72JP7N
Water Supply	Communal	Well 2	*371	1,114	87-P-3008
Water Supply	Communal	Well 3	*371	1,114	87-P-3008

*- indicates pumping rate was estimated based on the permitted rate (PTTW 2009), months of active pumping and consumptive water use.

3.3.3 Potential Non-Municipal Groundwater Users

Water users that extract groundwater or surface water for livestock watering, unserviced rural domestic use, fire fighting uses or at a rate less than 50,000 L/d do not require a valid Permit To Take Water from the Ministry of the Environment. Non-permitted water use was estimated at a subwatershed scale in the Tier Two Water Budget and Subwatershed Stress Assessment (Golder and AquaResource 2010) as the individual locations of the takings cannot be specified. The subwatershed scale estimate is not relevant for this study, as the non-permitted demands must be incorporated in the groundwater flow model as a pumping rate at a specific location. As part of this conceptual understanding study, large individual non-permitted water demands are considered. These potential competing demands may represent historic water takings that pre-date the PTTW process and do not require a valid PTTW, or may be a taking less than 50,000 L/d. To the best of our knowledge, the Study Area does not contain any large non-permitted users.

4.0 HYDROGEOLOGIC CHARACTERIZATION

The hydrogeologic characterization of the Study Area includes an understanding of the following key components:

1. The hydrostratigraphic framework (3D structure);
2. The hydrogeologic parameter values, which for flow are primarily hydraulic conductivity;
3. Observations of groundwater elevation (hydraulic head) and flow patterns; and
4. Groundwater recharge.

The following sections describe the current understanding of each of these components.

4.1 Regional Hydrostratigraphic Framework

A hydrostratigraphic framework generally consists of a three dimensional interpretation of the aquifer and aquitard continuity throughout an area. It is a key component of the conceptual hydrogeologic model for an area. This type of framework is typically the basis for hydrogeologic studies, and is the basis for three-dimensional numerical models. For the current study, the goal was to build-upon previous interpretations to develop the hydrostratigraphic framework across the Study Area.

Numerical models for the Barrie area, as well as for several other municipalities, were developed during the South Simcoe Groundwater Studies (Golder 2004) for the purpose of wellhead protection modelling. For these models, an overburden hydrostratigraphic framework was developed across the entire county of Simcoe. The regional framework consisted of interpretations or “picks” (over 75,000 picks of well records) at the top and base of each major regional aquifer unit (A1-A4), as well as the bedrock surface. These picks were used to define surfaces and thicknesses for each of the regional aquifer units, so that consistency was applied throughout all of the models. The surfaces were then refined on a local scale for each individual study. Cross sections were drawn iteratively throughout the process to cross-check surface continuity and to adjust interpretations according to borehole geology. The method of cross section delineation for this framework relied on a modified version of the Geological Survey of Canada (GSC) geomaterials codes. In general, materials that were considered to be primarily sand or gravel were delineated as aquifer materials, whereas materials reported to be primarily clay, silt, or fine-grained sediment were considered to be aquitard materials.

A total of four regional aquifer units have been defined throughout the models and are named A1 through A4, from top to bottom. The uppermost aquifer (A1) is largely associated with upland areas. The majority of the municipal wells are constructed in the A2 and A3 aquifers, found across much of the Study Area, particularly in the vicinity of the larger water supply systems. The A4 aquifer is commonly found in the bedrock valleys. Confining layers between the aquifers are denoted as C1 through C4, from top to bottom, respectively, with C1 located directly below A1. Despite the continuity of the hydrostratigraphic framework, it is important to note that pinchouts, lenses, and windows do occur within any given unit. For that reason, a more local description of the hydrostratigraphy within the Barrie area is presented below, along with a brief history of its development.

4.1.1 Local Study Area Hydrostratigraphic Framework

The hydrogeological conceptual model within the Barrie Study Area was developed during the South Simcoe studies (Golder 2004) and has been updated continuously since then by Golder as part of on-going studies. This conceptual model was developed using the Ontario Water Well Information System (WWIS), as well as test well and production well records. The water well database was updated with all available records from the City of Barrie and is the most reliable information base available. The thickness and distribution of the aquifers and confining layers are based primarily on well records from wells drilled using mud rotary techniques. As such, material descriptions are largely based on cuttings returned to surface, leading to uncertainty surrounding the borehole information.

Within the area of Barrie, the upper aquifer is found in the elevation range of approximately 300 to 220 masl. Regionally, the aquifer extends to over 350 masl, in the Oro Moraine. This aquifer is mostly unconfined. The portions of the upper aquifer identified in the Oro Moraine and the upland areas immediately west of the City (i.e., the Snow Valley and Innisfil Heights areas) correspond to the regional aquifer A1, which is mapped as ice contact stratified drift. In some places, this aquifer may be confined by surficial silty till material also mapped in the uplands. That confining layer is referred to as the upper aquitard (UC). In the lowland areas, the stratigraphic equivalent aquifer is mapped as coarse-grained lacustrine deposits, which are part of a regionally extensive sand plain extending west from Barrie to Angus. The texture of the upper aquifer is variable, but can be characterized overall as fine to medium sand with occasional occurrences of gravel. Detailed logging of this unit in the northwest part of Barrie (Dixon Hydrogeology 2001) indicates that the upper aquifer consists of a number of coarsening upward sequences of lacustrine sand with only minor silt, with an average hydraulic conductivity of approximately 8×10^{-5} m/s.

The A2 aquifer is found in the elevation range of approximately 175 to 230 masl within the lowland areas, but the stratigraphic equivalent extends up to approximately 250 masl to the northeast, under the Oro Moraine. The aquifer is interpreted to extend under Kempenfelt Bay and to the north (towards Midhurst). The lower elevation of the aquifer in the vicinity of Kempenfelt Bay corresponds with the deeper channelized aquifer and suggests that it may represent in-filled former river channels in this area. The A2 aquifer ranges in thickness from approximately 10 to 30 m in most areas. It is regionally extensive, but does pinch out in some areas, for example to the south in the Town of Innisfil and in the vicinity of the community of Sunnidale Corners to the northwest. It is thickest and most extensive towards the west and under the Oro Moraine. The aquifer is complex within the central core area of Barrie, where it consists of inter-layered sand and silt/clay materials. The A2 aquifer is overlain by ≥ 5 to 20 m of confining material in most areas, reported to consist of clay- and silt-rich material. The confining layer (C1) overlying the A2 aquifer has been cored and identified as varved clay and silt. This confining layer appears to be thin to non-existent in some areas, particularly west of Barrie toward Angus. At this latter location, a borehole drilled with auger techniques identified approximately 3 m of silt overlying the A2 aquifer. It is noted that the eastern part of this aquifer is interpreted to be in direct contact with Kempenfelt Bay, based on the base elevation of the bay and the interpreted aquifer extents near its shores. The material in this intermediate aquifer is largely described as sand, with some clast-rich portions.

The primary municipal aquifer in Barrie, referred to locally as the lower aquifer, consists of extensive sand and gravel; this unit is the source of the majority of Barrie's groundwater supply as well as that of the surrounding communities of Midhurst, Shanty Bay and Stroud. The lower aquifer consists of two distinct units in most areas, identified as A3 and A4 in the regional context. These aquifers are in direct contact with one another under the central Barrie area (and hence are grouped), as well as further to the west. It is noted that the A2 aquifer is in contact with the A3 aquifer in some discrete locations. Additionally, based on the base elevation of the Kempenfelt Bay and the elevation of the upper surface of the lower (A3) aquifer, this unit is also interpreted to be in contact with Kempenfelt Bay in areas further east (south of Shanty Bay).

The elevation of the discrete A3 aquifer ranges from approximately 150 to 195 masl. It ranges in thickness from approximately 10 to 40 m, and is regionally extensive. Well records to the northeast indicate that this aquifer pinches out in some areas and its continuity under the Oro Moraine is not known with certainty, as few wells are constructed to depth in that area. The elevation of the A4 aquifer in the Barrie area ranges from approximately 115 to 160 masl. This part of the lower aquifer is a channelized unit in the Barrie area, corresponding to the tunnel channel which extends from Barrie to Angus. Stratigraphic equivalents of this deep aquifer extend to the upland areas, and are typically much thinner and less transmissive.

4.2 Approach to Refining Well Field Hydrostratigraphy

Given the hydrostratigraphic framework described above, hydrostratigraphic surfaces were developed in preparation for three-dimensional groundwater modelling. The hydrostratigraphic units refer to groups of geologic layers that possess similar hydrogeologic characteristics and that are considered to act together as an aquitard or aquifer unit at the scale of the investigation. For this scale, geologic units at the formation scale are generally considered their own hydrostratigraphic unit.

For the current study, the goal was to build-upon previous interpretations to develop the hydrostratigraphic framework across the Study Area. This framework was adjusted where differences in interpretations exist, and where newly collected field data suggested modifications were required. These hydrostratigraphic surfaces will create the structure for the numerical groundwater model.

The hydrostratigraphic framework includes data from the following sources:

- Local Barrie model surfaces from the South Simcoe Groundwater Study (Golder 2004);
- Updates to the Barrie model surfaces (Golder 2009a);
- Regional model interpretations from the SGBWLS Tier Two Project (Golder and AquaResource 2009);
- Borehole interpretations from OGS Field Studies (Burt 2004, Burt 2006);
- Lake Simcoe Bathymetry (LSRCA).

The original conceptual model for the Study Area was developed using hydrogeologic cross sections, which were created based on geologic/hydrogeologic interpretations of the most-reliable data. The interpretation incorporates local knowledge of the area geology, key boreholes, as well as drilling and pumping test data to refine the data and map out stratigraphy in the region. Key interpretations have included the delineation of tunnel channel aquifers, aquitard windows, and bounded aquifer lenses. This process originally produced a set of surfaces used for the 2004 Barrie model in the South Simcoe Groundwater Study. Because the database used to create those surface sets was scrubbed for errors and data problems, both in the preliminary development and throughout the calibration process, the created surfaces provide a strong foundation for the Tier Three study.

The Barrie model (Golder 2004) was updated periodically as field data warranted or as needed for problem-specific applications. The most current of updates was in 2009 to delineate new wellhead protection areas for source protection vulnerability assessments (Golder, 2009a). Throughout the intervening time, new wells were added to the Barrie municipal system and surfaces were checked to ensure compatibility with the drillers logs of the constructed wells. In 2010, the model surfaces were used in the construction of regional surfaces throughout the South Georgian Bay - West Lake Simcoe Source Protection Region for the Tier Two Water Budget. During that study, the interpretation extended the most up-to-date Barrie model surfaces using control data from other local models such as the Wasaga Beach Model, the Angus Model, and the Tiny Township Model (all from the South and North Simcoe Groundwater Studies; Golder 2004; Golder 2006). Borehole lithologies were also used throughout the model construction to ensure that the surfaces remained geologically accurate.

For the current Tier Three study, the Study Area boundary extends slightly beyond the previous Barrie model boundary extents. Therefore, it was necessary to extend the Barrie surfaces to the new model boundary. To fill the data gaps, borehole interpretations ('picks') were used from the regional model surfaces north and south of the model area. The current Study Area also includes a portion of Lake Simcoe, south of Kempenfelt Bay; the bathymetry of that area was included in the current model to facilitate simulation of direct discharge to the lake bottom. This bathymetry was intersected with the model surfaces to determine which surfaces may interact with the base of Lake Simcoe. The same process had been used in the 2004 model for Kempenfelt Bay, however the current Study Area also includes a section of Lake Simcoe. New borehole data from subsurface investigations in Kempenfelt Bay were added into the interpretation database and were also used to modify the surfaces. High quality Ontario Geological Survey (OGS) geology data was also included (see Section 4.2.1).

The inclusion of the data listed above resulted in a realistic representation of the local aquifer system, as determined by borehole analysis. The resulting representation provides a well-founded regional hydrostratigraphic model that will facilitate a smoother calibration process and development of a numerical model that can be used for both the current water budgeting project as well as future projects. The locations of all of the boreholes used for interpreting the hydrostratigraphic surfaces are shown in Map 4.1. This dataset includes all of the newly appended data, as well as the original dataset.

4.2.1 Identification of High Quality Data

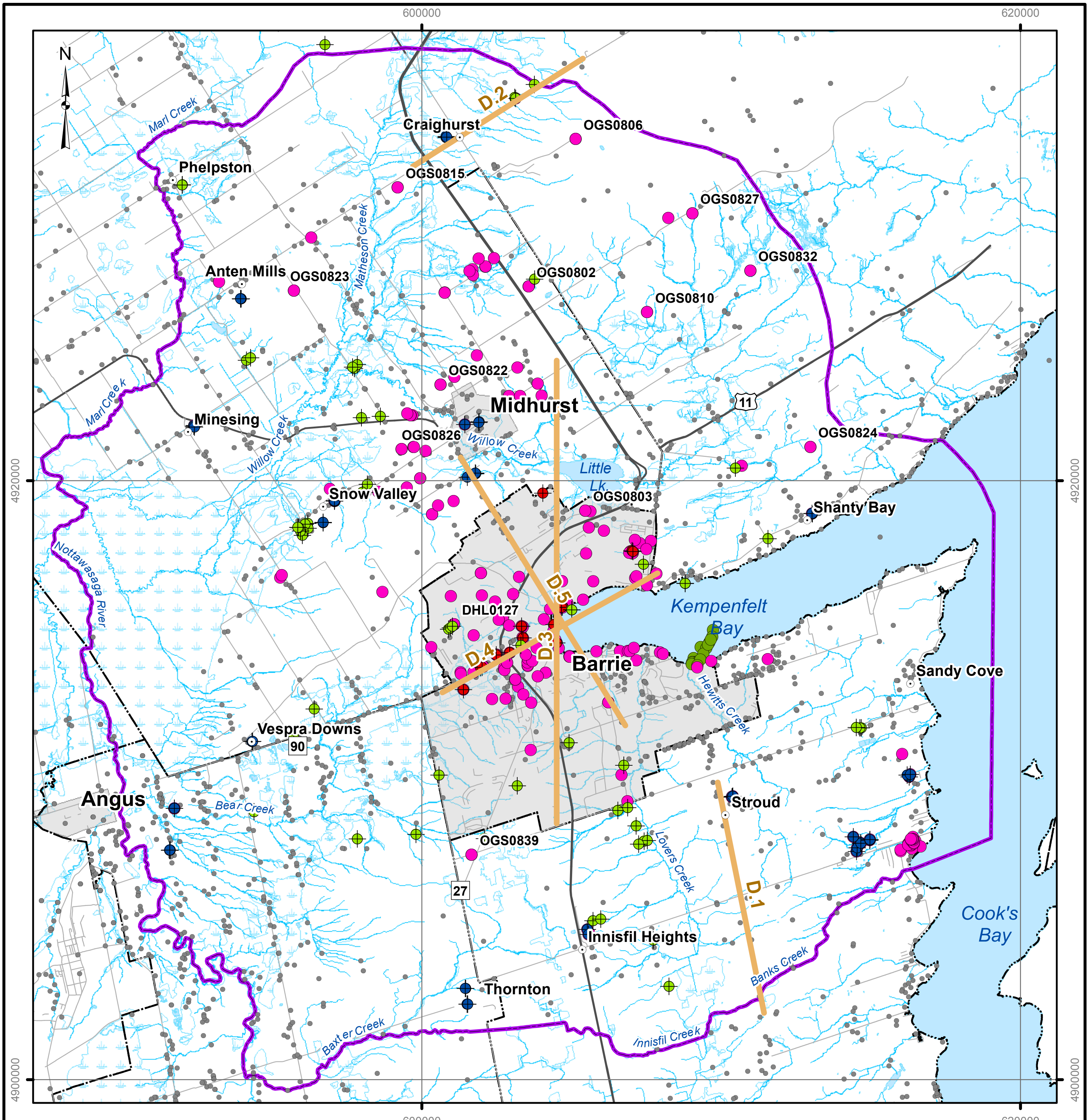
The hydrogeological setting described above provides the basis for the three dimensional hydrogeological model. The thickness and distribution of the aquifers and confining layers are based primarily on well records from mud rotary drilled wells, whose materials descriptions are largely based on cuttings returns. Boreholes used in the interpretation of the hydrostratigraphic surfaces underwent a high level of data scrubbing during the construction of cross sections for the South Simcoe models.

Database screening procedures throughout the South Simcoe studies involved:

- Assigning the DEM elevation to each well, and comparing the DEM elevation to the elevation originally recorded in the database. Wells where the DEM elevation differed by more than 10 m from the recorded elevation were rejected as they were presumed to be incorrectly located;
- Removal of all wells with a recorded UTM reliability code greater than 5 (indicating a positional accuracy of between 300 m to 1 km);
- Removal of wells where bedrock elevation did not reasonably correspond to surrounding bedrock elevation in adjacent wells, as those wells were presumed to be incorrectly located;
- Removal of wells where the recorded bottom depth of the borehole did not match the depth of the bottom of last geologic unit, as those wells were assumed to contain further errors; and
- Removal of wells that did not have a complete geologic sequence (geologic intervals missing).

This data scrubbing resulted in a refined standard dataset for the interpretation of the hydrostratigraphic surfaces. This resulted in a total of 2400 borehole interpretations that were deemed to be of higher quality, of out a possible 6600 boreholes which were contained within the original WWIS database.

From this, a high quality subset was identified. Professional knowledge of the local geology and drillers, as well as familiarity with the borehole construction and history from key wells was beneficial to this process. Borehole logs that had been previously reviewed throughout other projects were identified, these included OGS Wells, University Research Wells, landfill investigations or boreholes obtained through other groundwater field studies.



LEGEND

- Investigative (High Quality) Borehole
- Kempenfelt Bay Boreholes
- Picks
- Barrie Municipal Wells
- Other Municipal Wells
- Private Wells
- Towns/Villages
- Profile Locations
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary

Barrie Tier 3 Conceptual Understanding Report

AquaResource
A Division of Matrix Solutions Inc.

Golder Associates

IWC International Water Consultants Ltd.

Map 4.1

Stratigraphic Interpretation Locations

REFERENCES
Base Data - NVCA, 2009
Produced using information provided by the Ministry of Natural Resources, Copyright © Queen's Printer, 2010.
Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 07-Jun-2012; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

While boreholes drilled using rotary (mud) drilling contain important stratigraphic knowledge, the most accurate and most detailed source of data are continuously cored boreholes. There have been several field programs within the Study Area that provide this level of detail; these data have been incorporated into both the South Simcoe Database and the linked Barrie Tier Three database. The majority of the continuously cored boreholes were drilled by the OGS in 1990, 2004, 2005 and 2006. The 1990 drilling program resulted in 7 holes totalling 525 m, one of which, OGS-90-10, is within the current Study Area boundary (Barnett 1991). During the 2004 field season, 14 sonic boreholes, totalling 1185 m, were drilled and logged in the field. Two and one half inch monitoring wells with 1.5 m screens were installed by the Lake Simcoe Region Conservation Authority at selected boreholes (Burt 2006). Downhole geophysics was carried out on 11 of the 14 holes. The data consisted of written logs, which included unit descriptions with sample locations and representative photographs; graphic logs that include lithology, grain size, select carbonate results and downhole geophysics were also provided. In 2005 and 2006, a total of 18 holes were drilled, logged and sampled with the same methodology. Most of the 2005 and 2006 boreholes were focussed within the Oro Moraine. Of the 2004-2006 field program boreholes, 11 OGS boreholes are within the Tier Three boundary and are identified on Map 4.1.

Within the City centre, the depths and extents of the key aquifers found within the WWIS database are supported by the hydraulic testing of the municipal supply wells. Whereas interpretations of aquifer hydraulic properties are supported by long term hydraulic testing, data on the continuity and hydraulic conductivity of the confining materials are sparse.

4.2.2 Cross Section Interpretation

The surface generation was an iterative process including review and visualization of picks and surfaces in plan view, cross section and three dimensional views. The conceptual model surfaces were interpolated based on the geologic formation picks that are described above, with additional interpretive controls such as Lake Simcoe bathymetry and a 5 m DEM. All surfaces were constrained such that the layer elevation did not exceed the elevation of the overlying layers. This constraint is most important and relevant in the central portion of the Study Area where the deeper formations are closer to ground surface and where the upper formations are often non-existent and pinch out, particularly in areas of steep valleys.

The hydrostratigraphic surfaces were evaluated using cross sections with two priorities in mind: (1) to ensure that the extension of the Barrie model surfaces were geologically appropriate and in doing so created a link to the regional Tier Two model surfaces; and (2) to ensure that the local interpretation of geology within the Focus Area was up-to-date and appropriate. Two regional cross sections and three local cross sections have been included in Appendix A4 and are discussed below. The locations of these cross sections are shown on Map 4.1. The resulting isopachs of the generated surfaces are provided in Appendix A5.

4.2.2.1 *Linkages to Regional Conceptual Model*

Ensuring consistency between the Barrie model and the regional Tier Two model was a priority in extending the model surfaces. This linkage provides a better means to incorporate data from the regional model, such as deep cross boundary flows or material properties. In addition, using borehole picks from the regional interpretation means that the data used has already undergone a quality control process, and is a better foundation upon which we can make improvements. Two regional cross sections (Figures A4.1 and A4.2) have been selected for illustration purposes. These cross sections occur in areas where the model surfaces have been extended; therefore the cross sections show the transition of the surfaces from the South Simcoe Barrie model study area, to the surfaces of the regional Tier Two model. The first cross section, Figure A4.1, shows the largest extension in the south of the Study Area (Innisfil Heights). The original model boundary occurs at approximately 3.2 km from the right of the cross section. The surface extends another 4 km south to the current Tier Three model boundary. The extended area matches reasonably well to the boreholes within this area; the aquifers are generally thin and discontinuous in the Innisfil area. Additionally, the transition from one dataset to the other is smooth. Figure A4.2 shows the extension of the model surfaces in the Oro area, in the northeast of the Study Area. The South Simcoe model boundary extended to the 4.2 km mark on the cross section. The remainder of the surfaces was extrapolated to extend the surfaces 1 km further north.

4.2.2.2 *Cross Sections Local to Well Fields*

Capturing local well field-scale hydrogeology within the conceptual model is important in assessing local area risks. Three local cross sections (Figures A4.3 to A4.5) were selected for this report. Two of these cross sections, Figures A4.3 and A4.4 are analogous to cross sections used for evaluating the South Simcoe Barrie model surfaces and intersect almost all of the municipal wells. The third, Figure A4.5 was drawn to show the remainder of the municipal wells, as well as a perpendicular section through Kempenfelt Bay. The cross sections illustrate the distribution of Barrie’s interpreted municipal water supply aquifers relative to the elevations of the municipal well intake screens. These cross sections also illustrate the potential heterogeneity of the setting (recognizing the uncertainty with mud-rotary well logs), particularly within the tunnel channel deposits. Examples of the heterogeneity can be found at several locations where multiple well logs are very close (within 100m of one another) yet are logged to have starkly different lithologies (see Well 14 area). Given this heterogeneity, it is not possible for the interpreted hydrostratigraphic surfaces to match every borehole; rather the trend in observed in multiple logs, along with the knowledge of the hydraulic behavior was used to interpret the hydrostratigraphic layers, as described above.

4.3 Hydrogeologic Properties within Framework

Aquifer testing information is available for all but the oldest municipal wells in Barrie. Each of these tests provides a transmissivity estimate for aquifer A3. Most tests were completed over a 24-hour period; however, the most recent tests were extended to 72 hours. All available aquifer testing of the municipal wells were reviewed for this study. Overall, the transmissivity of Pressure Zone 1 in the centre of the city is highest, with interpreted values of transmissivity ranging from approximately 1,000 to 3,800 m^2/day. Poorer aquifer materials, and thinner zones of the aquifer layers exist on the flanks of the pressure zone reducing the effective transmissivity (after boundary effects) to about 1,000-1,500 m^2/day. Reported transmissivities in areas to the north and south are lower, typically below 2,600 m^2/day and as low as 325 m^2/day at the location of former Well 8. Table 4.1 provides a summary of the estimated aquifer parameters derived from pumping tests at the municipal wells. Transmissivities 'After Boundaries' refers to the Transmissivites calculated based on drawdown vs time slope (Cooper -Jacob method) after the influence of a negative boundary (ie increased drawdown/time slope) has become apparent.

TABLE 4.1 Aquifer Parameters from City of Barrie Municipal Testing Results

Name	Pumping Rate (L/s)	Test Duration (hour)	T (m^2/day)	T (after Boundaries) (m^2/day)	K (m/day)	S	Formation Depth (m)	Screen Setting (m)
Well No. 3A	77.7	24	2,875	(983)	125 (43)	3×10^{-4}	43 - 66	57.6 - 66.7
Well No. 4	76.6	24	1,250	-	78	4×10^{-4}	40 – 56	50 – 56
Well No. 4A	75.5	72	1,000-1,300	-	67 - 87		32 - 57	44 – 53.3
Well No. 5	75.8	24	2,050 – 2,470	-	52 - 63	2×10^{4}	63 - 102	88.4 - 106.7
Well No. 6*	83.4	24	2,530	(968)	79 (30)	2.5×10^{-2}	32 - 71.6	53.6 - 71.6
Well No. 7	91.0	24	3,380	(1,385)	125 (51)	7×10^{-3}	73 - 100.3	85.3 - 100.6
Well No. 8*	60.0	24	238 - 325	-	8 - 11	5×10^{-3}	41 - 70	46.9 - 69.5
Well No. 9	85.4	24	2,530	-	34	0.2	21 - 94.5	77 - 93
Well No. 10	56.9	48	581	(328)	24 (1)	10^{-4} - 10^{-5}	69 - 93.6	85.6 - 93.6
Well No. 11	91.0	72	1,209	-	36.6	8×10^{-4}	32 - 65.5	47.2 - 61.3
Well No. 12	106.0	30	1,043	(834)	26 (21)	1×10^{-3}	48 - 88.4	65.5 - 83.8
Well No. 13	75.8	24	2,620	-	37	-	27 - 97	82.9 - 89
Well No. 14	106.0	24	1,340	(1,117)	48.6	-	36 - 61	42 - 60.9
Well No. 15	106.0	24	1,800	-	75	5×10^{-4}	42 - 66	
Well No. 16	91.0	72	1,490	-	67	5×10^{-4}	52 - 74	64 - 73.5
Well No. 17	136.5	72	2,385 – 2,980	-	51 - 65	5×10^{-4}	68 - 114	86.2 - 104.8
Well No. 18	128.9	72	2,500 – 3,000	(1,570)	58 - 69 (36)	10^{-4} - 10^{-5}	67 - 110	87.5 - 106
Well No. 19	91.0	72	2,905	(1,445)	126 (63)	10^{-4} - 10^{-5}	71 - 93.6	84.4 - 93.7

*Note: Well 6 is nonoperational due to water quality concerns and Well 8 is sealed and abandoned.

4.3.1.1 *Central Barrie*

The transmissivity of the central part of aquifer A3 is estimated to range from approximately 1,000 to 3,800 m^2/day. The highest transmissivities are reported to be in the western part of the aquifer. The rated maximum well yields range from approximately 4,500 to 11,100 m^3/day (700 to 1,700 Imperial gallons per minute or IGM).

The testing of the wells in this area is influenced by the close proximity of the boundaries of the tunnel channel to the north and south, as well as by the influence of the operating wells during later testing.

The transmissivity of the lower aquifer in the lakeshore area is estimated to range from a low of approximately 325 m^2/day to the south at former Well 8, to a high of approximately 1,800 m^2/day at Well 15. The tested maximum well yields range from approximately 5,200 to 9,200 m^3/day (800 to 1,400 Imperial gallons per minute or IGM). Similarly to the core area wells, analysis of the test results indicates a bounded aquifer and/or lower aquifer transmissivity at distance.

4.3.1.2 *North and South Barrie*

The transmissivity of the Johnson Street wells (Wells 9 and 13) is reported to be approximately 2,600 m^2/day. The test data indicate that equilibrium conditions were not obtained during the testing of Well 13, and that unconfined conditions may exist in the area. Given this, and the relatively short duration of the test (24 hours), the true transmissivity of the aquifer in this area is considered to be in the lower part of the reported range. The tested maximum yield of Wells 9 and 13 ranges from approximately 6,500 to 7,400 m^3/day (1,000 to 1,130 Imperial gallons per minute or IGM).

The transmissivity of the aquifer in the Brownwood (Well 16) area is reported to be approximately 1,500 m^2/day. The tested maximum well yield was approximately 7,900 m^3/day (1,200 Imperial gallons per minute or IGM).

The transmissivity of the aquifer in the Huronia Road (Well 10) area is reported to be approximately 580 m^2/day. The tested maximum well yield was approximately 2,000 m^3/day (300 Imperial gallons per minute or IGM). This is consistent with the lower transmissivities reported elsewhere for the lower aquifer outside of the central channel area.

4.3.1.3 *Regional Model Area*

The transmissivities of wells outside of the Barrie area are used to define the aquifer hydraulic parameters in the regional model area.

The transmissivities of the aquifers utilized by these outlying systems range from approximately 50 to 700 m^2/day. The highest transmissivities are reported for the Midhurst system, which is located in a channelized aquifer unit to the north of Barrie.

4.4 Current Groundwater Level Monitoring Data

There are several groundwater studies within the Study Area that involve the collection of hydrogeological data (water levels, vertical gradients, etc.). Golder (2004) conducted a regional groundwater level and quality monitoring program in 2002 within Simcoe County that included the collection of information from the County of Simcoe landfill monitoring program, private well supplies, non-supply wells and municipal groundwater supply systems. The data were compiled and a database was constructed. Details regarding the sampling program are presented in the South Simcoe Municipal Groundwater Study report (Golder 2004). Data collected are incorporated into both the Simcoe County database, as well as the Barrie Tier 3 database. This data is linked to the Barrie Tier Three database to extract only those wells needed for the current study. Map 4.1 illustrates the locations of monitoring wells within the Study Area. These monitoring locations include both those from the WWIS database as well as a higher quality dataset from selected observation wells surrounding each well field. Map 4.2 shows the locations of the monitoring wells.

4.4.1 City of Barrie Monitoring

Municipal Monitoring Network

The Barrie municipal systems are monitored on a regular basis. The locations of these observation wells are shown on Map 3.2. The wells are also included in the Barrie Tier Three database and are considered high quality observation wells. Hydrographs for many of these wells are shown in Appendix A3. The locations of these wells are away from production wells, and therefore tend to reflect the production aquifer (within the city of Barrie) response to the overall Barrie Well system withdrawals. These hydrographs show excellent aquifer performance with essentially stable conditions or slight declines in response to increased withdrawals. Seasonal water levels respond to the variation in production with lower levels during the summer and recovering water levels in the spring and fall/winter. TW1/87 is located in the Barrie core area and shows that overall average annual levels and minimum levels have not changed significantly during the 10 years hydrograph period. Furthermore, based on the reported static level of 222.2 in April 1987, spring levels remain similar or only slightly less after 20 years. The other area monitoring locations show generally similar results, which demonstrates that aquifer performance remains satisfactory with no evidence of over pumping.

High Quality Monitoring Wells

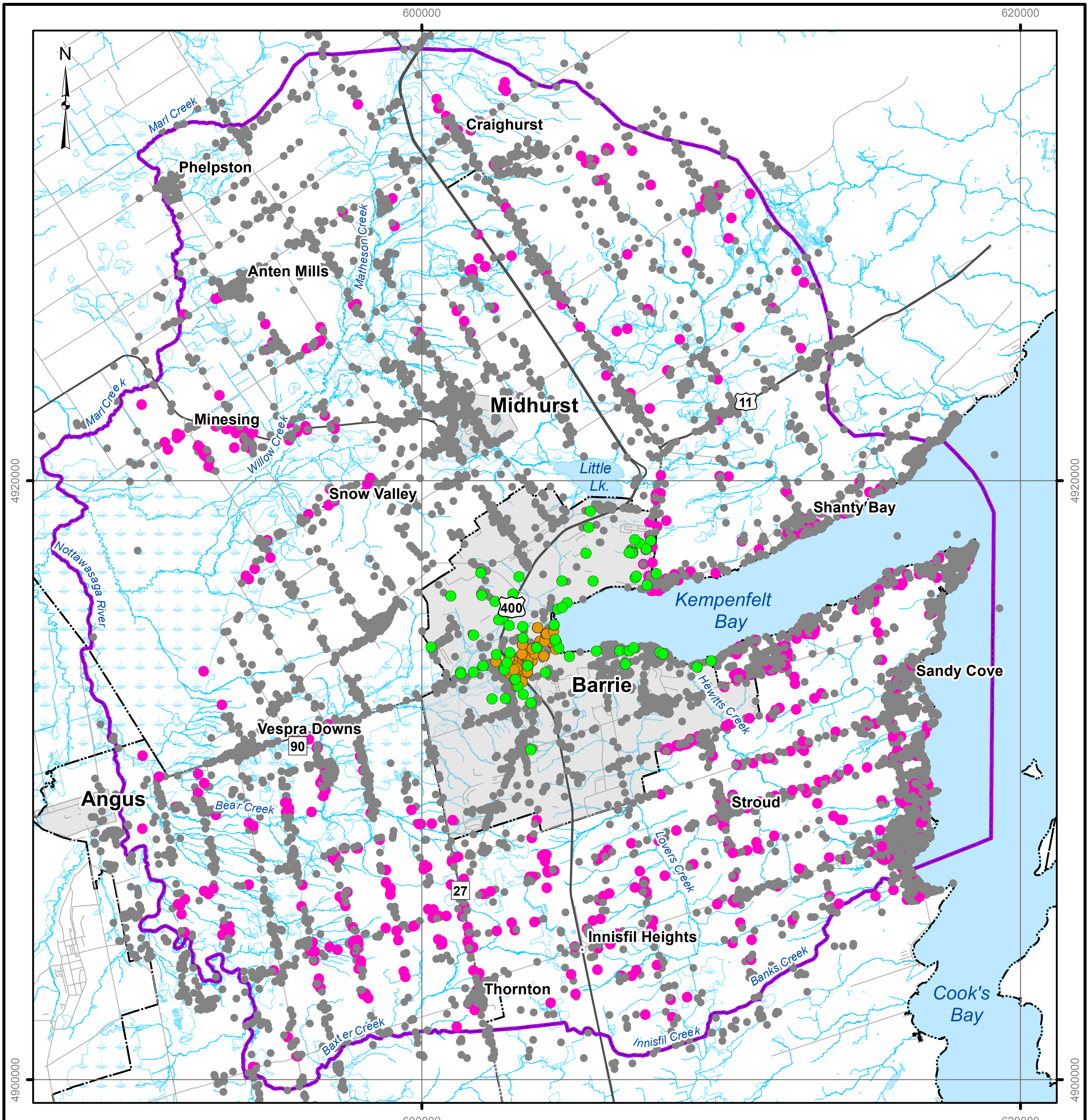
In addition to the municipal monitoring network, other high quality observation wells were identified. These high quality observations wells were extracted from a conducted by Golder (2009b) to more-accurately map flow directions in the immediate vicinity of municipal production wells. These wells, which include the municipal monitoring network, are indicated on Map 4.2.

4.5 Water Level Mapping

Earlier studies indicated the general groundwater flow patterns in the vicinity of the Barrie area (IWS 1981; Dixon 2001; Golder 2004). Maps 4.3 and 4.4 illustrate the shallow and deep groundwater equipotentials within the Study Area; recognizing that groundwater flow is perpendicular to equipotentials (at least within the same aquifer), these maps can be used to approximate groundwater flow directions. These maps were derived within the South Simcoe Groundwater Study and are based on observed water levels in observation and pumping wells.

4.5.1 Groundwater Flow Patterns

Based on the contours in Maps 4.3 and 4.4, water levels throughout the Study Area are noted to mimic topography. Groundwater flow is predicted to converge on Kempenfelt Bay from a flow divide that generally follows the focus area outline toward the west and southern edge of the City and the City boundary to the north. Groundwater recharging west of this divide generally flows toward the Nottawasaga River basin. Groundwater gradients within the shallow groundwater regime typically range



LEGEND

- City of Barrie Multilevel Wells
- City of Barrie Monitoring Network
- High Quality Dataset
- Standard Dataset
- Towns/Villages
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary

REFERENCES
Base Data - NVCA, 2009
Produced using information provided by the Ministry of Natural Resources, Copyright © Queen's Printer, 2010.
Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 07-Jun-2012; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

Barrie Tier 3 Conceptual Understanding Report

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Map 4.2

Observation Wells

LEGEND

- Towns/Villages
- Shallow Water Contour Levels Interval 10m (masl)
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary

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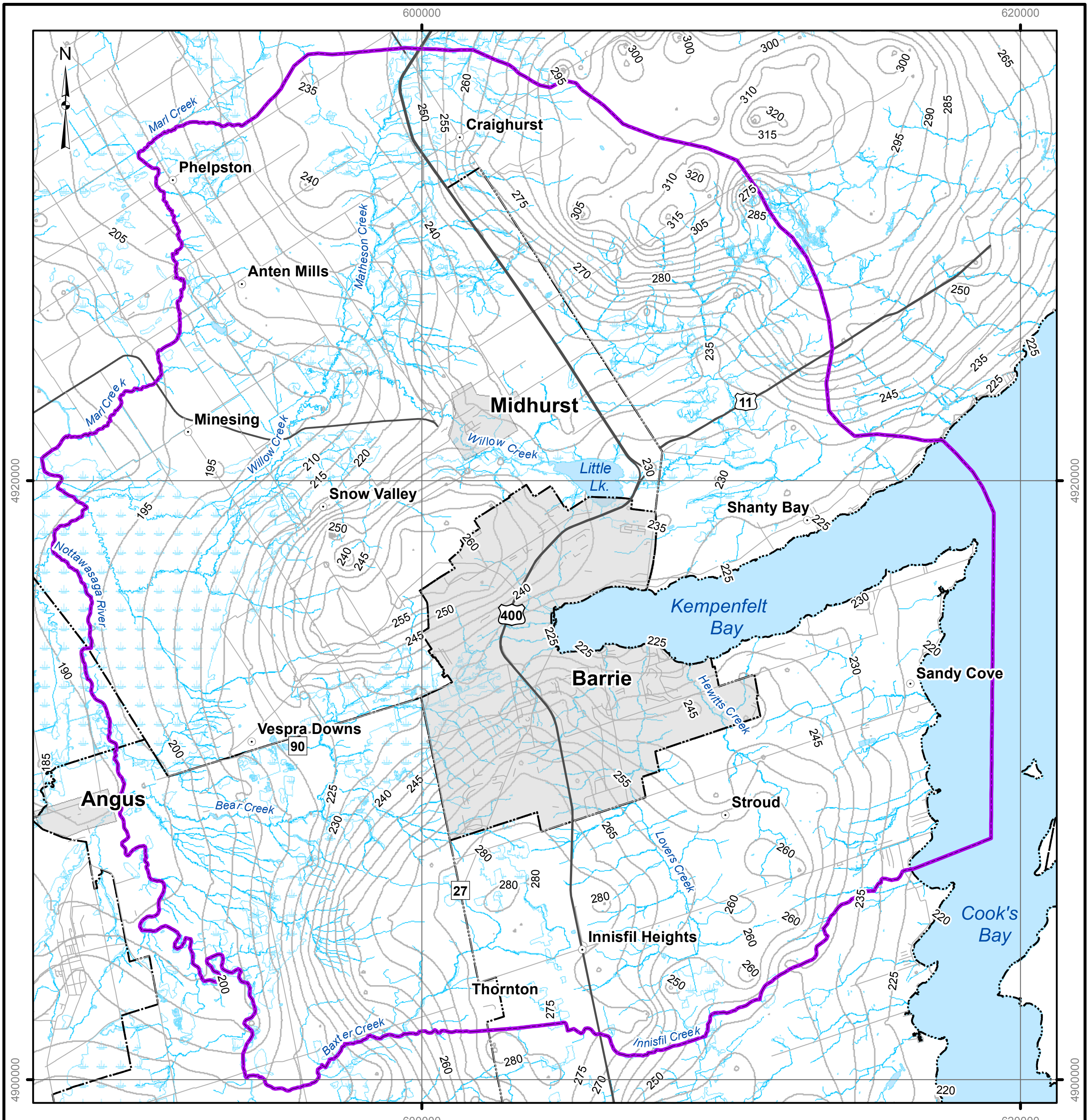
Kilometres

Map 4.3

Shallow Equipotentials (A1)



LEGEND

- Towns/Villages
- Deep Water Contour Levels Interval 5m (masl)
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary

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Map 4.4

Deep Equipotentials (A3)

REFERENCES
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from 4 m/km to 6 m/km; however, gradients of up to 19 m/km have been measured on the flanks of the Oro Moraine (Golder 2004).

It is hypothesized that shallow groundwater flow from the upland areas north and south of the Bear Creek Wetland sustain this wetland, year-round. A review of available base flow monitoring from the Bear Creek Wetland illustrate a seasonal fluctuation in base flow that strongly corresponds with climatic changes throughout the 2007-2008 period (I.W.S. 2009). A review of the stratigraphic surfaces across the valley also supports this hypothesis as Aquifer A1 is delineated to thin dramatically from the north and south uplands to the lowland area where the wetland is located. This shallow flow system is also expected to be sustaining many of the cold water creeks located within the City of Barrie (e.g., Whiskey, Hotchkiss, and Kidd Creeks).

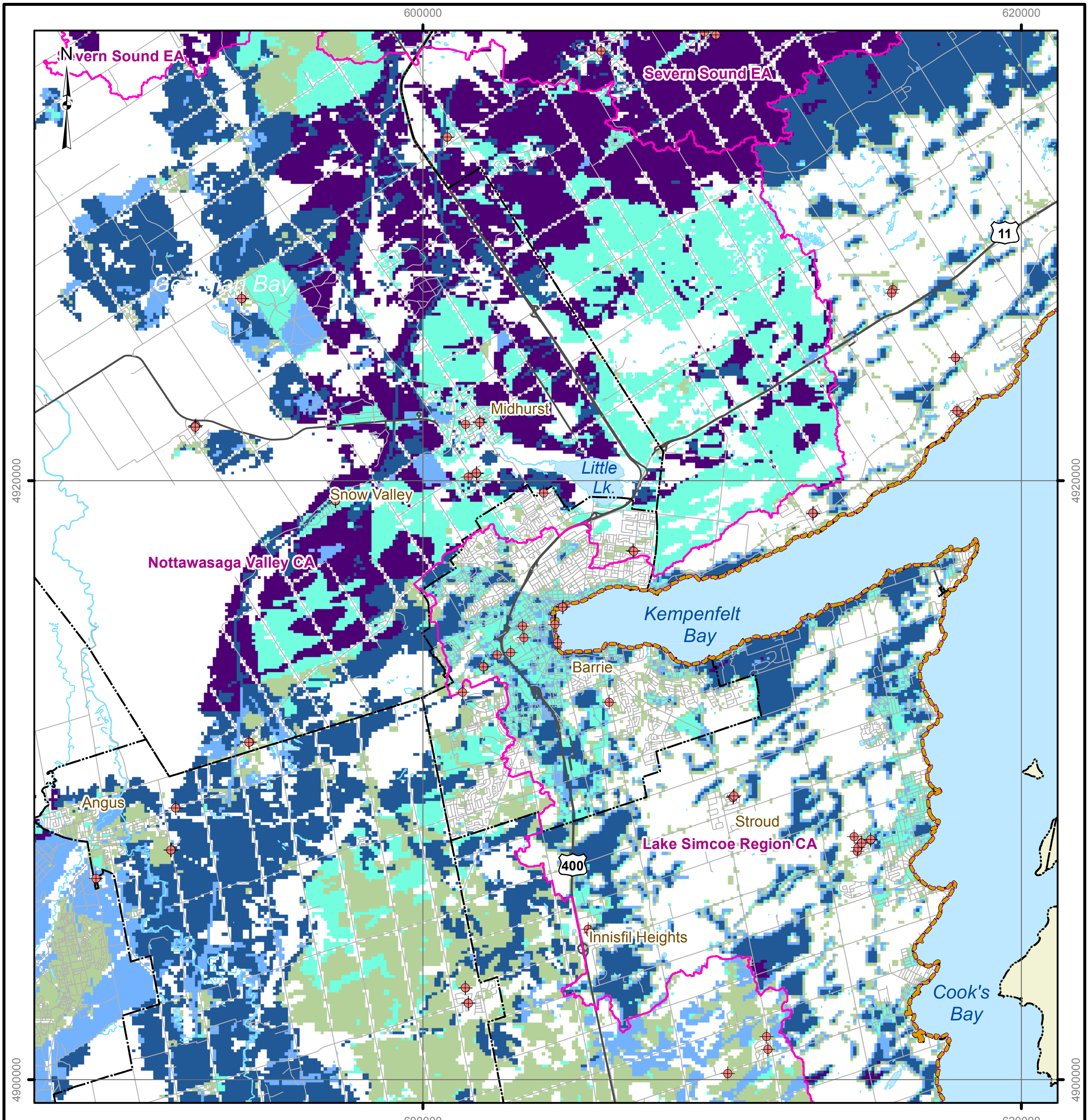
A comparison of Maps 4.2 and 4.3 can be used to infer vertical hydraulic gradients and potential flow directions. This comparison generally shows the direction of vertical hydraulic gradients to be downward within the majority of Study Area, and particularly throughout the upland areas. However, upward gradients are also evident, particularly beneath the City Centre, along the shore of Kempenfelt Bay. Wells located along this shoreline (e.g., Wells 12 and 15) historically flowed when drilled and are currently returning to this state now that local pumping has ceased. Similarly, upward hydraulic head differences are mapped to occur along the western boundary of the Study Area beneath the Minesing Wetlands. Maps illustrating upward and downward gradients within the watershed are presented in Golder (2004).

4.6 Groundwater Recharge

Precipitation, ground surface topography, land use activities, surface water features and the spatial distribution of subsurface aquifer units all play a role in determining groundwater recharge. Precipitation is the primary source of groundwater recharge (i.e., the amount of water that infiltrates through the unsaturated zone and ultimately reaches the water table). In general, the hydraulic conductivity of surficial sediments, slope of the topography, physiography, land use activities, and soil moisture content (including the depth to water table) are the primary controls on recharge. Recharge is enhanced in areas were the ground surface is hummocky and water cannot move as easily to contribute as runoff to nearby creeks and rivers.

The best estimate of recharge rates for the Study Area have been calculated from two adjacent surface water models of the Study Area, namely Hydrologic Simulation Program-FORTRAN (HSP-F; U.S. EPA 1997) and Precipitation-Runoff Modeling System (PRMS; Leavesley et al. 1983). Both modeling codes were developed as part of the Tier Two Water Budget for the Study Area. The HSP-F model was developed by NVCA (2010) for the Nottawasaga Valley and Severn Sound watersheds. The PRMS model was developed by Earthfx (2010b) for the Lake Simcoe watersheds. Information on the development and calibration of these models can be found in Earthfx (2010b) and NVCA (2010). The annual average recharge rates estimated across the Study Area range from a low of less than 50 mm/year to a high of greater than 450 mm/year. Map 4.5 illustrates the estimated recharge distribution within the two conservation area jurisdictions.

As illustrated on this map, differences between the predicted recharge rates along the boundaries of the two models are evident. It is important to note that these recharge rates were created with two independent models, each with differing assumptions, parameters, boundary conditions, and levels of calibration. To overcome this inconsistency and to improve upon the reliability of the recharge estimate,



LEGEND

- Water Supply Well
- Road
- Expressway / Highway
- Open Water
- Watershed Boundary
- Township Boundary
- Study Area Boundary

Recharge (mm/yr)

- 0 - 75
- 75 - 150
- 150 - 225
- 225 - 300
- 300 - 375
- 375 - 450

REFERENCES

Base Data - NVCA, 2009. LSRCA, 2009.
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Scale 1:180,000

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Kilometres

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Map 4.5

Model Recharge per Hydrologic Response Unit

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Project: 2010007 BarrieTier3

a new model is being constructed to generate a consistent set of recharge rates for the Study Area. That work is being completed as part of Phase 3 of this study; model selection critera for this work is presented in Section 5 of this report.

4.7 Groundwater Model Development

To complete the Tier Three assessment, an updated groundwater model is being developed for the Study Area. This model will utilize the same software as the previous model (FEFLOW), however it will cover the extended Study Area and incorporate all of the features described in this section. In this manner, the updated model will build upon the previous work, enhancing the characterization that supports the modeling calculations.

The groundwater model will be developed and calibrated in the same manner as was applied for the Tier Two water budget evaluation; however, the Tier Three model will necessarily contain more refined parameter distributions and be more closely calibrated to available high quality data water level data (presented in Section 4.4), and groundwater base flow data (see Section 5.1).

Prior to applying the model for the Tier Three assessment, the model will be calibrated to both steady-state and transient (time-varying) water level / pumping conditions to enhance the interpretation capabilities.

5.0 HYDROLOGICAL CHARACTERIZATION

This section provides a summary of the Study Area's hydrology and available data. Hydrological characterization is a key component in the development and calibration of a surface water model, which will be used to generate groundwater recharge estimates. The selection of the surface water model is included in Section 5.4.2.

5.1 Streamflow Data

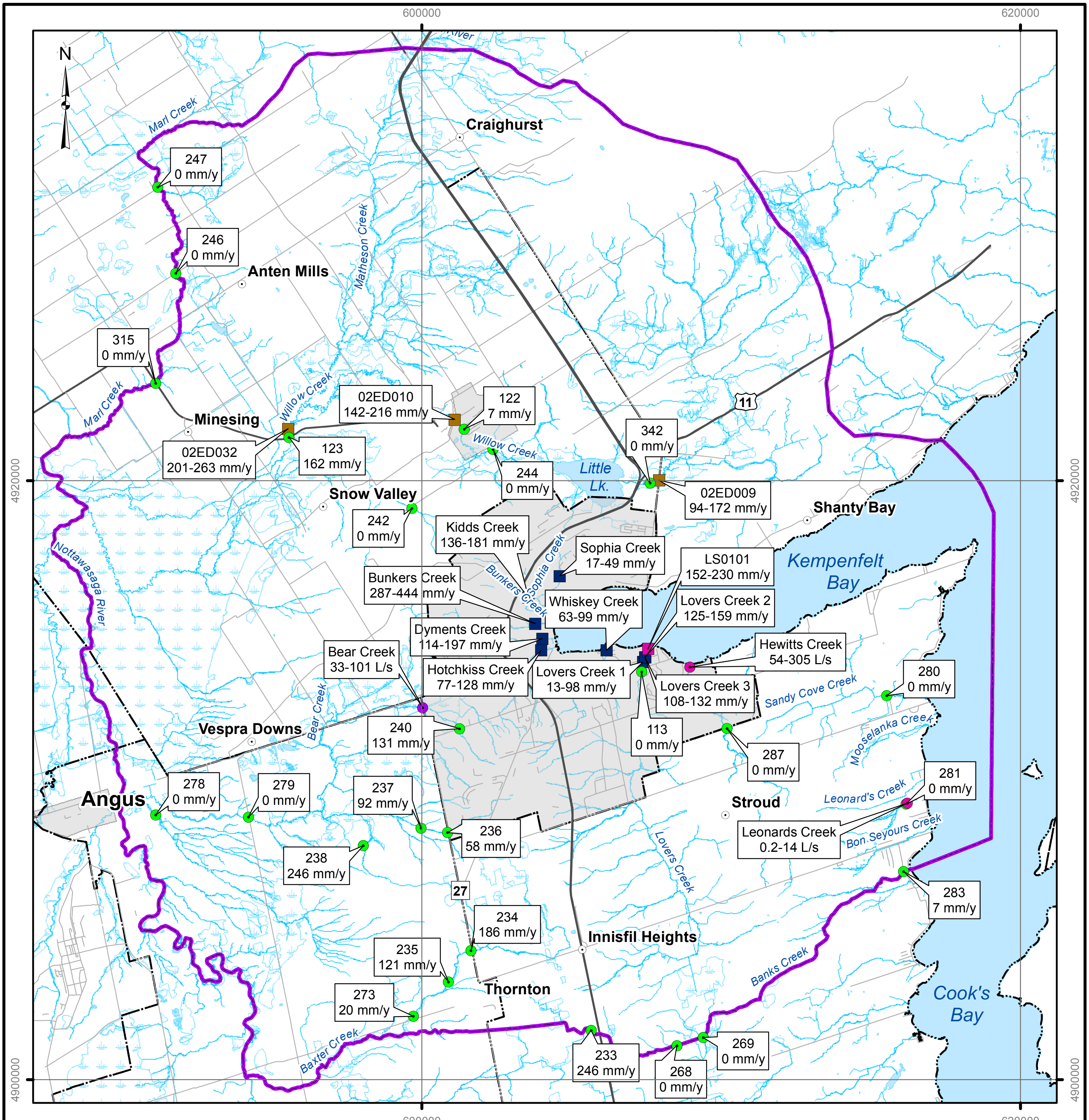
There are four long-term continuous streamflow monitoring gauges within the Study Area, eight short-term monitoring gauges, and 28 locations with spot flow measurements (see Map 5.1). There are two historic and one active streamflow monitoring gauges on Willow Creek that are maintained and operated by Water Survey Canada (WSC) through the HYDAT program. HYDAT data undergoes a rigorous quality assurance/quality control process to publish estimates of streamflow that are as accurate as possible. In addition to operating the stream gauge structure to a national standard, WSC also corrects observed data for:

- Backwater effects due to ice and aquatic plant effect, which artificially raises the water level resulting in falsely high calculated streamflow; and

- Equipment malfunctions, sensor drift, or estimates data lost due to equipment failure.

Due to the level of care taken to collect and publish the flow estimates, the HYDAT dataset is generally considered to be the best available.

The WSC Willow Creek above Little Lake (02ED009) gauge is 1.5 km upstream of Little Lake and has a drainage area of 95 km^2. The gauge was in operation from 1973-1995. The WSC Willow Creek at Midhurst (02ED010) gauge is 4 km downstream of Little Lake and has a drainage area of 127 km^2. This



LEGEND

- Gauge Locations - City of Barrie
- Gauge Locations - LSRCA
- Gauge Locations - WSC
- Spot Flow Locations - Golder
- Spot Flow Locations - IWS
- Spot Flow Locations - LSRCA
- Towns/Villages
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary

Station ID
Baseflow (mm/yr)
or
Spotflow Range (L/s)

Station Label

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Map 5.1

Streamflow Monitoring Locations

REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 07-Jun-2012; Created By: ccurry

Scale 1:180,000
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Kilometres

gauge was in operation from 1973-1998. The WSC Willow Creek near Minesing (02ED032) gauge is located 1 km downstream of the confluence with Matheson Creek and has a drainage area of 242 km^2. This gauge is currently in operation and has corrected data for 2005-2008.

The fourth long-term continuous stream gauge is on Lovers Creek and is maintained and operated by LSRCA. The gauge is located 100 m from the outlet of Lovers Creek and drains an area of 60 km^2. There is measured streamflow data from 2001-2009; however 2009 data have not been corrected for ice and will not be used in this assessment. Prior to 2001, streamflow at this location was estimated based on different models the LSRCA uses to estimate ungauged drainage areas. These models consisted of a regression relationship and areally weighting flow from all gauged areas; these estimated data were not used in this assessment.

Stantec Consulting completed a creek flow monitoring assessment for the City of Barrie in 2009 and 2010 (Stantec 2010). Stantec collected data from 2009 to 2010 on Sophia Creek, Kidds Creek, Bunkers Creek, Dyments Creek, Hotchkiss Creek, and Whiskey Creek. Continuous (5 min) streamflow data from March to November are available along these creeks (see Map 5.1). Data were also collected at three locations along Lovers Creek in October and November 2009.

To assist in characterizing the hydrology within the Study Area, a variety of streamflow and base flow statistics were computed based on the data recorded at the ten stream gauges, as indicated on Map 5.1 by square symbols. The stream gauge summaries sheets are included in Appendix A6. Available data from each gauge were analyzed according to the following streamflow characteristics:

- Mean annual streamflow (m^3/s and mm over the upstream area);
- Mean annual base flow (m^3/s and mm over the upstream area);
- Base flow index (BFI), which is the ratio of base flow to total streamflow;
- Recession constant (days) which is the number of days for base flow to recede by one log cycle;
- Low flow statistics including the lowest 7-day or 30-day average flow for a return period of 2, 5, 10 or 20 years;
- Mean monthly streamflow (m^3/s);
- Mean monthly base flow (m^3/s) including both a high and low estimate (see below);
- Median monthly flow (m^3/s), which is the flow observed 50% of the time;
- 10^{th} percentile flow exceedance (m^3/s), which is streamflow that is exceeded only 10% of the time and is an indicator of typical high flows;
- 90^{th} percentile flow exceedance (m^3/s), which represents streamflow that is exceeded 90% of the time and is an indicator of typical low flows; and
- Peakiness (also called the 10:90 ratio), which is the ratio of the flow exceeded 10% of the time to the flow exceeded 90% of the time. Peakiness is a measure of how quickly a catchment responds to a

precipitation event and returns to pre-event flow conditions. Areas with lower permeability soils would be expected to have higher peakiness.

The statistics listed above were computed using three numerical programs. A base flow separation exercise was performed on the continuous streamflow data to obtain estimates of base flow. The base flow separation routine used in this analysis is the Base flow Separation Program, included with the Soil and Water Assessment Tool (SWAT) hydrologic model. This routine employs a digital filtering technique meant to replicate by-hand hydrograph separation. This program, previously been known as BFLOW, was found to be the most appropriate (Bellamy et al. 2003) and has been selected as the optimum base flow separation technique for studies completed for a variety of Conservation Authorities, including Ausable Bayfield, Maitland Valley and the Grand River. The program outputs three different daily base flow estimates. The high and low base flow estimates were included in the summary statistics (mean monthly and mean annual base flow). The base flow index (BFI) is the ratio of base flow to total streamflow.

The recession constant was determined using a program called RECESS (Rutledge 1998) developed by the USGS (U.S. Geological Survey). This program assumes that there are no flow diversions or water control structures, such that all or nearly all groundwater discharges to the stream or is lost to evapotranspiration.

The low flow statistics were determined using a tool called DFLOW version 3.1 (U.S. EPA (Environmental Protection Agency) 2006).

For the ten gauges, the high and low mean annual base flow estimates are included on Map 5.1 in mm/year. Expressing the base flow as a depth over the upstream area allows for a direct comparison between measurements.

Spot flow measurements were taken at the locations within the Study Area by LSRCA, I.W.S., and Golder Associates (Map 5.1). LSRCA provided spot flow measurements near the outlet of Leonard's Creek from 2005 to 2010 and Hewitts Creek from 2008 to 2010. The spot flow measurements are included in Table 5.1. IWC collected stream flow measurements on Bear Creek at Highway 27 from 2007 to 2009. Water levels were continuously monitored and 16 stream discharge measurements were taken periodically according to the golf ball method as described in MNR Manual of Instructions –Aquatic Habitat Inventory Surveys (IWS 2009). The station was abandoned in August 2000 due to water levels backing up from beaver activity. The measured spot flows are listed in Table 5.1. High spot flow measurements that were obviously not representative of base flow conditions (i.e., peak flows) were flagged and not included in the analysis. The range of the remaining recorded spot flows is included on Map 5.1 for Hewitts, Leonard's and Bear Creeks.

TABLE 5.1 Spot flow measurements taken at Leonard's Creek and Hewitts Creek by LSRCA and at Bear Creek by IWC

Leonard's Creek (LSRCA)		Hewitts Creek (LSRCA)		Bear Creek (IWC)	
Date	Flow (m^3/s)	Date	Flow (m^3/s)	Date	Flow (m^3/s)
24-Jun-05	*0.010	13-Jun-08	0.175	3-Jan-07	0.077
8-Aug-05	0.000	4-Jul-08	0.169	23-Mar-07	*0.162
6-Sep-05	0.000	30-Jul-08	0.235	25-May-07	0.048
4-Oct-05	0.003	14-Aug-08	*1.080	22-Jun-07	0.040

Leonard's Creek (LSRCA)		Hewitts Creek (LSRCA)		Bear Creek (IWC)	
Date	Flow (m^3/s)	Date	Flow (m^3/s)	Date	Flow (m^3/s)
31-Oct-05	0.004	11-Sep-08	0.153	27-Jul-07	0.035
12-Apr-06	*0.034	17-Sep-08	0.305	14-Sep-07	0.053
14-Jun-06	0.006	24-Oct-08	0.146	13-Nov-07	0.080
8-May-06	*0.013	9-Dec-08	0.182	21-Apr-08	*0.131
17-Jul-06	0.001	6-Feb-09	0.120	2-Jun-08	0.101
9-Aug-06	0.001	24-Mar-09	*0.180	14-Jul-08	0.071
21-Aug-06	0.001	16-Apr-09	*0.220	11-Aug-08	*0.140
24-May-07	*0.014	9-Jun-09	0.228	17-Sep-08	*0.105
25-Jun-07	0.002	7-Jul-09	0.073	22-Oct-08	0.091
26-Aug-08	0.004	13-Aug-09	0.072	27-Apr-09	*0.288
23-Sep-08	0.014	21-Sep-09	0.054	19-Jun-09	0.073
25-Jun-09	0.008	16-Oct-09	0.088	7-Aug-09	0.033
22-Jul-09	0.003	10-Nov-09	0.117		
22-May-09	*0.014	17-Dec-09	0.135		
4-Sep-09	0.007	6-Jan-10	0.076		
14-Sep-09	0.003	5-Feb-10	0.067		
27-May-10	0.008	14-Apr-10	*0.099		
		18-May-10	*0.100		

Spotflow locations correspond to labels on Map 5.1
*Not included in analysis

In August 2002, a low flow survey was completed by Golder Associates as part of the South Simcoe Municipal Groundwater Study (Golder 2004). The survey consisted of taking spot flow measurements after a period of little or no rainfall at 133 locations in the South Simcoe region (Golder 2004). Due to the dry conditions during the survey, the measured flows are generally indicative of base flow conditions (sustained groundwater conditions). Most flow measurements were estimated using the velocity-area method as described in Golder (2004). A total of 25 of the surveyed locations are within the Study Area and are shown on Map 5.1 with the measured unit base flow expressed as a depth over the upstream area (mm/year). The surveyed locations within the Study Area include:

- One location on Hewitts Creek;
- One location on Sandy Cove Creek, one on Leonard's Creek, and one on Banks Creek in Innisfil Creeks subwatershed;
- One location on Lovers Creek;
- Three locations on Baxter Creek and six locations on Bear Creek in Middle Nottawasaga subwatershed;
- Three locations on Marl Creek in Lower Nottawasaga subwatershed;
- Three locations along the headwaters of Innisfil Creek; and
- Five locations along Willow Creek and a tributary.

The spot flow measurements from the low flow survey are summarized in Table 5.2.

TABLE 5.2 Summary of Spot Flow Measurements performed during a Low Flow Survey by Golder in August 2002

Golder Station ID	Subwatershed	Watercourse	Drainage Area (km^2)	Base flow (L/s)	Unit Base flow ($L/s/km^2$)	Unit Base flow (mm/year)	Easting	Northing
283	Innisfil Creeks	Banks Creek	8.82	2	0.22	7	616101	4906948
281	Innisfil Creeks	Leonard's Creek	7.35	0	0.03	1	616208	4909191
280	Innisfil Creeks	Sandy Cove Creek	15.45	10	0.62	20	615531	4912824
287	Hewitts Creek	Hewitts Creek	12.54	16	1.25	39	610191	4911728
113	Lovers Creek	Lovers Creek	59.66	141	2.37	75	607411	4912290
233	Innisfil Creek	Innisfil Creek	3.48	0	0	0	605655	4901647
269	Innisfil Creek	Innisfil Creek	6.51	0	0	0	609403	4901405
268	Innisfil Creek	Innisfil Creek	7.59	32	4.22	246	608526	4901145
234	Middle Nottawasaga	Baxter Creek	12.78	0	0	0	601645	4904310
235	Middle Nottawasaga	Baxter Creek	14.18	8	0.58	186	600890	4903265
273	Middle Nottawasaga	Baxter Creek	19.77	31	1.59	131	599716	4902118
240	Middle Nottawasaga	Bear Creek	1.11	13	11.77	371	601262	4911720
238	Middle Nottawasaga	Bear Creek	4.34	0	0	0	598045	4907818
236	Middle Nottawasaga	Bear Creek	5.51	0	0	0	600856	4908248
237	Middle Nottawasaga	Bear Creek	7.48	8	1.01	121	599973	4908399
278	Middle Nottawasaga	Bear Creek	20.75	2	0.08	2	591100	4908835
279	Middle Nottawasaga	Bear Creek	60.34	82	1.36	37	594198	4908764
342	Willow Creek	Willow Creek	100.28	35	0.35	11	607627	4919917
244	Willow Creek	Willow Creek	119.99	114	0.95	127	602377	4921046
122	Willow Creek	Willow Creek	129.36	272	2.1	532	601413	4921725
123	Willow Creek	Willow Creek	241.64	967	4	195	595560	4921452
242	Willow Creek	Willow Creek trib	6.32	12	1.85	58	599672	4919080
247	Lower Nottawasaga	Marl Creek	33.41	56	1.68	47	591170	4929792
246	Lower Nottawasaga	Marl Creek	57.13	126	2.2	92	591774	4926923
315	Lower Nottawasaga	Marl Creek	79.77	242	3.03	162	591100	4923259

Source: Golder (2004)

5.2 Instream Flow Studies

Instream flow studies refer to flow or water level requirements for ecological purposes (e.g., fish populations). At this time, there are no known instream flow studies in the Study Area.

5.3 Groundwater Surface Water Interaction

A key component of the Tier Three assessment is the evaluation of the potential impact of municipal water takings on other uses, including the potential reduction of discharge to surface water features, or induced recharge from surface water features. A review of potential areas of groundwater / surface water interaction suggests two areas where municipal pumping impacts will need to be evaluated as part of the Tier Three assessment: coldwater streams and perennial wetlands fed by groundwater (particularly fens and swamps).

As seen in Map 2.4, there are numerous coldwater streams in the Study Area. The classification as coldwater streams along with sustained non-zero base flow conditions (as illustrated in Tables 5.1 and 5.2) indicates that these streams are groundwater fed and typically have sustained summer flows. These streams include Willow Creek downstream of Little Lake and its tributary Matheson Creek; the upper reaches of the Barrie Creeks (Kidds, Bunkers, Dyments, Hotchkiss and Whiskey Creeks); Lovers Creek; Hewitts Creek; some of the small creeks in the Town of Innisfil (Bon Secours Creek and Banks Creek); and finally sections of Marl Creek, Bear Creek, Baxter Creek, Innisfil Creek and the Nottawasaga River.

Wetlands in Ontario are protected under the Planning Act, R.S.O, 1990 and the Provincial Policy Statement 2005 (PPS). The PPS states that development and site alteration will not be permitted in significant wetlands south and east of the Canadian Shield. A ‘significant’ wetland is any "area identified as ‘provincially significant’ by the Ministry of Natural Resources (MNR) using evaluation procedures established by the Province, as amended from time to time." Wetlands which are not ‘provincially significant’ can be classified as ‘locally significant’ or ‘other’.

Within the Study Areas, the Minesing Wetland Complex is a PSW and the Bear Creek Wetland Complex (96% of which is a swamp) is considered a locally significant wetland. As such, potential impacts of pumping on both of these features must be assessed as part of the Tier Three study.

Based on the existing conditions of coldwater streams and thriving wetlands in the immediate vicinity of the Barrie municipal wells, it is not expected that adverse impacts will occur. As shown in Section 3.0 (Tables 3.1 and 3.2), most of the water supply wells are drilled in the lower aquifers (A3 and A4) and are evidently isolated from shallow surface water features, except perhaps near Wells 2 and 6, which are no longer operational.

5.4 Surface Water Modelling

In Phase 3 of the Barrie Tier Three Local Area Risk Assessment, a numerical model of hydrologic processes will be built and calibrated to generate physically-based recharge estimates under historic climatic conditions, including drought conditions. Once the model is calibrated to the level of detail required, it will also be utilized to refine water budget predictions from the Tier Two analysis.

5.4.1 Surface Water Model Overview

For the Tier Two Stress Assessment, the Study Area contained portions of two surface water (hydrologic) models that were independently developed and calibrated. As a result, there were different assumptions within each model and variations in results (predicted runoff / recharge) from each model. Both of the modelling tools developed have strengths and weaknesses, which while acceptable for the Tier Two assessment, needed to be refined for the Tier Three assessment. To complete the hydrologic modelling for the Tier Three assessment, several modelling codes (including HSP-F and PRMS used for the Tier Two assessment), were evaluated and the preferred code was selected (see Section 5.4.2).

The surface water model will be used to generate estimates of groundwater recharge to input into the groundwater flow model. This will be accomplished by building a model of the Study Area using the selected software, calibrating the model to available observed streamflow data (see Section 4.0), and verifying the calibrated model against a different set of observed data. Both continuous streamflow data and spot flow measurements will be utilized in the calibration/verification exercise. The model should be able to reasonably replicate the observed streamflow values. The calibration efforts will be focused on the mean annual streamflow and the mean monthly streamflow, particularly in the summer months when low flows are indicative of base flow conditions. The annual water balance will also be assessed and the average annual groundwater recharge will be output from the model. In this manner, the model will contain the appropriate level of physical relations such that we can have confidence that the predicted recharge / runoff characteristics are reasonable for both steady-state and transient (drought) scenarios.

Based on the available streamflow data (see Section 4.0), the recommended period of calibration for the model is 1985-2010 with 1975-1984 as a verification period. Based on this calibration, it is anticipated that the model will be able to provide time-varying recharge estimates for the period from 1950 to 2010.

5.4.2 Model Selection

Several surface water models and integrated groundwater-surface water models were reviewed to complete the recharge estimation modelling exercise. These included the two modelling software packages used in the Tier Two Assessment HSP-F and PRMS, as well as GAWSER and the integrated model MIKE-SHE. The following table highlights the differences between the numerical models, as they relate to this study.

TABLE 5.3 Model Selection Criteria for Four Streamflow Generation Models

Criteria	GAWSER	HSP-F	PRMS	MIKE SHE
Full Name	Guelph All-Weather Sequential-Events Runoff	Hydrological Simulation Program - Fortran	Precipitation-Runoff Modeling System	Système Hydrologique Européen
Distributor	Schroeter and Associates, 2001	U.S. Environmental Protection Agency	U.S. Geological Survey	DHI Water and Environment
Documentation	Schroeter and Associates, 2001	Bicknell et al., 1997	Leavesley et al., 1983	DHI, 2009
Lumped or Distributed	Distributed	Lumped / Distributed*	Distributed	Fully distributed
Physical or Empirical Basis	Physical	Physical / Empirical	Physical	Physical
Stochastic or Deterministic	Deterministic	Deterministic	Deterministic	Deterministic
Integrated model	Not integrated	Not integrated	Not integrated	Fully integrated
Input Requirements	• Timeseries of: - Rainfall - Snowfall - Max/Min Air Temperature • Physical measurements of land area, channels and reservoirs • Land Use • Surficial Geology/Soils	• Timeseries of: - Precipitation - Potential ET - Air Temperature - Dewpoint* - Wind* - Solar Radiation* *Used for energy balance snowmelt method • Physical measurements of land area, channels and reservoirs	• Timeseries of: - Precipitation - Max/Min Air Temperature - Solar Radiation for Snowmelt • Physical measurements of land area, channels and reservoirs • Topography • Land Use • Surficial Geology/Soils	• Spatial (gridded) data of - Precipitation - Air Temperature - Potential ET - Solar Radiation (for snowmelt) - Topography - Soils - Land use - Subsurface geology (if using 3D groundwater model) - River geometry
Output format	Tabular format	Tabular format	Tabular format	Gridded or tabular format 3-Dimensional analysis
Infiltration Methods	• Green and Ampt	• Empirical relationships • (Based on Philips Equation)	• Contributing-area concept (Empirical relationships) • Philips Equation (storm mode)	• Richards Equation • Gravity Flow • 2-Layer water balance (Green and Ampt)
Potential Evapotranspiration Methods	• Linacre Method	• User-defined timeseries	• Pan evaporation • Hamon Method • Jensen - Haise Method	• User-defined timeseries
Representation of Subsurface and Groundwater	• Linear Reservoir for subsurface storage and groundwater storage	• Linear Reservoir	• Linear or Nonlinear Subsurface Reservoir • Linear Groundwater Reservoir	• 2-Layer Subsurface Linear Reservoir • Finite Difference 3D

Criteria	GAWSER	HSP-F	PRMS	MIKE SHE
System				Subsurface Flow • 2-Layer Groundwater linear reservoir • Finite Difference 3D Groundwater Flow
Snowmelt Algorithm	• Temperature Index Method • Considers snowmelt, refreeze, redistribution, compaction, accumulation	• Temperature Index Method • Energy Balance Method • Considers snowmelt, refreeze, compaction, accumulation	• Energy Balance Method • Considers snowmelt, refreeze, accumulation	• Temperature Index Method • Considers snowmelt, refreeze, redistribution, accumulation
Channel Routing Method	• Muskingham • Lag and Route Method	• Empirical Relationship	• Daily mode - None (only as defined surface reservoirs) • Storm mode – Kinematic Wave Approximation	• Muskingham Cunge • Dynamic Wave Equation • Full Hydraulic Analysis
Overland Routing Method	• Area-time vs time method • Single linear reservoir & lag-and-route method	• Chezy-Manning Equation and Empirical relationship	• Daily mode - Linear Soil Zone Reservoir • Storm mode – Kinematic Wave approximation	• Finite Difference • Subcatchment-based
Computational Timestep	No real limit – minutes to days	1 minute to 1 day	Daily mode – 1 day or greater Storm mode – 1min to 1 day (rainfall only; no snow)	Varied by the software depending on the processes (minutes to days)
Link to GIS	No	No	No	Yes
User Interface	No	Yes – WinHSPF as part of the BASINS program	No	Yes
Documentation	Good	Good	Good	Excellent
Technical Support	Fair	Good	Good	Very Good
Software Cost	Low cost	Free on US EPA website (http://www.epa.gov/ceampubl/swater/hspf/)	Free on USGS website http://water.usgs.gov/software/PRMS/	High cost ($15,000 - $30,000)

*Note: The modeller can modify the model structure to generate distributed results, as was done in the Tier Two application.

For the Tier Three assessment, the primary function of the surface water model is to generate groundwater recharge estimates. Therefore some of the key criteria for this application from the above table include:

1. An integrated model;
2. A detailed and distributed representation of physical processes;
3. A good snowmelt routine;
4. A physically-based infiltration method;
5. An hourly time step; and
6. Good visualization and GIS integration capabilities.

A model that satisfies these criteria will provide greater insight into groundwater and surface water interactions and a better representation of the variability in soil moisture content in the unsaturated zone.

Based on the criteria listed above, the MIKE SHE model was selected for this assessment for the following reasons:

1. MIKE SHE is the only fully integrated surface and groundwater model. It has the ability to include a complete representation of the subsurface using a three-dimensional finite difference solution which facilitates a dynamic interaction between the groundwater and surface water regimes. In addition, MIKE SHE is coupled with the river modelling package MIKE-11 to perform the hydraulic analysis. This enables for one-dimensional simulation of river flows and full, dynamic coupling of surface and subsurface flow processes in MIKE-11and MIKE-SHE.

2. MIKE SHE provides a detailed representation using physically based equations and fully distributed three-dimensional property distributions. As a fully distributed model, the spatial variation of model inputs is incorporated into the model input and output (e.g., precipitation and topography). Computations of flow within the domain are computed on a gridded basis and the model domain is discretized into model cells according to a selected model resolution.

3. The snowmelt routine in MIKE SHE is based on the temperature index method or a modified degree-day method. This method is commonly used in hydrologic models as it has low input requirements and is relatively simple to calibrate. The energy balance method, although also widely used, has extensive input requirements.

4. MIKE SHE provides a modular approach to hydrologic modelling, which provides the flexibility to implement complex or simple approximations to all major processes of the hydrologic cycle. A variety of physically-based infiltration methods are available depending on the level of detail desired.

5. In MIKE SHE, the time step is controlled by the software with maximum allowed time steps specified for each process by the user. This method allows for the model to run very short time steps during periods of heavy rainfall and longer time steps during dry periods.

6. Model inputs can be prepared using GIS tools and imported directly into the MIKE SHE software. The graphical user interface allows the user to visualize in three dimensions both the model input and output. This is an invaluable resource and greatly improves the understanding of the natural system. It also improves model calibration, eases debugging efforts, and facilitates model review.

Successful experience in applying MIKE SHE to other sites, as well as the technical qualifications outlined above, provide confidence that this approach will generate reasonable groundwater recharge estimates.

6.0 SUMMARY !b5 NEXT STEPS

This interim technical memorandum provides an overview of the conceptual understanding of the physical features pertinent to the Tier Three Water Budget and Local Area Risk Assessment for the Barrie Study Area. The information provided herein is intended to communicate our understanding with the peer review members and study team such that data gaps can be identified and potentially filled with any previously unknown data sources, experience, or knowledge. The goal of this effort is to ensure all of the correct information is being applied toward developing realistic numerical tools, which will subsequently be used to perform the Tier Three scenario assessment and risk evaluation.

- Sections of this report have been designed to provide an overview of the following key components:
- Surface and sub-surface knowledge regarding the known features and their characteristics, including
- Topography, Climate, Land Use, Streams, Creeks, Wetlands, Physiography, and geology;
- Water Demand, including municipal, non-municipal permitted, and other demands that compete for water within the same water source;
- Hydrogeologic conditions throughout the Study Area, including the understanding of hydrostratigraphy, material property values (e.g., hydraulic conductivity), available calibration data, and groundwater supply from recharge; and
- Hydrology conditions throughout the Study Area, including the understanding of stream flow variability and base flow conditions, instream flow assessments, and groundwater / surface water interaction potential.

Based on the understanding presented, this memo also provides a recommendation for proceeding with the development of numerical modelling tools to facilitate the Tier Three scenario evaluation, and thus the Risk Assessment. The recommended numerical modelling tools include:

- MIKE SHE surface water model of the Study Area to characterize surface and shallow subsurface processes, with the goal of predicting time-varying recharge conditions that can be used to prescribe recharge for all required Tier Three scenarios; and
- FEFLOW groundwater model covering the entire Study Area that will build-upon previous modelling with the same modelling tool and enhance the model calibration and prediction capabilities in preparation for the Tier Three scenario evaluation.

Any data gaps identified through this interim review will aid the project team in developing realistic numerical tools consistent with the site conceptual model and available data.

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BARRIE TIER THREE WATER BUDGET AND

LOCAL AREA RISK ASSESSMENT

CONCEPTUAL UNDERSTANDING MEMORANDUM

APPENDIX A1: TABLE OF HISTORICAL REFERENCES

Table A.1: Reviewed References

DOC_AUTHOR	DOC_YEAR	DOC_NAME	DOC_AUTHOR_AGENCY	AQR Ref ID	Added to WebPortal	Folder
Dixon, V.R.	**1980**	Assessment of Barrie's Groundwater Resources, Prepared for the Barrie Public Utilities Commission (PUC).	International Water Consultants	129	1	BARRIE
Golder Associates Inc.	**2009**	City of Barrie Source Water Protection Study Capture Zone Modelling - Increase Yield of Wells 17/18 (Letter)	Golder Associates Inc.	35	1	BARRIE
City of Barrie	**2010**	Barrie in a Changing Climate: a focus on Adaptation	Ontario Centre for Climate Impacts and Adaptation Resources at MIRARCO	36	1	BARRIE
Golder Associates Inc.	**2009**	City of Barrie Well 19 Permit to take water application (Letter)	Golder Associates Inc.	37	1	BARRIE
Golder Associates Inc. and Waterloo Hydrogeologic	**2004**	South Simcoe Groundwater Study. WHPA-City of Barrie Appendix E	Golder Associates Inc. and Waterloo Hydrogeologic	38	1	BARRIE
Richardson Foster Ltd.	**2005**	Detailed Stormwater Management Report 1818 Subdivision, City of Barrie	Richardson Foster Ltd.	39	1	BARRIE
Marshall Macklin Monaghan Ltd.	**2004**	Barrie - Environmental Impact Study - Addendum to EIS for 1818	Marshall Macklin Monaghan Ltd.	40	1	BARRIE
Marshall Macklin Monaghan Ltd.	**1999**	Environmental Impact Study for 1818, Wetland Hydrology section	Marshall Macklin Monaghan Ltd.	41	1	BARRIE
Jacques Whitford Environment Ltd.	**2002**	Environmental Impact Statement Molson Park Redevelopment (not complete, no appendices)	Jacques Whitford Environment Ltd.	42	1	BARRIE
Terraprobe	**1997**	Geotechnical Investigation proposed South Shore Sanitary Trunk Sewer Extension, Dock Road and Cox Mill Road, Barrie	Terraprobe	43	1	BARRIE
G.M. Sernas & Associates Ltd.	**1993**	Storm water management report - Lance Gate Subdivision (Introduction & borehole data only)	G.M. Sernas & Associates Ltd.	44	1	BARRIE
Kuehl, G.A. and V.R. Dixon	**1981**	PUC City of Barrie Assessment of Barrie GW Resources	International Water Consultants Ltd	88	1	BARRIE
	2003	TCE Update - Q and A. http://www.barrie.ca/docs/TCEQA.pdf	City of Barrie	128	1	BARRIE
Hodgins, B.L.	**1987**	PUC Groundwater Investigation Well 9 and Test Wells Tiffin West and Tiffin East	International Water Supply	130	1	BARRIE
Hodgins, B.L.	**1987**	PUC Groundwater Investigation Well 9 and Test Wells Tiffin West and Tiffin East	International Water Supply	130	1	BARRIE
Hodgins, B.L.	**1988**	Groundwater Investigation - Tiffin West, Phase I	International Water Supply	131	1	BARRIE
Hodgins, B.L.	**1990**	Groundwater Investigation - Tiffin West	International Water Supply	132	1	BARRIE
Kuehl, G.A.	**1990**	Aquifer Performance Assessment - Proposed Well No. 14,	International Water Supply	133	1	BARRIE
Kuehl, G.A.	**1991**	Barrie Well and Aquifer Performance Review 1980-1990	International Water Supply	134	1	BARRIE
Kuehl, G.A.	**1993**	Barrie Well and Aquifer Performance Review 1993	International Water Supply	135	1	BARRIE

DOC_AUTHOR	DOC_YEAR	DOC_NAME	DOC_AUTHOR_AGENCY	AQR Ref ID	Added to WebPortal	Folder
Kuehl, G.A.	**1994**	Class Environmental Assessment - Alternative Water Supply, Groundwater Supply	International Water Supply	136	1	BARRIE
Kuehl, G.A.	**1995**	Detailed Groundwater Investigation - St. Vincent Street - North TW 2/95 Site	International Water Supply	137	1	BARRIE
Kuehl, G.A.	**1997**	Barrie Well and Aquifer Performance Review 1997	International Water Supply	138	1	BARRIE
Kuehl, G.A.	**1999**	Groundwater Investigation Barrie West Area	International Water Supply	139	1	BARRIE
Kuehl, G.A.	**1999**	Groundwater Investigation - Huronia Road and Lockhart Road Area	International Water Supply	140	1	BARRIE
Kuehl, G.A.	**2001**	Groundwater Under the Direct Influence of Surface Water Assessment	International Water Supply	141	1	BARRIE
Kuehl, G.A. and M.R. Fairbanks	**2001**	City of Barrie Test Well Survey	International Water Supply	142	1	BARRIE
Mack, S. and G.A. Kuehl	**2002**	Construction and Testing of Well 17	International Water Supply	143	1	BARRIE
Kuehl, G.A.	**2003**	Well and Aquifer Performance Assessment for System Renewal Permit	International Water Supply	144	1	BARRIE
Kuehl,G.A.	**2004**	Construction and Testing of Cross Street Well 18	International Water Supply	145	1	BARRIE
Kuehl, G.A.	**2005**	Additional Groundwater Supply Barrie West Area and Aquifer Performance Review	International Water Supply	146	1	BARRIE
Kuehl, G.A.	**2009**	Construction and Testing of Boulton Court Well 19	International Water Supply	150	1	BARRIE
Kuehl,G.A.	**2007**	Hydrogeologic Study to Support Increased Capacity Wells 17 & 18	International Water Supply	151	1	BARRIE
Kuehl, G.A.	**2010**	Barrie Well and Aquifer Performance Review 2010 Hydrographs	International Water Supply	152	1	BARRIE
Hodgins, B.L.	**1976**	Report Groundwater Investigation Township of Essa Angus Project No 5-0212	International Water Supply Ltd	83	1	BORDEN
Easton, J.A. and V.R. Dixon	**1992**	Defence construction Canada Canadian forces Base Borden well field review	Dixon Hydrogeology Ltd	95	1	BORDEN
Easton, J.A.	**1993**	Department of national Defence Canadian forces Base Borden Construction and testing of well 6	Dixon Hydrogeology Ltd	105	1	BORDEN
Golder Associates Ltd.	**2010**	Township of Essa Municipal Supply Wells Capture Zone and Equipotential Surface Review	Golder Associates Ltd.	45	1	ESSA
Golder Associates Ltd.	**2008**	Township of Essa, Angus Water Supply, Brownley Capture Zone Modelling	Golder Associates Ltd.	46	1	ESSA
S.S. Papadopulous & Associates Inc.	**2007**	Analysis of groundwater flow and delineation of capture zones for Mansfield water supply wells	S.S. Papadopulous & Associates Inc.	47	1	ESSA
Golder Associates Inc. and Waterloo Hydrogeologic	**2004**	South Simcoe Groundwater Study, WHPA-Township of Essa, Appendix H	Golder Associates Inc. and Waterloo Hydrogeologic	48	1	ESSA

DOC_AUTHOR	DOC_YEAR	DOC_NAME	DOC_AUTHOR_AGENCY	AQR Ref ID	Added to WebPortal	Folder
Universal Geotechnique Ltd	**1966**	31D4-138 Bridge Nottawasaga River Essa Township	Universal Geotechnique Ltd	86	1	ESSA
Wilson, I.D.	**1990**	Water Supply Survey Hamlet of Baxter Township of Essa	Ian D. Wilson Associates Ltd	89	1	ESSA
Hendy, G.R., V.R. Dixon, and M. Monier-William	**1989**	Township of Essa West half lot 28, concession 3 volume 2 Production well site A - Angus Site Hydrogeological investigation	Dixon Hydrogeology Ltd	93	1	ESSA
Ministry of Transportation	**1990**	31D5-329 Highway 90 and Pine River Town of Angus	MTO - Ministry of Transportation	96	1	ESSA
Easton, J.A.	**1996**	Hydrogeological investigation testing of the centre street wells	Dixon Hydrogeology Ltd	98	1	ESSA
Wilson, I.D.	**1985**	Well construction, Police Village of Angus	Ian D. Wilson Associates Ltd	110	1	ESSA
Hendy, G.R. and V.R. Dixon	**1989**	Township of Essa West Half Lot 28, Concession 3 Volume 1 Construction and Testing of Production Well 1/88	Dixon Hydrogeology Ltd	113	1	ESSA
Bryck, L.G.	**2001**	Hydrogeologic Appraisal, Angus Water System	Hydroterra	125	1	ESSA
Golder Associates Ltd.	**2010**	Township of Essa Municipal Supply Wells Capture Zone and Equipotential Surface Review	Golder Associates Ltd.	45	1	ESSA
P.F. McKenna	**1974**	Township of Innisfil Groundwater Survey	Ministry of the Environment	49	1	INNISFIL
Golder Associates Inc.	**2010**	Technical Memorandum- Town of Innisfil Municipal Supply Wells Capture Zone and Equipotential Surface Review	Golder Associates Inc.	50	1	INNISFIL
Peto MacCallum Ltd	**1990**	Preliminary Geotechnical/Hydrogeological Investigation - Proposed Innisfil Industrial Park	Peto MacCallum Ltd	51	1	INNISFIL
Terraprobe	**1990**	Hydrogeologic Study - Proposed Residential Subdivision - Mills Point Technical Landing - Township of Innisfil, Ontario	Terraprobe	52	1	INNISFIL
Terraprobe	**1990**	Proposed Residential Land Development Part Lot 7, Concession VII, Township of Innisfil, Lovers Creek Infiltration Area	Terraprobe	53	1	INNISFIL
Gartner Lee	**1991**	Environmental Investigation - Sherbrooke Shores Subdivision - Township of Innisfil	Gartner Lee	54	1	INNISFIL
Jagger Hims Ltd	**1994**	Servicing Options Study for Official Plan Amendment, Proposed Industrial Plan of Subdivision, Innisfil-400 Industrial Park, Town of Innisfil	Jagger Hims Ltd	55	1	INNISFIL
C.C. Tatham & Associates Ltd.	**2001**	Town of Innisfil, Lakeshore Water Works Engineer's Report	C.C. Tatham & Associates Ltd.	56	1	INNISFIL
Harden Environmental	**2003**	Hedge Hog Golf Club, Hydrogeological Evaluation and Environmental Impact Statement	Harden Environmental	57	1	INNISFIL
Geospec	**2003**	Slope Stability Assessment, 3988 Guest Road, Town of Innisfil	Geospec	58	1	INNISFIL
Golder Associates Inc. and Waterloo Hydrogeologic	**2004**	South Simcoe Groundwater Study WHPA - Town of Innisfil, Appendix I	Golder Associates Inc. and Waterloo Hydrogeologic	59	1	INNISFIL

DOC_AUTHOR	DOC_YEAR	DOC_NAME	DOC_AUTHOR_AGENCY	AQR Ref ID	Added to WebPortal	Folder
Golder Associates Ltd.	**2006**	Town of Innisfil, Golf Haven Water Supply, Construction and Testing of Well 2	Golder Associates Ltd.	60	1	INNISFIL
Dixon, V.R.	**1990**	Innisfil Heights Industrial Park Water Supply - Groundwater Supply Evaluation	Dixon Hydrogeology Ltd	111	1	INNISFIL
Easton, J.A.	**2008**	Town Of Innisfil: Innisfil Heights Water System PTTW Renewal Report Wells 2 and 3	Golder Associates	114	1	INNISFIL
Bryck, L.G.	**1974**	Stroud Well 2	Hydrology Consultants Limited	116	1	INNISFIL
Kirk, J.W.	**1971**	Stroud Well 1	International Water Supply Ltd	117	1	INNISFIL
Wilson, I.D.	**1986**	Well Construction and Evaluation, Community of Stroud, Township of Innisfil	Ian D. Wilson Associates Ltd	118	1	INNISFIL
Dixon, V.R. And Easton, J.A.	**1990**	Township of innisfil Lot 7, Concession 8 Innisfil Heights water supply construction and testing of well 3	Dixon Hydrogeology Ltd	119	1	INNISFIL
Dixon, V.R.	**1992**	Town of Innisfil, Innisfil Heights Well Field - Assessment of Potential Nitrate Contamination	Dixon Hydrogeology Ltd	120	1	INNISFIL
Golder Associates Inc.	**2010**	Technical Memorandum- Town of Innisfil Municipal Supply Wells Capture Zone and Equipotential Surface Review	Golder Associates Inc.	50	1	INNISFIL
Terraprobe	**2002**	Geotechnical Investigation, Proposed Dare Residence, Township of Oro-Medonte	Terraprobe	61	1	ORO
Gartner Lee Ltd.	**2002**	Environmental Analysis, Proposed Residential Golf Course Community, Ucci Consolidated Companies Inc., Township of Oro-Medonte	Gartner Lee Ltd.	62	1	ORO
Terraprobe	**2003**	Geotechnical Assessment, Proposed Access Pathway, 129 Brambell Rd, Township of Oro-Medonte	Terraprobe	63	1	ORO
Golder Associates Inc. and Waterloo Hydrogeologic	**2004**	South Simcoe Groundwater Study WHPA - Township of Oro-Medonte, Appendix K	Golder Associates Inc. and Waterloo Hydrogeologic	64	1	ORO
Terraprobe	**2004**	Geotechnical Investigation, Proposed Stair Case Construction, Barrie Terrace, Township of Oro-Medonte	Terraprobe	65	1	ORO
Geospec	**2004**	Subsurface Investigation and Slope Stability Assessment, Proposed Boathouse, 2295 Lakeshore Rd E, Township of Oro-Medonte	Geospec	66	1	ORO
Terraprobe	**2005**	Slope Stability Assessment, Proposed Terraced Observation Deck and Boathouse, 3055 Ridge Road, Township of Oro-Medonte	Terraprobe	67	1	ORO
Golder Associates Ltd.	**2005**	North Simcoe Groundwater Study WHPA - Township of Oro-Medonte, Appendix F	Golder Associates Ltd.	68	1	ORO
Golder Associates Ltd.	**2010**	Groundwater Flow Model and Capture Zone Development, Warminster Well 1 and Well 3	Golder Associates Ltd.	69	1	ORO
Golder Associates	**2010**	Groundwater Flow Model and Capture Zone Development,	Golder Associates Ltd.	70	1	ORO

DOC_AUTHOR	DOC_YEAR	DOC_NAME	DOC_AUTHOR_AGENCY	AQR Ref ID	Added to WebPortal	Folder
Ltd.		Horseshoe Highlands Well 1 and Well 2				
Golder Associates Ltd.	**2010**	Oro-Medonte Municipal Supply Wells, Capture Zone and Equipotential Surface Review Technical Memo	Golder Associates Ltd.	71	1	ORO
Golder Associates Ltd.	**2010**	Groundwater Flow Model and Capture Zone Development, Sugarbush Municipal Supply Wells	Golder Associates Ltd.	72	1	ORO
Lee, S.J. and V.R. Dixon	**1992**	Oro seventh line aggregate pits hydrogeological study	Dixon Hydrogeology Ltd	106	1	ORO
Rether, G.	**1999**	Evaluation of Municipal Wells, Well 1 and 2, Shanty Bay, Township of Oro-Medonte	Ian D. Wilson Associates Ltd	122	1	ORO
Bryck, L.G.	**2001**	Hydrogeologic Appraisal, Craighurst Estate Water System	Hydroterra	123	1	ORO
Bryck, L.G.	**2001**	Hydrogeologic Appraisal, Shanty Bay Water System	Hydroterra	124	1	ORO
AquaResource Inc.	**2009**	Grand River Watershed Creek Integrated Water Budget	AquaResource Inc.	2	0	other
AquaResource Inc.	**2009**	Grand River Watershed Tier 2 Water Quantity Stress Assessment	AquaResource Inc.	3	0	other
AquaResource Inc.	**2008**	Saugeen Valley / Grey Sauble / Northern Bruce Peninsula Tier One Water Budget	AquaResource Inc.	4	0	other
AquaResource Inc.	**2008**	Credit Valley Watershed Water Budget and Stress Assessment	AquaResource Inc.	5	0	other
AquaResource Inc. and Golder Associates	**2009**	Nottawasaga Valley Conservation Authority Water Budget Model – Geological/Hydrostratigraphic Model Development	AquaResource Inc. and Golder Associates	1	0	REGIONAL
Chapman, J.L. and Putman, D.F.	**1984**	The Physiography of Southern Ontario, Special Volume 2, Ontario.	Ontario Geological Survey	11	0	REGIONAL
Golder Associates Inc.	**2004**	South Simcoe Groundwater Study. Report completed using the Province of Ontario’s Groundwater Protection Fund.	Golder Associates Inc.	19	1	REGIONAL
Lake Simcoe Region Conservation Authority	**2008**	Tier 1 Water Budget and Water Quantity Stress Assessment for the Lake Simcoe Watershed. September 2008.	Lake Simcoe Region Conservation Authority	23	1	REGIONAL
Lake Simcoe Region Conservation Authority	**2009**	Tier 1 Water Budget and Water Quantity Stress Assessment for the Nottawasaga Valley Watershed. December 2009.	Lake Simcoe Region Conservation Authority	24	1	REGIONAL
Nottawasaga Valley Conservation Authority	**2010**	The Report on the HSPF Model NVCA and SSEA Watersheds. (Draft). Tier 2 Water Budget Source Water Protection.	Nottawasaga Valley Conservation Authority	27	1	REGIONAL
South Georgian Bay-Lake Simcoe Source Protection Region	**2006**	South Georgian Bay-Lake Simcoe Watershed Preliminary Conceptual Water Budget Report.	South Georgian Bay-Lake Simcoe Source Protection Region	31	1	REGIONAL
Nottawasaga Valley Conservation	**2009**	Fisheries Habitat Management Plan, Nottawasaga Valley Conservation Authority Area of Jurisdiction	Nottawasaga Valley Conservation Authority and	82	1	REGIONAL

DOC_AUTHOR	DOC_YEAR	DOC_NAME	DOC_AUTHOR_AGENCY	AQR Ref ID	Added to WebPortal	Folder
Authority and Fisheries and Oceans Canada			Fisheries and Oceans Canada			
Kuehl, G.A.	**1996**	Development of a Natural Heritage System for the County of Simcoe	International Water Supply	94	1	REGIONAL
Earthfx Inc.	**2010**	Black-Severn Watershed Tier One Water Budget and Stress Assessment.	Earthfx Inc.	14	0	REGIONAL
Earthfx Inc.	**2010**	Water Balance Analysis of the Lake Simcoe Basin using the Precipitation-Runoff Modelling System (PRMS)	Earthfx Inc.	15	1	REGIONAL
Waterloo Hydrogeologic Inc, Golder Associates Ltd, and Dixon Hydrogeology Ltd	**2003**	South Simcoe Municipal Groundwater Study	Waterloo Hydrogeologic Inc	101	0	REGIONAL
Beckers, J.	**1998**	Modelling the Oro Moraine Multi-Aquifer System: Role of Geology, Numerical Model, Parameter Estimation and Uncertainty		147	1	Regional
	2008	Integrated Watershed Management Plan	L.S.R.C.A.	148	1	Regional
	2008	Basin Wide Report	L.S.R.C.A	149	1	Regional
	2004	Sedimentology of Quaternary sediments beneath Lake Simcoe		170	1	REGIONAL
Barnett, P.J.	**1988**	64. Project Number 86-12. Quaternary Geology of the Eastern Half of the Elmvale Area, Simcoe County	Ontario Geological Survey	153	1	REGIONAL
Barnett, P.J.	**1989**	35. Project Number 86-13. Quaternary Geology of the Barrie and Elmvale Area	Ontario Geological Survey	154	1	REGIONAL
Barnett, P.J.	**1991**	Preliminary Report on the Stratigraphic Drilling of Quaternary Sediments in the Barrie Area, Simcoe County, Ontario	Ontario Geological Survey	155	1	REGIONAL
Barnett, P.J.	**1991**	23. Project Unit 86-13. Quaternary Geology of the Barrie Area, Simcoe County, Ontario	Ontario Geological Survey	156	1	REGIONAL
Beckers, J. and E.O.Frind	**2001**	Simulating groundwater flow and runoff for the Oro Moraine aquifer system. Part 11. Automated calibration and mass balance calculations	Journal of Hydrology	157	1	REGIONAL
Burt, A.K.	**2004**	35. Project Unit 03.21. Three Dimensional Modelling of Thick Quaternary Deposits in the Barrie Area, Central Ontario	Ontario Geological Survey	158	1	REGIONAL
Burt, A.K.	**2006**	33. Project Unit 03.21. Three Dimensional Modelling of Thick Quaternary Deposits in the Barrie Area, Central Ontario	Ontario Geological Survey	159	1	REGIONAL
Burt, A.K.	**2007**	21. Project Unit 03.21. Three Dimensional Modelling of Thick Quaternary Deposits in the Barrie Area, Central Ontario	Ontario Geological Survey	160	1	REGIONAL
Burt,A.K. and D.F.Russell	**2005**	26. Project Unit 03.21. Three Dimensional Modelling of Thick Quaternary Deposits in the Barrie Area, Central Ontario	Ontario Geological Survey	161	1	REGIONAL

DOC_AUTHOR	DOC_YEAR	DOC_NAME	DOC_AUTHOR_AGENCY	AQR Ref ID	Added to WebPortal	Folder
Gwyn, Q.H.J.	**1972**	31.Quaternary Geology of the Alliston-Newmarket Area, Southern Ontario	Ontario Geological Survey	162	1	REGIONAL
S.Holysh, S.D.Davies and D. Goodyear	**2004**	28. Project Unit 04-028. An Investigation into Buried Valley Aquifer Systems in the Lake Simcoe Area	Ontario Geological Survey	163	1	REGIONAL
Kor, P.S.G and D.W. Cowell	**1998**	Evidence for catastrophic subglacial meltwater sheetflood events on the Bruce Peninsula, Ontario	Canadian Journal of Earth Science	164	1	REGIONAL
Beckers, J. and E.O.Frind	**2000**	Simulating groundwater flow and runoff for the Oro Moraine aquifer system. Part 1. Model formulation and conceptual analysis	Journal of Hydrology	165	1	REGIONAL
Brennand, T.A. and J. Shaw	**1993**	Tunnel channels and associated landforms, south central Ontario> their implications for ice-sheet hydrology	Canadian Journal of Earth Science	166	1	REGIONAL
Shaw, J. and R. Gilbert	**1989**	Evidence for large-scale subglacial meltwater flood events in Southern Ontario and Northern New York State	Geology (Journal)	167	1	REGIONAL
Shaw, J., Rains B., Eyton R., and L. Weissling	**1996**	Laurentide subglacial outburst floods: landform evidence from digital elevation models	Canadian Journal of Earth Science	168	1	REGIONAL
Slattery, S.R.	**2003**	25. Project Number 03-021. Subsurface Mapping of the Barrie Area, Central Ontario	Ontario Geological Survey	169	1	REGIONAL
Golder Associates Inc. and Waterloo Hydrogeologic	**2004**	South Simcoe Groundwater Study WHPA - Township of Springwater, Appendix L	Golder Associates Inc. and Waterloo Hydrogeologic	73	1	SPRINGWATER
Dixon Hydrogeology Ltd.	**2004**	Township of Springwater, Hillsdale Water Supply, Construction and Testing of Well 3	Dixon Hydrogeology Ltd.	74	1	SPRINGWATER
Golder Associates Ltd.	**2005**	North Simcoe Groundwater Study WHPA - Township of Springwater, Appendix J	Golder Associates Ltd.	75	1	SPRINGWATER
Golder Associates Ltd.	**2005**	Township of Springwater, Community of Phelpston, WHPA	Golder Associates Ltd.	76	1	SPRINGWATER
Golder Associates Ltd.	**2007**	Snow Valley WHPA Modelling	Golder Associates Ltd.	77	1	SPRINGWATER
Golder Associates Ltd.	**2010**	Springwater Municipal Supply Wells, Capture Zone and Equipotential Surface Review, Technical Memo	Golder Associates Ltd.	78	1	SPRINGWATER
Ministry of the Environment	**2004**	Certificate of Approval - Anten Mills Water Supply System	Ministry of the Environment	79	1	SPRINGWATER
Ministry of the Environment	**2005**	Certificate of Approval - Midhurst Water Supply System	Ministry of the Environment	80	1	SPRINGWATER
Ministry of the Environment	**2008**	Certificate of Approval - Snow Valley Water Supply System	Ministry of the Environment	81	1	SPRINGWATER
Easton, J.A. and V.R. Dixon	**1992**	Del trend 43T-88019 west half lot 16, concession 4 Township of Vespra construction and testing of wells 1/91 and 2/91	Dixon Hydrogeology Ltd	84	1	SPRINGWATER

DOC_AUTHOR	DOC_YEAR	DOC_NAME	DOC_AUTHOR_AGENCY	AQR Ref ID	Added to WebPortal	Folder
Wilson, I.D.	**1986**	Preliminary hydrogeological evaluation proposed residential development Oakdale Estates	Ian D. Wilson Associates Ltd	85	1	SPRINGWATER
Hendy, G.R.	**1993**	Construction and testing production well pw1-93 proposed Vespra downs development Part West Half lot 22, concession 12	Jagger Hims Ltd	87	1	SPRINGWATER
MacLarentech Inc	**1990**	Draft report to Marathon realty company limited toronto, ontario groundwater supply evaluation Midhurst - Vespra	MacLarentech Inc	90	1	SPRINGWATER
Lee, S.J. and J.A. Easton	**2001**	Township of Springwater: Hendrie Properties - Anten Mills Testing of Wells 1 and 2	Dixon Hydrogeology Ltd	91	1	SPRINGWATER
Lee, S.J.	**1998**	Snow valley secondary plan Township of Springwater Hydrogeological study	Dixon Hydrogeology Ltd	92	1	SPRINGWATER
Easton, J.A.	**1998**	Glenbrook heights subdivision west half lot 16; concession 5 (Vespra) township of Springwater construction and testing well 3/98	Dixon Hydrogeology Ltd	97	1	SPRINGWATER
Easton, J.A.	**1998**	Township of Springwater: West Half Lot 16; Concession 4 (Vespra) Carson Road Well field Permit To Take Water Amendment	Dixon Hydrogeology Ltd	99	1	SPRINGWATER
Wilson, I.D.	**1990**	Township of Vespra Midhurst Groundwater investigation and Well Construction Program	Ian D. Wilson Associates Ltd	100	1	SPRINGWATER
Kristjanson, J. and A.G. Hims	**1989**	Preliminary hydrogeological evaluation proposed subdivision Township of Vespra	Jagger Hims Ltd	102	1	SPRINGWATER
Lee, S.J. and J.A. Easton	**2002**	Township of Springwater: Hendrie Properties - Anten Mills Construction and Testing of Well 3	Dixon Hydrogeology Ltd	103	1	SPRINGWATER
Wilson, I.D.	**1987**	System capacity evaluation Midhurst area water supply system, community of Midhurst Township of Vespra	Ian D. Wilson Associates Ltd	104	1	SPRINGWATER
Dixon, V.R.	**1989**	Township of Vespra Midhurst Growth Alternatives Report on Hydrogeological studies	Dixon Hydrogeology Ltd	107	1	SPRINGWATER
Kuehl, G.A.	**1987**	Well evaluation proposed residential development Oakdale Estates	International Water Supply Ltd	108	1	SPRINGWATER
Wilson, I.D.	**1973**	Report on an Aquifer Test: Anten Mills, Township of Vespra	Ian D. Wilson Associates Ltd	109	1	SPRINGWATER
Easton, J.A.	**2000**	Construction and testing Carson road well 4	Dixon Hydrogeology Ltd	112	1	SPRINGWATER
Wilson, I.D.	**1992**	Well Evaluation, Well 4 Community of Minesing, Township of Vespra	Ian D. Wilson Associates Ltd	121	1	SPRINGWATER
Easton, J.A.	**2004**	Minesing Water Supply -Construction of Well 2/04	Golder Associates	126	1	SPRINGWATER
Bowles, R.L., Laverty, J. and D. Featherstone	**2007**	Minesing Wetlands Study	NVCA and Friends of Minesing Wetlands	127	1	SPRINGWATER
Barnett, P.J.	**1997**	Quaternary Geology, eastern half of the Barrie and Elmvale areas; Map 2645, Scale 1:50,000.	Ontario Geological Survey	6	0	

DOC_AUTHOR	DOC_YEAR	DOC_NAME	DOC_AUTHOR_AGENCY	AQR Ref ID	Added to WebPortal	Folder
Barnett, P.J.	**1992**	Quaternary geology of Ontario; In P.C. Thurston, H.R. Williams, R.H. Sutcliffe and G. M. Stott (Editors), Geology of Ontario. p. 1101-1090	Ontario Geological Survey	7	0	
Barnett, P.J.	**1990**	Tunnel valleys: evidence of catastrophic release of subglacial meltwater, central-southern Ontario, Canada; in Abstracts with Programs, Geological Society of America, Northeastern Section, Syracuse, New York, p. 3.	Geological Society of America	8	0	
Bellamy, S., Boyd, D., Whiteley, H.	**2003**	Base flow Separation Techniques	Grand River Conservation Authority	10	0	
Province of Ontario.	**2006**	Clean Water Act	Province of Ontario.	12	0	
Deane., R.E.	**1950**	Pleistocene Geology of the Lake Simcoe District, Ontario, Geological Survey of Canada. Memoire 256, 108p. Accompanied by Map 992A, Scale 1:126,730.	Geological Survey of Canada	13	0	
Finamore, P.F. and Bajc, A.F.	**1984**	Geology 1981 and 1982. Quaternary Geology of Orillia Area, Southern Ontario; Ontario Geological Survey, 1984. Map P2697, Geological Series – Preliminary Map, Scale 1:50,000.	Ontario Geological Survey	16	0	
Golder Associates Inc.	**2005**	North Simcoe Groundwater Study. Report completed using the Province of Ontario's Groundwater Protection Fund.	Golder Associates Inc.	17	0	
Golder Associates Inc.	**2006**	Tiny Township Groundwater Study. Report completed using the Province of Ontario's Groundwater Protection Fund.	Golder Associates Inc.	18	0	
Great Lakes Information Network, (GLIN)	**2006**	Lake Huron Current Water Levels. http://www.great-lakes.net/envt/water/levels/levels-cur/hurwlc.html#gen	Great Lakes Information Network, (GLIN)	20	0	
Gravenor, C.P.	**1957**	Surficial geology of the Lindsay-Peterborough area, Ontario; Geological Survey of Canada, Memoir No. 288,60p.	Geological Survey of Canada	21	0	
Kassenaar, J. D. C., and E. J. Wexler.	**2006**	Groundwater Modelling of the Oak Ridges Moraine Area. In CAMC-YPDT Technical Report #01-06.	Earthfx Inc.	22	0	
Lake Simcoe Region Conservation Authority	**2009**	Tier 1 Water Budget and Water Quantity Stress Assessment for the Severn Sound Watershed. June 2009.	Lake Simcoe Region Conservation Authority	25	1	
Leavesley, G.H., Lichty, R.W., Troutman, B.M., and Saindon, L.G.	**1983**	Precipitation-Runoff Modeling System: User's Manual: U.S. Geological Survey Water-Resources Investigations Report 83-4238, 207 p.	U.S.G.S.	26	0	
Ontario Ministry of the Environment	**2006**	DRAFT Assessment Report: Guidance Module 7. Water Budget and Water Quantity Risk Assessment. http://www.ene.gov.on.ca/envision/gp/5600e_waterbudget.pdf	Ontario Ministry of the Environment	28	0	
Ontario Ministry of the Environment	**2009**	Clean Water Act (2006). Technical Rules: Assessment Report.	Ontario Ministry of the Environment	29	0	

DOC_AUTHOR	DOC_YEAR	DOC_NAME	DOC_AUTHOR_AGENCY	AQR Ref ID	Added to WebPortal	Folder
Ontario Stone, Sand & Gravel Association (OSSGA)	**2006**	Groundwater in the Aggregate Industry, 4 p., Accessible at: http://www.ontariossga.com/publications.htm	Ontario Stone, Sand & Gravel Association (OSSGA)	30	0	
U.S. EPA.	**1997**	Hydrological Simulation Program – FORTRAN (HSPF) Version 11.0 User's Manual for Release 11.	U.S. EPA.	32	0	
WASY	**2009**	FEFLOW	WASY	33	0	
B.J. Todd, J.A.M. Hunter, R.L. Good, R.A. Burns, M. Douma, S.E. Pullan and C.F.M. Lewis	**2003**	Seismostratigraphy of Quaternary Sediments beneath Lake Simcoe, Ontario: results of the 1992 and 1993 expeditions of the MV J. Ross Mackay	Geological Survey of Canada	34	1	

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BARRIE TIER THREE WATER BUDGET AND

LOCAL AREA RISK ASSESSMENT

CONCEPTUAL UNDERSTANDING MEMORANDUM

APPENDIX A2: WELL CONSTRUCTION DETAILS

Table A2.1 Summary of Barrie Municipal Well Construction Details

LOC ID	Well Name	Permitted Rate (m^3/d)	Moe Number	Well Construction Date	Screened Interval Depth (m)	5 M DEM ELEV (masl)	Total Depth (m)	Pump Setting Depth (m)	Diameter (mm)	Tested Yield (L/sec)	Pre-Pumping Static Level Depth (m)	Notes
NA	Well 1		5700230	21-Jul-37	32-38.7	221	38.7	27.4	0.356	83.9	-6.1	Abandoned in 1996
12260	Well 10	4546	5714078	25-Feb-77	86-93.6	251.1506	93.87	54.9	0.254	56.8	25.8	Non Operational
15062	Well 11	9100	5719264	14-Jun-84	47.2-61.3	220.5697	61.56	42.7	0.305	91.2	1.3	
14103	Well 12	9100	5717393	01-Apr-81	65.8-84	219.8701	88.69	30.5	0.305	106.1	-1.81	
42959	Well 13	6552	5724686	15-Feb-89	81-97.8	257.9959	99.06	48.8	0.356	75.8	3.35	
42841	Well 14	9100	5727877	22-Aug-90	42.2-61.3	220.4413	60.96	39.6	0.305	106.1	6.41	
42832	Well 15	9100	5728705	19-Nov-91	45.7-66.7	219.9503	67.66	30.5	0.305	106.1	7.68	
42813	Well 16	7862	5733545	26-Feb-98	61.3-73.8	253.5994	74.67	36.6	0.4	90.9	18.46	
42592	Well 17	11230	5737406	09-Aug-02	77.1-86.3	235.2326	105.156	36.6	0.4	130	15.12	
42597	Well 18	11230	5739442	16-Aug-04	87.5-106	234.3471	106	36.6	0.4	130	17.34	Backup and Peak; Shared Rate with 18
59762	Well 19	7862	DHL0385	03-Aug-07	84.4-93.6	234.8734	93.77	35	0.406	91	15	Not yet Operating
NA	Well 2		5700235	13-Jul-48	16.8-21.9	221.9	21.9	18.3	0.356	75.8	-3	Non Operational
42730	Well 3A	6552	5732108	27-Jun-95	96-107	228.1287	111.25	42.7	0.356	75.8	3	Replaced Well 3 in 1998
40261	Well 4	6552	DHL0195	19-Oct-59	50-56.1	227.5542	56.08	30.5	0.406	76.5	4.4	
2832	Well 5	6552	5700271	06-Nov-63	88-106.1	232.2017	107.28	24.4	0.305	75.8	6.3	
NA	Well 6		5706146	17-Jan-69	53.6-72	231.6	72	18.3	0.406	83.3	3.9	Non Operational
9079	Well 7	6552	5709125	25-Sep-72	86-100.7	234.8944	100.58	30.5	0.406	90.9	11.1	
NA	Well 8		5711799	28-Oct-74	46.3-69.7	226.8	69.7	24.4	0.254	68.2	1.4	Abandoned in 2001
11277	Well 9	6552	5712496	11-Sep-75	77-93	258.2424	93.87	51.8	0.305	75.8	21.2	