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CITY OF BARRIE
TIER THREE WATER BUDGET AND LOCAL AREA
RISK ASSESSMENT

Report Prepared for:

LAKE SIMCOE REGION CONSERVATION AUTHORITY

Prepared by:

AQUARESOURCE
A Division of
MATRIX SOLUTIONS INC.

IN PARTNERSHIP WITH

IWC

Golder Associates

Final Report
July 2013
Breslau, Ontario

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A Division of
MATRIX SOLUTIONS INC.

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EXECUTIVE SUMMARY

This report describes a Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) completed for the municipal drinking water systems within the City of Barrie in the Province of Ontario, Canada. As a requirement under the Province's *Clean Water Act*, the purpose of this project was to evaluate the water quantity risk level and identify potential water quantity threats to these municipal drinking water systems.

The Province of Ontario introduced the *Clean Water Act* (Bill 43) to ensure that all residents have access to safe drinking water. Under the *Clean Water Act*, Source Protection Authorities are required to conduct technical studies to identify existing and potential water quality and quantity threats to municipal drinking water. Through the development of community-based Source Water Protection Plans actions will be implemented to reduce or eliminate any significant drinking water threats.

As one component of the required technical studies, Tier One and Tier Two Water Quantity Stress Assessments have been completed for many subwatersheds across the province. The purpose of a Water Quantity Stress Assessment is to compare available groundwater and surface water supply to the demand from existing, future and planned drinking water systems. Where the ratio of water demand to water supply is high, subwatersheds have been classified as having a "Moderate" or "Significant" potential for water quantity stress. Source Protection Authorities are required to complete a Tier Three Assessment when municipal water supply wells are located within a subwatershed classified as having a moderate or significant potential for water quantity stress.

The City of Barrie's groundwater supply system consists of 14 wells constructed within deep overburden aquifers, located mostly within the Barrie Creeks Subwatershed, which surrounds and drains to the west end of Kempenfelt Bay, Lake Simcoe. The Tier Two Water Budget and Subwatershed Stress Assessment completed for the South Georgian Bay West Lake Simcoe watershed (Golder and AquaResource 2010) identified the Barrie Creeks Subwatershed as having a Significant potential for groundwater stress. The identification of this stress indicator led to the requirement of municipal systems located within the watershed to be assessed under a Tier Three Assessment. Despite this indication of potential stress, to date, the City of Barrie has not had any issues meeting their water quantity requirements.

This report details the Tier Three Assessment carried out for the City of Barrie. It summarizes the process and results of the Local Area Risk Assessment. Three technical appendices (Appendix A: Conceptual Understanding, Appendix B: Recharge Estimation Using MIKE SHE and Appendix C: Groundwater Flow Model Construction and Calibration) summarize the development of the conceptual and numerical hydrologic and hydrogeologic models used to complete the assessment.

Scope of Work

The scope of work completed in this Tier Three Assessment and documented in this report follows the Province's *Technical Rules (MOE 2009) and Water Budget and Water Quantity Risk Assessment Guide* (MNR and MOE 2011).

The following tasks were completed for this study:

1. Develop the conceptual understanding of the Study Area.
2. Develop and calibrate a groundwater flow model with sufficient detail to simulate groundwater flow near municipal wells and surface water features.
3. Develop and calibrate a surface water model to simulate variable streamflow in the area and to estimate groundwater recharge rates in the Study Area.
4. Apply the calibrated surface water and groundwater models to assess the water budget components in the Study Area and in the vicinity of municipal wells.
5. Complete a Local Area Risk Assessment for the municipal wells located in the Study Area.
6. Complete Significant Groundwater Recharge Area delineation and mapping.

Water Budget Tools

As part of the Tier Three Assessment, surface water and groundwater modelling tools were developed to assess the sustainability of the municipal water sources. The models were developed based on a detailed characterization of the groundwater and surface water systems, and they were refined around wells to a level supported by available data. The models were calibrated to represent typical operating conditions under average (steady state) and variable (transient) pumping conditions.

The groundwater and surface water modelling approach was designed to simulate average and drought conditions, represent the detailed hydrologic and/or hydrogeologic conceptual model, and integrate the inputs and outputs of the surface water and groundwater models (e.g., groundwater recharge, baseflow). The groundwater flow model was developed using FEFLOW (DHI-WASY 2009) based on the best geological and hydrogeological data available for the Study Area. The surface water model was developed using MIKE SHE (DHI-WASY 2011a, b). Appendices B and C of this report describe the development and calibration of the surface water model and groundwater model in detail, respectively.

Consumptive Water Demand

Consumptive water demand is defined as the amount of water that is removed from a water source but not returned to the same water source within a reasonable amount of time. Consumptive water takers within the Study Area, including both municipal and non-municipal permitted water takings were compiled within this Study. The permitted consumptive water takings were simulated directly in the groundwater flow model as they have the potential to influence water levels and affect the model calibration.

Other water uses that rely on the quantity of groundwater supplies within the subwatershed were also identified in this assessment. These additional water uses include surface water features that rely on groundwater discharge for sustaining coldwater fisheries (and similar environmental/ecological communities), and for recreational use.

Current and historical groundwater pumping and monitoring data were also compiled as part of this study, and it was found that the City of Barrie has never experienced water quantity limitations from their municipal pumping well system.

Tier Three Water Budget

A detailed water budget for the Barrie Creeks Subwatershed was developed using the enhanced Tier Three water budget tools described above. Approximately 910 mm/year of precipitation falls within the subwatershed (average annual precipitation at the Ministry of Environment [MOE] Barrie climate station). Of this, approximately 50% leaves the subwatershed as evapotranspiration and 30% leaves as overland flow; the remainder recharges the groundwater system.

Groundwater modelling results indicate that total groundwater flow into the Barrie Creeks Subwatershed across the subwatershed boundaries is significant with approximately 43,600 m^3/d of groundwater estimated to be flowing into the subwatershed from adjacent subwatersheds (Willow Ck. to the north, Middle Nottawasaga to the west, and Lovers Ck. to the south). Municipal pumping induces much of the cross-boundary flow from the Nottawasaga Valley Watershed (Willow Creek and Middle Nottawasaga).

Local Area Risk Assessment

A Local Area was delineated surrounding the municipal supply wells in the Study. This area was delineated as outlined in the Province's Technical Rules (MOE 2009) based on a combination of 1) the cone of influence of the municipal wells, and 2) land areas where recharge has the potential to have a measurable impact on water levels at the municipal wells.

A set of Risk Assessment scenarios was developed to represent the municipal allocated quantity of water (existing, committed, and planned pumping rates); and current and planned land uses. The calibrated surface water and groundwater flow models were used to estimate both the changes in water levels in the municipal supply aquifer and the impacts to groundwater discharge and baseflow under average and drought climate conditions.

Conclusions

Based on the results of the Risk Assessment modelling scenarios, the Local Area, which includes all of the City of Barrie's municipal supply wells, was classified as having a Low Risk Level. In large part, the start-up of a surface water supply to meet municipal demands has lowered the risk of the system. In addition, the groundwater wells are screened within highly productive aquifers that are relatively isolated from the shallow system by a low permeability intervening aquitard.

Following the Technical Rules, no consumptive water users and potential reductions to groundwater recharge within the Local Area are classified as significant water quantity threats.

Recommendations

Recommendations for the City of Barrie:

1. Maintain and Enhance Monitoring Programs.

    a. Monitoring and reporting programs associated with Permits to Take Water are already in place and should be continued. Monitoring data should be reviewed and maintained on an ongoing basis recognizing the relationship between municipal groundwater withdrawals and surface water discharge. Additional shallow monitors throughout the City would also be beneficial in understanding and further characterizing the aquitards windows.

    b. Flow gauging and other assessments of key surface water features such as Bear Creek and the Barrie Creeks should be enhanced to monitor the long term trends in surface water features. This data could be used to better characterize the stream and its interaction with the groundwater flow system. It could also be used in future updates to the groundwater flow model to support the model calibration, as it would provide baseline operational field data to better understand the role of groundwater discharge to stream ecology.

2. Rehabilitate and maintain wells routinely. The Risk Analysis Scenarios showed that safe drawdown can be exceeded when wells experience deteriorated well performance; these conditions have been avoided in the past with routine rehabilitation efforts and it is recommended that the City continue their efforts to this end. Alternative pumping scenario plans using current pumping rates (since the supplementation provided by the surface water supply) should be established to maintain supply during periods when individual wells need to be offline for maintenance; such scenarios should be used to develop guidelines as to how many wells can be offline at any given time.

3. Update Regional Water Budget Models. The Lake Simcoe Region Conservation Authority maintains water budget modelling tools to help manage and protect the water resources across the watershed. Hydrogeologic, hydrologic and operational insights gained from this Tier Three Assessment should be incorporated into the regional scale models developed by the LSRCA. These modelling tools should be updated periodically as new information is gathered and insights evolve within the watershed.

4. Maintain and Enhance Water Conservation Programs. Although the City of Barrie can meet municipal water demands under average climate conditions, current water conservation programs should be maintained to ensure that per-capita water demand does not increase and to encourage decreases. Opportunities to reduce water demand within the City should be considered. Any reduction in the per capita water use will enhance local ecosystem health.

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1.0 INTRODUCTION

The Province of Ontario introduced the *Clean Water Act* (Bill 43) to ensure that all residents have access to safe drinking water. Under the *Clean Water Act*, Source Protection Authorities are required to conduct technical studies to identify existing and potential water quality and quantity threats to municipal drinking water. Through the development of community-based Source Water Protection Plans, actions will be implemented to reduce or eliminate any significant drinking water threats.

Under the requirements of the *Clean Water Act*, municipalities may be required to complete a Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) to assess the ability of the municipal water sources to meet committed and planned water demands. Tier Three Assessments are required where municipal wells or intakes are located in subwatersheds that were classified as having a Moderate or Significant stress level as part of a Tier Two Subwatershed Stress Assessment completed under the requirements of the *Clean Water Act*. The Tier Three Assessments identify municipal wells or intakes that may be unable to meet their allocated water demands under average or drought conditions.

Following the completion of the South Georgian Bay West Lake Simcoe Tier Two Subwatershed Stress Assessment (Golder and AquaResource 2010), a Tier Three Assessment was required for the City of Barrie, as the municipal wells are located within the Barrie Creeks Subwatershed (Figure 1.1) which was classified as having a Significant stress level in the Tier Two subwatershed stress assessment. While there are no documented issues with respect to the municipal sources meeting demand, the municipalities are required to complete a Tier Three Water Budget and Local Area Risk Assessment. Figure 1.2 illustrates the locations of municipal water supplies considered in this project.

This report details the Tier Three Water Budget and Local Area Risk Assessment carried out for the City of Barrie and summarizes the process and results of the assessment. Three companion reports relating to the various milestones of this project are included as appendices, including background information relating to the geology and hydrogeology of the area, current and planned water demands, and the development of the conceptual and numerical hydrologic and hydrogeologic models used to complete this Tier Three Assessment.

1.1 Study Team

The project team was directed by a technical team comprising members of the following organizations:

- Ministry of Natural Resources (MNR)
- The City of Barrie
- Lake Simcoe Region Conservation Authority, as the lead managing authority for the South Georgian Bay Lake Simcoe (SGBLS) Source Protection Region
- Nottawasaga Valley Conservation Authority

The consultant project team responsible for the completion of this project included:

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

1.2 Clean Water Act Water Budget Framework

The *Clean Water Act* requires that each Source Protection Committee prepare an Assessment Report for their Source Protection Areas in accordance with Ontario Regulation 287/07 (General Regulation) and the Technical Rules for the Assessment Report. A requirement of the Assessment Report is the development of water budgets that assess the threats to water quantity sources under a tiered framework. Tier One and Tier Two Assessments of this framework evaluate the subwatershed's hydrological stresses, while the Tier Three Assessment examines threats to water quantity sources and evaluates the ability of the sources to meet a community's current and planned drinking water needs.

Water Budgets developed under the *Clean Water Act* (2006) provide a quantitative measure of the hydrologic cycle components and a conceptual understanding of the processes and pathways by which surface water and groundwater flows through a watershed or subwatershed. Key deliverables of the water budget analysis include the surface water and groundwater flow models, which are available for future use and application.

The Tier One and Tier Two Subwatershed Stress Assessments estimate the hydrologic stress within a subwatershed and they also identify those subwatersheds, which have the potential for local stresses to result in local water shortages at municipal wells. The subwatershed stress assessment is dependent on hydrologic parameters estimated in the water budget.

A Tier Three Water Budget and Local Area Risk Assessment is completed for two reasons: 1) to estimate the risk level associated with a municipality being able to sustain its allocated (existing, committed or planned) water supply pumping rates; and 2) to identify threats placed on the drinking water sources that may influence the municipality's ability to meet their allocated pumping rates. The Tier Three Assessment is completed for all municipalities where their drinking water sources are located within a subwatershed having a "Moderate" or "Significant" water quantity stress as determined in the Tier Two Stress Assessment. A Tier Three Water Budget uses numerical groundwater and/or surface water models that are refined from those used in the Tier Two models whenever possible. The Tier Three models should be developed with the accuracy and refinement needed to evaluate hydrologic or hydrogeologic conditions at a water supply well or surface water intake.

In general, Water Quantity Stress Assessments provide a consistent approach for evaluating the long-term reliability of the Province's drinking water sources, and they identify drinking water quantity threats located within local vulnerable areas where moderate or significant risks have been identified.

1.2.1 Tier Three Water Budgets and Local Area Risk Assessments

A Tier Three Water Budget and Local Area Risk Assessment is undertaken for municipal groundwater wells that are located within subwatersheds that were assigned a Moderate or Significant potential for water quantity stress in the Tier Two Subwatershed Stress Assessment, or that have had a historical issue with the water sources meeting municipal water demands.

The objective of the Tier Three Assessment is to evaluate the risk level associated with a municipality being able to meet its planned water quantity requirements considering increased municipal water demand, future land development, drought conditions, and other water uses. The Tier Three Assessment uses refined surface and/or groundwater flow models and involves a much more detailed study of the available groundwater or surface water sources. Various scenarios are evaluated with the models assessing the groundwater and the surface water flows and levels, and the interactions between them.

The ratio of water demand to water supply used to assess stress for Tier One and Tier Two is not used for the Tier Three Assessment. Instead, the Tier Three Risk Assessment evaluates the potential that a community may not be able to meet its current or planned water demands from a water source (e.g., stream, lake, or aquifer).

Estimates of consumptive water demand are a major component of a Tier Three Assessment. Consumptive water demand refers to the amount of water taken from a water source (e.g., surface water or groundwater) and not returned to that water source. The Tier Three Assessment identifies water uses (e.g., municipal and industrial) and estimates consumptive demand for each use.

Tier Three Assessments use detailed numerical groundwater and/or surface water models on a local scale. Models are developed with the accuracy and refinement needed to evaluate hydrologic or hydrogeologic conditions at a water supply well (or intake) and, whenever possible, should be refined from the Tier Two Assessment models. The models developed for the Tier Three Assessment are scaled appropriately to evaluate the potential impacts of planned water demands on other water uses (e.g., ecological requirements). Water budget models are also developed to represent a refined conceptual hydrologic or hydrogeologic model and are calibrated to the best extent possible to represent average annual and drought conditions.

Numerical groundwater and surface water models are used to delineate the “Local Area” for groundwater wells. In the Tier Three Risk Assessment, numerical models are used to estimate the impact of increased water demand, variable climate, and land use development on a well or surface water intake using a variety of modelling scenarios. Where these scenarios identify the potential that a well or intake will not be able to supply their allocated rates, the Local Area is assigned a Moderate or Significant Water Quantity Risk Level. Once the Risk Level is assigned to the Local Area, activities within the Local Area that remove water from an aquifer or surface water body without returning that water to the same aquifer or surface water body (i.e., consumptive water uses) are identified as drinking water threats. Similarly, activities that reduce groundwater recharge to an aquifer within the Local Area are also identified as drinking water threats. The drinking water threats within the Local Area are then classified as Moderate or Significant depending on the Risk Level assigned to the Local Area. If the Risk Level is Significant, all consumptive water uses and reductions in recharge are classified as significant drinking water threats. The Risk Assessment modelling scenarios also considers the need to meet the water demand requirements of other uses.

Rules and technical guidance for completing Tier Three Assessments are provided in Part IX of the Technical Rules (MOE 2009), MOE technical bulletins (MNR and MOE 2010), and the MNR/MOE water budget guide (MNR and MOE 2011).

1.2.2 Tier Three Methodology

The following steps were completed for the City of Barrie Tier Three Water Budget and Local Area Risk Assessment:

1. Develop the Conceptual and Numerical Tier Three Assessment Models. The first step in the Tier Three Assessment is the development of a conceptual water budget. Additional detailed hydrogeologic and/or hydrologic characterization is undertaken within and surrounding the municipal wells and intakes as part of the Tier Three Assessment. These conceptual models form the basis for the development of numerical models that should be calibrated to represent typical operating conditions under average and variable climate conditions.

2. Characterize Municipal Wells. The Tier Three Assessment requires a detailed characterization of wells and intakes specifically identifying the low water operating constraints of those wells and intakes.

3. Estimate the Allocated Quantity of Water. This task compiles and describes existing, committed, and planned pumping rates for municipal wells.

4. Identify and Characterize Drinking Water Quantity Threats. Drinking water quantity threats should include municipal and non-municipal consumptive water demands as well as reductions to groundwater recharge.

5. Characterize Future Land Use. An evaluation of the potential impact of future land use changes on drinking water sources should be included. This task will typically involve a comparison of Official Plans with current land use and incorporate assumptions relating to imperviousness for planned developments.

6. Characterize Other Water Uses. The Assessment should identify other uses (e.g., ecological flow requirements) that might be influenced by municipal pumping and identify water quantity constraints according to those other uses.

7. Delineate Vulnerable Areas. The Groundwater Quantity Vulnerable Areas, WHPA-Q1 (Well Head Protection Area for Water Quantity) and WHPA-Q2 should be delineated using the Tier Three Water Budget Model.

8. Evaluate Risk Scenarios. A series of scenarios will take into account the allocated quantity of water for each well and intake, average and drought conditions, and future land use. The scenarios should be evaluated in terms of the ability to pump water at each well or intake along with the impact to other water uses.

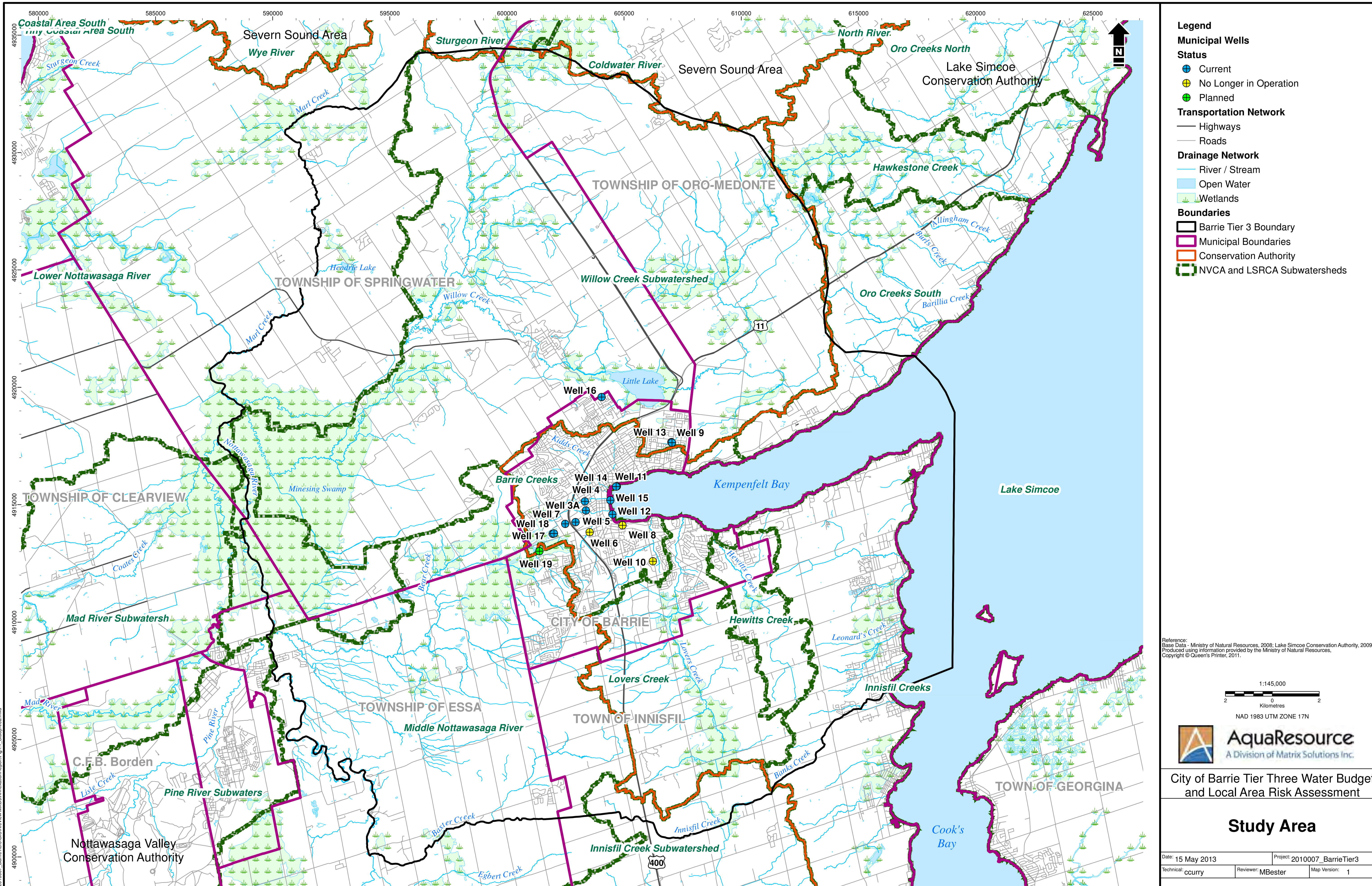
9. Assign Risk Level. A risk ranking (Low, Moderate, Significant) should be assigned to each of the vulnerable areas based on the results of the risk scenarios. An uncertainty level (e.g., high, low) will accompany each Risk Level ranking.

10. Identify Drinking Water Quantity Threats and Areas Where They Are Significant and Moderate. Drinking water quantity threats as consumptive uses or reductions in recharge within the vulnerable areas should be identified.

1.3 The Study Area

The Study Area in this assessment is illustrated in Figure 1.1 and includes the City of Barrie, and portions of the Townships of Essa, Innisfil, Springwater and Oro-Medonte, all within the County of Simcoe. The Study Area boundary was delineated to encompass the Barrie Creeks subwatershed and to include all municipal wells and other water uses that may have an impact on the municipal water sources. The Study Area extends beyond the subwatershed boundary, so that the boundary conditions applied at the perimeter of the numerical model have a minimal impact on the predictions made within the well field areas, and so that deep cross boundary flows between the subwatershed and its neighbouring subwatersheds could be quantified. The extents were also delineated based on groundwater divides that were interpreted from regional interpretations of shallow and deep groundwater levels and previous modeling efforts (Golder 2004). The complete Study Area covers an area of 800 km^2 and occupies both the Nottawasaga River watershed and the Lake Simcoe watershed within Simcoe County; however, the primary focus of the characterization study is on the City of Barrie well field and the immediate surrounding area.

The northern portion of the Study Area contains the Willow Creek Subwatershed, which drains a portion of the Oro Moraine and the Snow Valley uplands into the Nottawasaga River and Minesing Wetland. The Middle Nottawasaga River Subwatershed in the southwest of the Study Area contains Bear Creek, which originates from headwaters located on the southwest side of Barrie and drain westward to the Nottawasaga River. In the centre of the Study area, is the Barrie Creeks subwatershed, which is named based on the presence of a number of small streams that all flow within the City of Barrie and drain into Kempenfelt Bay, Lake Simcoe. Three subwatersheds in the southeast of the Study Area, Lovers Creek, Hewitts Creek and Innisfil Creeks Subwatersheds also drain into Lake Simcoe.



Legend
Municipal Wells
Status
Current
No Longer in Operation
Planned
Transportation Network
Highways
Roads
Drainage Network
River / Stream
Open Water
Wetlands
Boundaries
Barrie Tier 3 Boundary
Municipal Boundaries
Conservation Authority
NVCA and LSRCA Subwatersheds
Severn Sound Area
Wye River
Sturgeon River
Coldwater River
North River
Oro Creeks North
Lake Simcoe Conservation Authority
Tiny Coastal Area South
Coastal Area South
Sturgeon Creek
Marl Creek
TOWNSHIP OF ORO-MEDONTE
Hawkestone Creek
Allingham Creek
Bass Creek
Oro Creeks South
Barillia Creek
Lower Nottawasaga River
TOWNSHIP OF SPRINGWATER
Hendrie Lake
Willow Creek
Willow Creek Subwatershed
Little Lake
Well 16
Well 13
Well 9
Kidds Creek
Barrie Creeks
Well 14
Well 11
Well 4
Well 15
Well 3A
Well 12
Well 7
Well 5
Well 18
Well 8
Well 17
Well 6
Well 10
Well 19
Kempenfelt Bay
Lake Simcoe
TOWNSHIP OF CLEARVIEW
Minesing Swamp
Nottawasaga River
Coates Creek
Bear Creek
Hewitts Creek
Mad River Subwatersh
CITY OF BARRIE
Leonard's Creek
Lovers Creek
Innisfil Creeks
Mad River
TOWNSHIP OF ESSA
TOWN OF INNISFIL
Middle Nottawasaga River
C.F.B. Borden
Pine River
Pine River Subwaters
Lisle Creek
Banks Creek
TOWN OF GEORGINA
Baxter Creek
Innisfil Creek
Innisfil Creek Subwatershed
Cook's Bay
Nottawasaga Valley Conservation Authority
Egbert Creek
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Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
Produced using information provided by the Ministry of Natural Resources,
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City of Barrie Tier Three Water Budget and Local Area Risk Assessment
Study Area
Date: 15 May 2013
Project: 2010007_BarrieTier3
Technical: ccurry
Reviewer: MBester
Map Version: 1

Figure 1.1

Land use within the Study Area is composed of urban areas, aggregate extraction areas, golf courses and various rural land uses. Land use within the Barrie Creeks Subwatershed is mostly urban, however, there are some natural heritage features including wetlands, such as the Bear Creek wetland near the City of Barrie's western city limit.

The City of Barrie draws most of its municipal groundwater supply from within the Barrie Creeks Subwatershed as illustrated on Figure 1.2. Of the city's 14 wells, ten of these wells are directly within the subwatershed, and the remaining four (Wells 9, 13, 16, and 19) are located within 1 km of the subwatershed boundary. Up until 2011, the City was entirely reliant on groundwater for its municipal drinking water needs. In August 2011, a surface water supply was brought online to service the south portion of the city to support expected population growth within this region. The city's fourteen deep groundwater supply wells will remain in operation to supply the remainder of the city in the central and north distribution zones. The volume of water needed from the wells to supply the City, has been decreased significantly due to the contribution from the surface water supply.

1.4 Project Scope

The scope of work completed in this Tier Three Assessment and documented in this report follows the Province's Technical Rules (MOE 2009).

The following tasks were completed for this study:

1. Develop and calibrate a Local Area groundwater flow model with sufficient detail to simulate groundwater flow near wells and streams.

2. Develop and calibrate a surface water model to simulate variable stream flow and to estimate groundwater recharge rates in the Study Area.

3. Apply the calibrated surface water and groundwater models to assess the water budget components in the Study Area and in the vicinity of municipal wells.

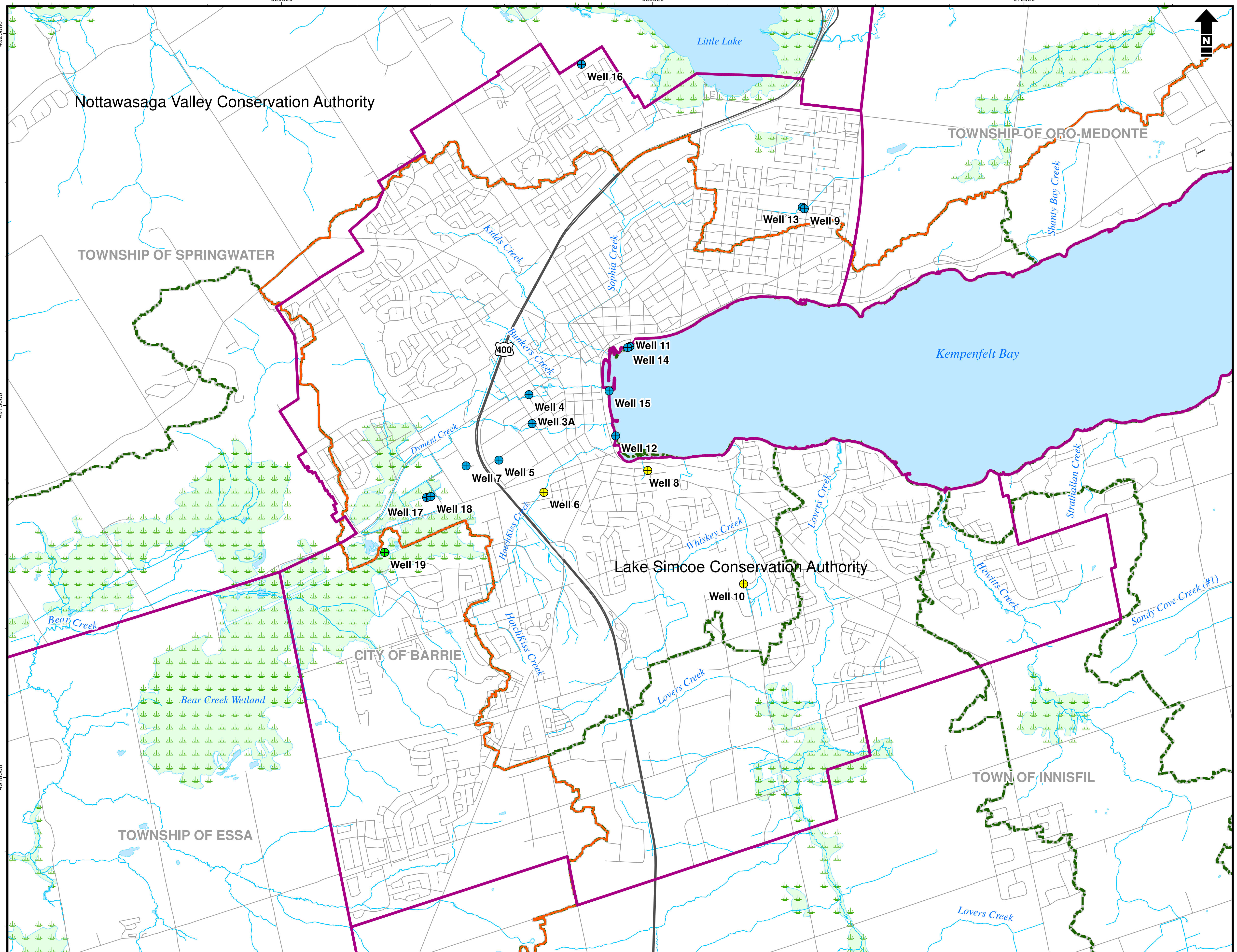
4. Complete a Local Area Risk Assessment for the municipal wells located in the Study Area.

1.5 Organization of This Report

This report is organized into the following sections:

Section 1: Introduction. The Clean Water Act water budget framework and the scope of this project are outlined in this section.

Section 2: Conceptual and Numerical Models. This section provides a brief overview of the conceptual understanding of the area and the tools used within the Assessment. Detailed descriptions are contained in Appendices A, B and C.



Legend

Municipal Wells

Status

- Current
- No Longer in Operation
- Planned

Transportation Network

- Highways
- Roads

Drainage Network

- River / Stream
- Open Water
- Wetlands

Boundaries

- Barrie Tier 3 Boundary
- Municipal Boundaries
- Conservation Authority
- NVCA and LSRCA Subwatersheds

Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
Produced using information provided by the Ministry of Natural Resources,

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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Municipal Systems

Date: 15 May 2013	Project: 2010007_BarrieTier3
Technical: ccurry	Reviewer: MBester
Map Version: 1	

Figure 1.2

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Section 3: Water Demand. This section outlines the consumptive water uses within the Study Area and estimates demand for those uses.

Section 4: Tier Three Water Budget. This section outlines the Water Budget results compiled using the output of the calibrated groundwater and surface water flow models. Details of the modelling tools are contained within Appendices B and C.

Section 5: Local Area Risk Assessment. This section outlines the Risk Assessment methodology, the delineation of vulnerable areas, as well as the model scenarios and results. The sensitivity analysis methodology and results are also presented. Spatial mapping and the delineation of the WHPA-Q1, WHPA-Q2, and the Local Area are presented and the Local Area Risk Level is assigned.

Section 6: Water Quantity Threats. Significant water quantity threats identified in this study are listed and discussed.

Section 7: Significant Groundwater Recharge Areas. The methodology and results of the Significant Groundwater Recharge Areas (SGRAs) are delineated and discussed in this section.

Section 8: Data and Knowledge Gaps. This section identifies data and knowledge gaps, which if addressed, may either influence the results of the risk assessment or alternatively assist water managers with managing water quantity risks.

Section 9: Summary and Conclusions. This section outlines the study conclusions, data and knowledge gaps, and the limitations and use of the report.

Section 10: References.

2.0 CONCEPTUAL AND NUMERICAL MODELS

Appendix A contains a detailed description of the conceptual understanding for the Barrie Area (AquaResource et al, 2011a). The following sections provide a brief overview to put the Risk Assessment in context.

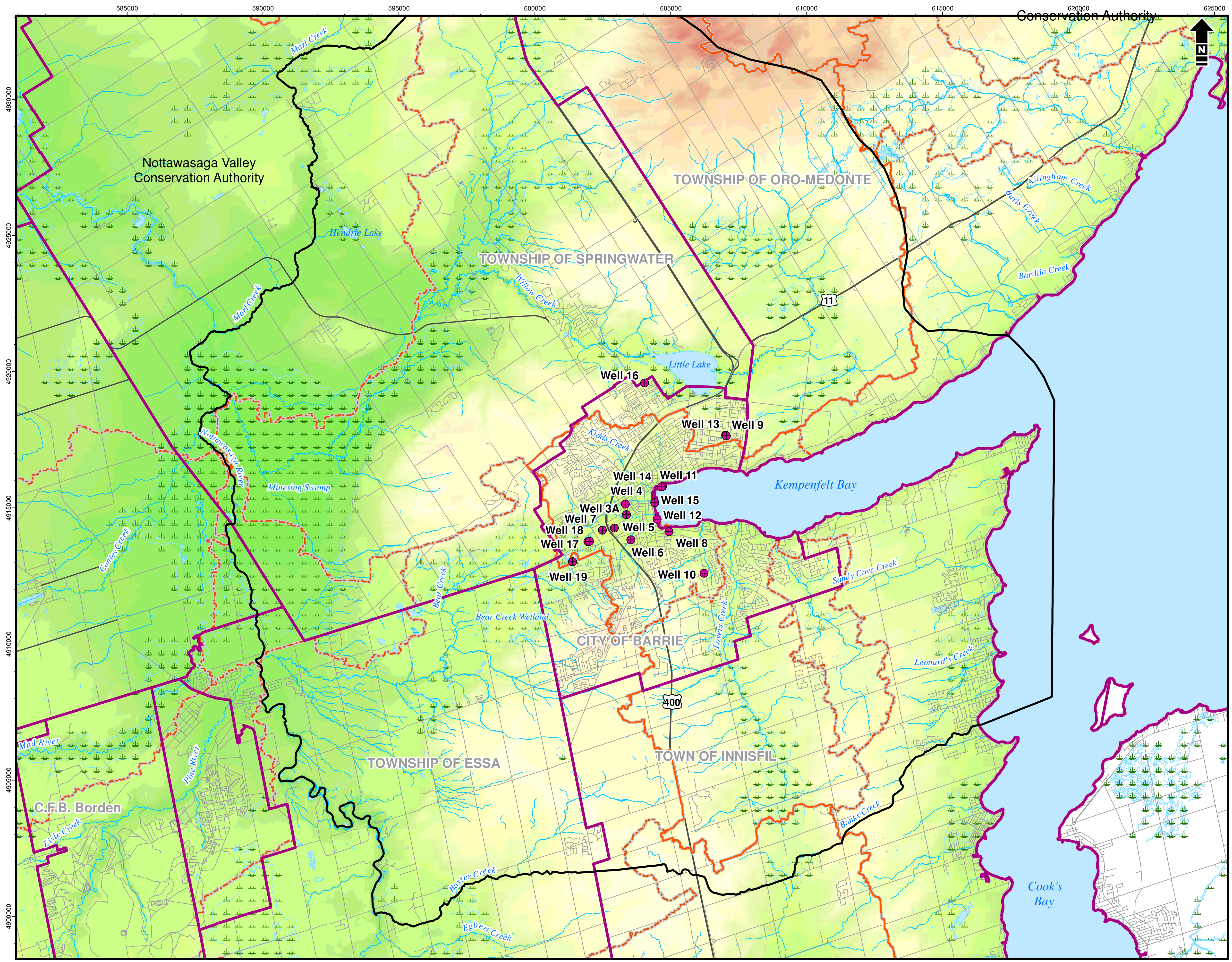
2.1 Topography and Physiography

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 (Figure 2.1).

Regionally, ground surface elevation in the Study Area reaches a high of 375 m above sea level (asl) in the north east along the Oro Moraine, a high of 300 m asl in the Innisfil Heights area in the south, and a low of 180 m asl within the Minesing Wetlands/Nottawasaga River complex. In contrast, the elevation of Kempenfelt Bay (Lake Simcoe) is approximately 220 m asl. Topography in the Study Area is influenced by the present-day stream network, as well as the drainage network from the last glaciation (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. These drainage systems 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 m asl at Highway 400 and Mapleview Drive in the south, and Ferndale Drive and Livingstone Street in the north, to a low of approximately 220 m asl 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; these creeks include 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 western portion of the City of Barrie.



Legend

- Municipal Wells

Transportation Network
- Highways
- Roads

Drainage Network
- River / Stream
- Open Water
- Wetlands

Boundaries
- Barrie Tier 3 Boundary
- Municipal Boundaries
- Conservation Authority
- NVCA and LSRCA Subwatersheds

Ground Surface Elevation (masl)

High : 415

Low : 170

Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
Produced using information provided by the Ministry of Natural Resources,

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Ground Surface Topography

Date: 15 May 2013	Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 2.1

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2.2 Hydrologic Characterization

2.2.1 Subwatersheds

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 Figure 2.2. The Study Area was delineated to include known natural drainage boundaries and therefore is coincident with several subwatershed boundaries.

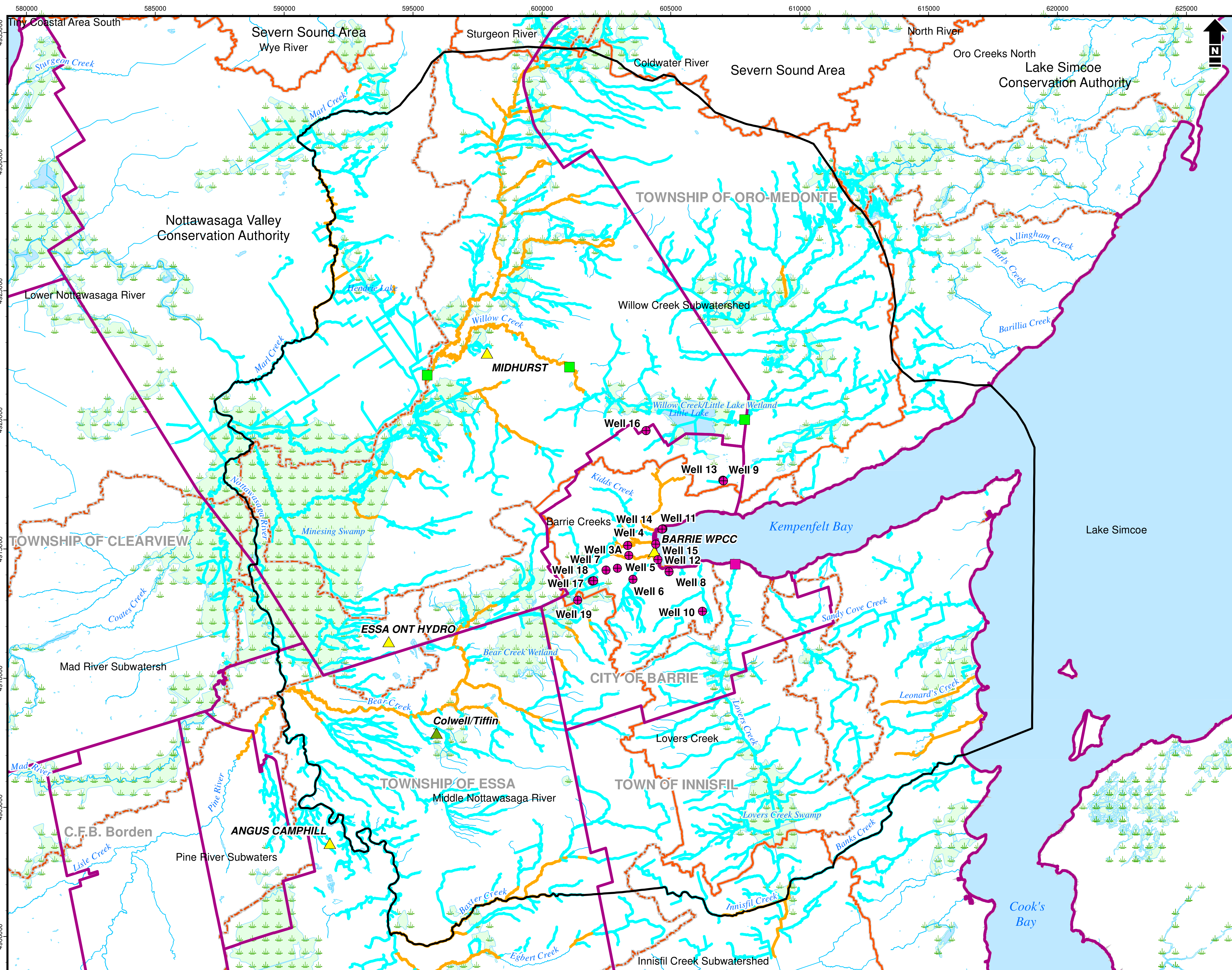
The subwatershed of interest in this study is the Barrie Creeks Subwatershed (38 km^2) which is comprised of a series of small streams and creeks that drain the central portion of the City of Barrie to Kempenfelt Bay. To the north of this subwatershed, the Willow Creek Subwatershed drains the largest portion of the Study Area (340 km^2), with Willow Creek as its major tributary. In the southwest, the Middle Nottawasaga Subwatershed(300 km^2) comprises the area directly west of the Barrie municipal supply wells, draining this area via Bear Creek to the Nottawasaga River. 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. Additional details on each subwatershed can be found in Appendix A and its associated references.

In addition to streams, several larger surface water features can be found in the Study Area. 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. Aside from this, there are few inland lakes. The largest, Little Lake, is 2.3 km^2 on the northern border of the City of Barrie. It is situated along Willow Creek and is within a topographic depression, and as such, receives water primarily through groundwater discharge from adjacent slopes. There are also several wetland features within the Study Area (Figures 2.1 and 2.2). 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. This and other wetlands are discussed in detail within Appendix A, as well as in Section 2.4.2.1 below.

2.2.2 Monitoring

Climate and hydrometric surface water monitoring is conducted at stations in and near the Study Area as shown on Figure 2.2. Meteorological data (e.g., climate normals of temperature and precipitation) are obtained from stations maintained by the Meteorological Service of Canada (MSC). Records of stream flow are maintained by the Water Survey of Canada (WSC), Nottawasaga Valley Conservation Authority (NVCA) and Lake Simcoe Region Conservation Authority (LSRCA). For the present Study Area, mean annual temperature and precipitation have been averaged and estimated to be 7.7°C and 910 mm, respectively, over a 60 year period (Appendix B).

For the same time period in which Climate Normals are available (1990-2005), mean annual flow data was also collected and analyzed (Appendix B). Together, these data permit an initial estimate for the water balance of the area. Additional climate and flow monitoring data from various stations can be found in Appendices A and B.



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Legend

- Municipal Wells
- LSRCA Stream Gauge
- WSC Stream Gauge
- Environment Canada Climate Stations
- NVCA Climate Stations

Fish Community Classification

- Warmwater
- Coldwater

Drainage Network

- River / Stream
- Open Water
- Wetlands

Boundaries

- Barrie Tier 3 Boundary
- Municipal Boundaries
- Conservation Authority
- NVCA and LSRCA Subwatersheds

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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Surface Water Features

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Technical: ccurry	Reviewer: MBester	Map Version: 1	

Figure 2.2

2.3 Hydrogeologic Characterization

2.3.1 Quaternary Geology

The Quaternary aged deposits of the area are primarily a result of deposition during the last glaciation of the Quaternary period, known as the Wisconsinan glaciation. The Wisconsinan glaciation followed a climatic period where temperatures were warmer than at present and the terrain was dominated by a large river, known as the Laurentian River that flowed between Wasaga Beach and Toronto. Flow in this river was interrupted during the late Wisconsinan glaciation and overlain to the south by the Oak Ridges Moraine. North of this Moraine, the Laurentian Valley is infilled with a succession of glacial deposits (till/diamict) with intervening interglacial deposits (lacustrine and fluvial). Steep sided valleys at Kempenfelt Bay, Willow Creek and Matheson Creek dominate the topography (Barnett 1990). These valleys are considered to be erosional features resulting from sub-glacial catastrophic flood events that occurred during the latter phases of the most recent glaciation. A pre-existing (i.e., prior to the flood event) surface of lacustrine varved silt and clay has been observed in the flanks of the Kempenfelt Bay channel at the Barrie Landfill. Similar lacustrine deposits are found in upland areas of the Township of Oro-Medonte Township.

The stratigraphic sequence recorded in the valley areas generally is not repeated under the upland areas. In the valley areas of Willow Creek and Kempenfelt Bay a sequence of coarse gravel and soft lacustrine sediments is often recorded and the stratigraphy is variable over very short distances. In upland areas thick aquifer sequences are generally absent and stratigraphic units are traceable over greater distances than in the valley areas.

Underlying the unconsolidated Quaternary aged sediments, which can be 200 m thick in some places, the bedrock surface is relatively flat in the vicinity of Barrie with an approximate elevation of 110 to 130 m asl (Appendix A).

2.3.2 Hydrostratigraphy

Hydrostratigraphic units are derived from stratigraphic units based on their general hydrogeologic properties. The delineation of hydrostratigraphic units based on geologic descriptions from borehole logs is a relatively rough approximation; however, the available information is used in conjunction with interpretations of the regional and local spatial distribution of geologic units. Units composed primarily of coarser grained overburden materials (e.g., sands and gravels) or higher transmissivity bedrock units are referred to as aquifers and units composed of lower permeability overburden (e.g. clay or fine-grained tills) or poorly transmissive bedrock units are referred to as aquitards.

The hydrostratigraphic unit structure (Table 2.1) was developed in an earlier phase of this project and builds upon previous studies throughout the area. The regional hydostratigraphic structure of the Study Area is defined based on the Quaternary geologic deposits within the upland area and extended through lowland valley deposits. 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.

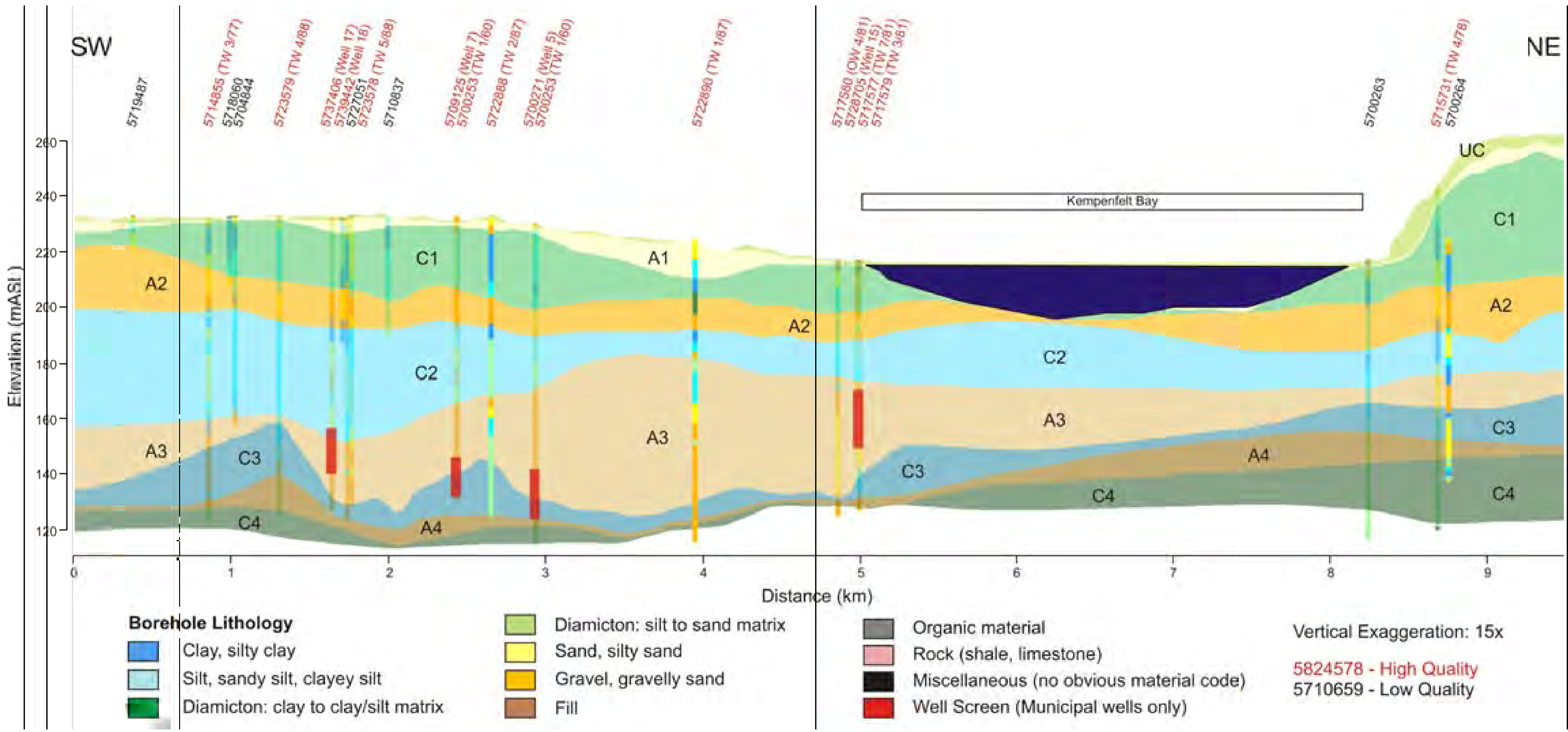
These deposits create a regionally extensive and complex aquifer system. Till plains in the Study Area (i.e., Innisfil area) represent localized and regional aquitards that act to impede the vertical movement of groundwater (and potential contaminants) to underlying aquifers.

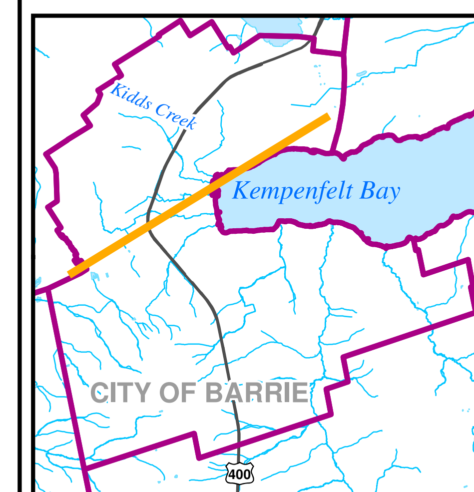
The aquifer system is generally described as containing four major sand and gravel aquifer units (from shallowest to deepest: A1, A2, A3 and A4, Figure 2.3). These four aquifer units are defined based on their relative stratigraphic position (e.g., Mackinaw Interstade) and are commonly identified based 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 defined hydrostratigraphic units.

A deep, highly-transmissive aquifer (A3) is found under the central portion of the City of Barrie within the tunnel-channel deposits associated with the lowland area (Figure 2.3). This aquifer extends in an east-west direction from Kempenfelt Bay west towards the Angus-Borden area (referred to as the Barrie-Borden aquifer). Overlying silt and clay aquitard deposits confine the lower municipal aquifers. The pressure created from this confinement has historically resulted in local flowing artesian conditions within the municipal wells screened in A3/A4, particularly those located along the shoreline of Kempenfelt Bay. The aquifer system in the Study Area is described in greater detail within the Conceptual Understanding Report (Appendix A, Section 2, and Appendix C, Section 2.1).

TABLE 2.1 Hydrostratigraphic Conceptual Model Layers

Hydrostratigraphic Unit	Description
UC	Till pockets
A1	Fine-grained sand aquifer, semi confined, outwash sands overlain by till in some areas
C1	Clayey silt aquitard
A2	Fine-grained sand aquifer, semi-confined, outcrops in some areas
C2	Sandy silt aquitard, bottom extent of Kempenfelt Bay near city centre
A3	Sand/Gravel aquifer, fully confined, thick and combined with A4 along tunnel channel valley
C3	Aquitard
A4	Basal aquifer, discontinuous and fully confined, combined with A3 in some areas
C4	Basal aquitard
Bedrock	





Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
Produced using information provided by the Ministry of Natural Resources,

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Hydrostratigraphic Cross Section

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Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 2.3

2.4 Groundwater and Surface Water Interaction

2.4.1 Groundwater Recharge Distribution

Groundwater recharge is a hydrologic process where water moves downward from the ground surface to the underlying groundwater flow system. This process usually occurs in the unsaturated zone below plant roots and is often expressed as a flux to the water table surface. In general, it is the portion of precipitation that is not lost to evapotranspiration, interflow or overland flow to streams. The amount of groundwater recharge is influenced by the hydraulic conductivity of surficial sediments, slope of the topography, land use, and soil moisture content.

The calibrated MIKE SHE surface water flow model was used to estimate the spatial distribution of groundwater recharge for the FEFLOW groundwater flow model. Estimated recharge rates ranged from a low of 0 mm/year in saturated wetlands to a maximum of 350 mm/year in the upland areas such as the Oro Moraine. As the surface water and groundwater flow models were both calibrated to baseflow, or low flow conditions, the estimated overall average recharge rate across the model is considered reliable. Appendix B outlines how the MIKE SHE model was created and calibrated and the resulting estimated recharge distribution within the Study Area.

2.4.2 Ecological Resources

There are a variety of ecological resources in the Study Area including coldwater fisheries and Provincially Significant Wetlands (PSWs). Additional resources in the Study Area, including Environmentally Sensitive Areas (ESAs) and Areas of Natural and Scientific Interest (ANSIs), are described further in Appendix A.

2.4.2.1 *Coldwater Fisheries*

The thermal regime of a river or stream can provide a general indication of the groundwater and surface water interaction. Groundwater discharge is important to the subwatersheds as the upwelling areas are critical for fisheries spawning and also for maintaining a moderate temperature and flow in creeks and streams. Coldwater fisheries have been mapped in various stream reaches within the Study Area, particularly in the headwaters, as shown on Figure 2.2. Some of these include all of or parts of Nottawasaga River, Willow Creek, Innisfil Creek, Bear Creek, and Lovers Creek. Coldwater stream data shown in the aforementioned figures was provided by the LSRCA and NVCA.

2.4.2.2 *Wetlands*

PSWs are identified by the Ontario MNR using the Ontario Wetland Evaluation System and are recognized as having ecological significance. There are eight PSWs within the Study Area (Figure 2.2), three of which are in close proximity to the City of Barrie wells, Lover’s Creek Swamp, Bear Creek Wetland and Willow Creek/Little Lake Wetland. Descriptions of these and other wetlands within the Study Area are characterized in Appendix A.

2.5 Land Use and Land Use Change

In addition to consumptive water uses, the MOE Technical Rules (MOE 2009) identify reductions in groundwater recharge as potential water quantity threats. As such, the Tier Three modelling scenarios must consider the impact of existing and future land development on groundwater recharge and consequently the impact on municipal water sources.

The following steps were undertaken to identify potential changes in land use within the Study Area:

1. A map of existing land use was created (Figure 2.4).
2. A map of future land use was created using the Official Plan mapping (Figure 2.5).
3. A map identifying the areas of land use change was created by comparing future land use and existing land use (Figure 2.6).
4. The recharge reduction for each of the areas of future land use change was estimated.

The potential impact of stormwater management measures and low impact development techniques was not considered when estimating recharge reduction for future land use.

2.5.1 Existing Conditions Land Use

A land use map (Figure 2.4) was created during the South Georgian Bay – West Lake Simcoe Tier Two Study (Golder and AquaResource 2010). The land use mapping was based on land cover data from the LSRCA published in 2008 (LSRCA 2008) and from the Nottawasaga Valley Conservation Authority (NVCA) published in 2007 (NVCA 2007). Similar to the Tier Two Study, in areas of overlap, the LSRCA data was used as it was the most recent data.

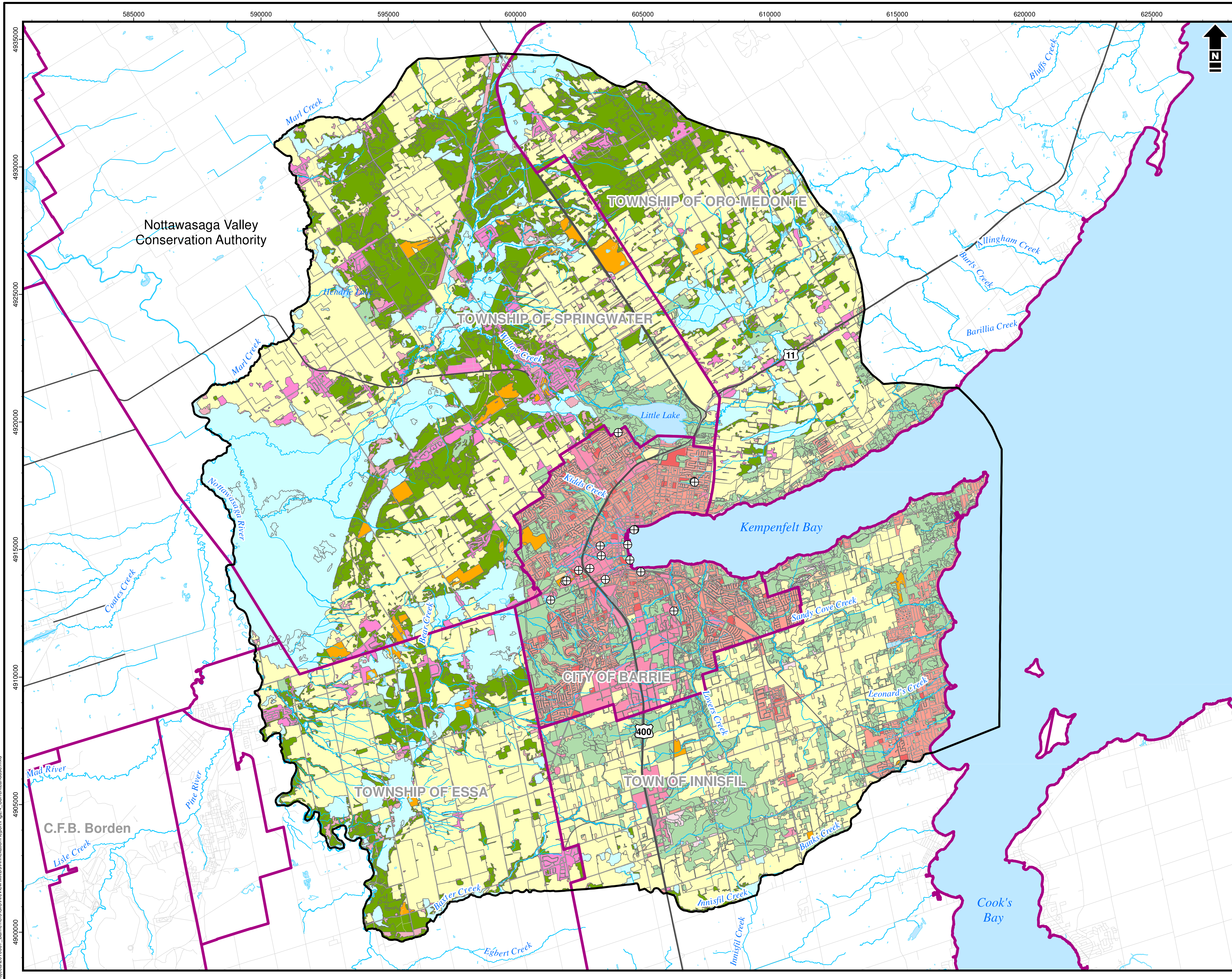
2.5.2 Official Plan Land Use

Future land use within the Study Area is shown on Figure 2.5. The future land use mapping was provided by the 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).

2.5.3 Land Use Change

Figure 2.6 illustrates land areas where land use may change according to the Official Plans as compared to current land use. This figure was created by digitally overlaying Figure 2.4 and Figure 2.5 using a Geographic Information System, and selecting the areas where proposed land use change would cause imperviousness to increase.

The most significant land use changes that may potentially occur in the Study Area are located in the south area of the City of Barrie, as well as small pockets of infilled development throughout the city. The



Legend

⊕ Municipal Wells

Transportation Network

- Highways
- Roads

Drainage Network

- River / Stream
- Open Water

Boundaries

- Barrie Tier 3 Boundary
- Municipal Boundaries

Current Landuse

- Aggregrate Extraction (active/inactive)
- Agriculture
- Natural Heritage Feature
- Woodlands (Deciduous, Coniferous, Mixed)
- Aquatic
- Open Space/Manicured Open Space
- Rural Development
- Transitional
- Urban
- Institutional
- Estate Residential
- Commercial/Industrial
- High-Intensity Development
- Low-Intensity Development
- Transportation Corridors

Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
Produced using information provided by the Ministry of Natural Resources,

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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Current Conditions Land Use

Date: 15 May 2013		Project: 2010007_BarrieTier3
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 2.4

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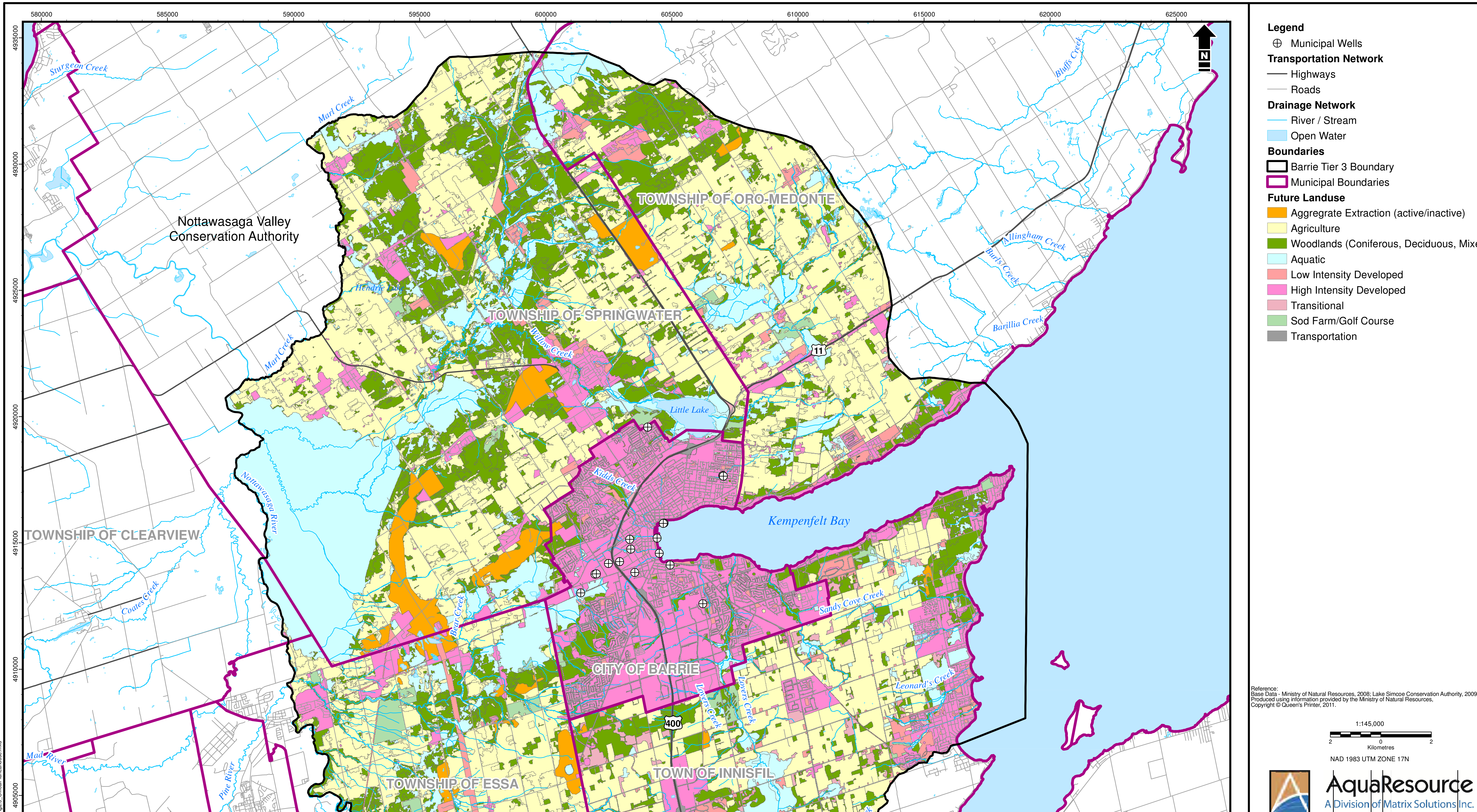

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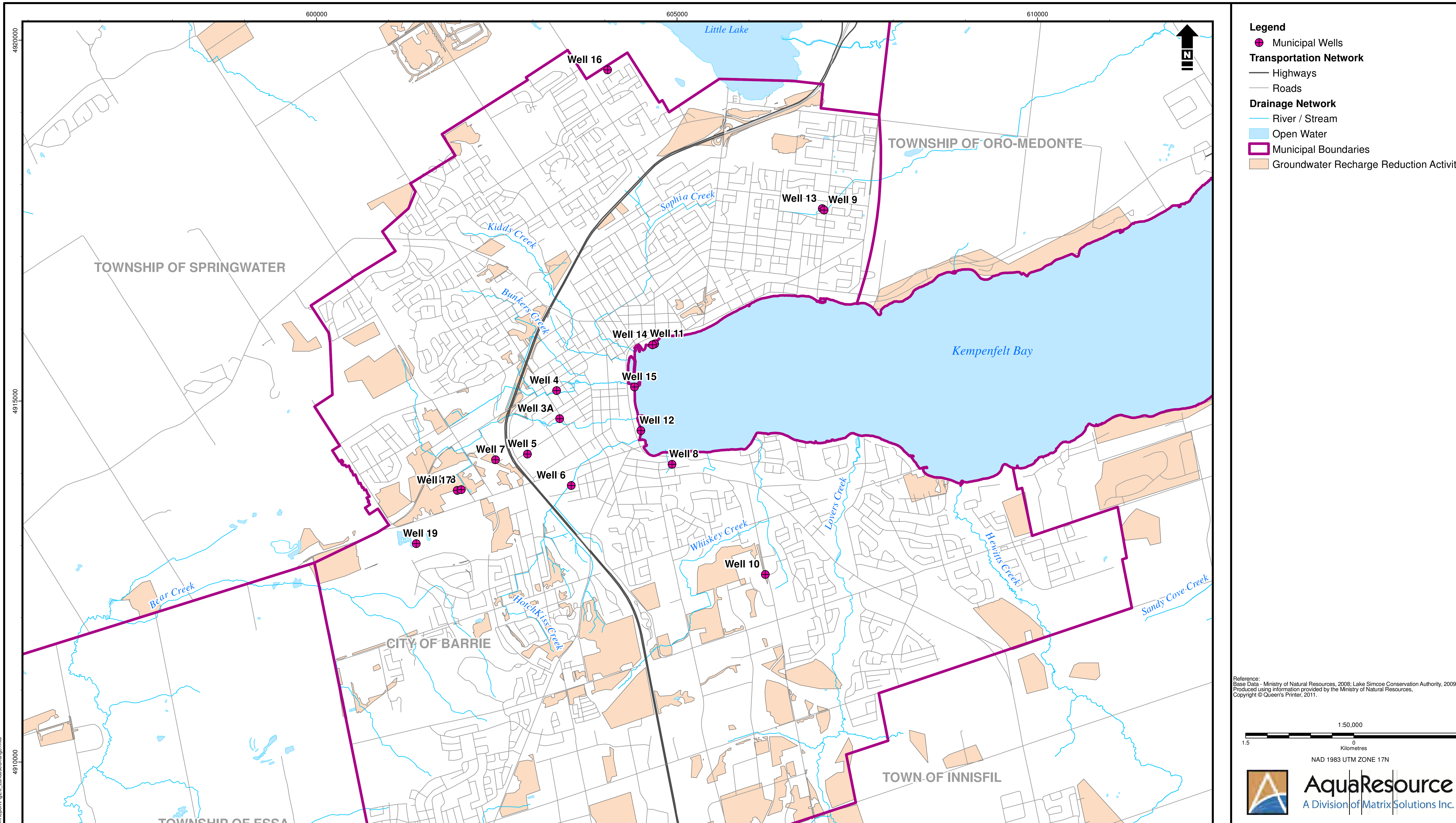
City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Official Plan Land Use

Date: 15 May 2013	Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 2.5

E:\Projects\2010007_BarrieTier3\GIS\ArcView\MXDs\AnnexationReport\Fig2.5_OfficialPlanLanduse.mxd



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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Land Use Change (Existing to Official Plan)

Date: 15 May 2013		Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1	

Figure 2.6

E:\Projects\2010007_BarrieTier3\GIS\ArcView\MXDs\AnnexationReport\Fig2.6_LanduseChange.mxd areas of reduced recharge potential (Figure 2.6) are not likely to impact the city of Barrie wells, as they are relatively small compared to the total area contributing recharge to the wells (Golder 2005) and generally not located within high recharge areas.

Land Use Change and Recharge Reduction

The groundwater flow model represents changes in land use by reducing groundwater recharge proportionally to the amount of impervious area. The recharge reduction for the Risk Assessment scenarios assumes that mitigation measures such as recharge or infiltration ponds, or similar best management practices, are not taken into consideration (as specified in the Technical Rules; MOE 2009).

Table 2.2 summarizes the recharge reduction factors applied to the land use areas that, according to the Official Plans, will be modified in the future (Figure 2.6). The recharge reduction factors were obtained by comparing recharge estimates for each soil class, for urban and nonurban land use classifications (e.g., recharge on rural sands was compared to recharge on urban sands). It was assumed that recharge reduction for high density and low density urban development is the same.

TABLE 2.2 Recharge Reduction Estimates Applied for Future Land Use Areas

Soil Class	Average Recharge (mm/year)		Average Recharge Decrease
	Urban Areas	Non-Urban Areas	
Sand	234	325	28%
Gravel	221	318	31%
Silt/Till	107	196	46%
Clay	57	62	10%

2.6 Water Budget Models

As part of the Tier Three Assessment framework, surface water and groundwater modelling tools are developed to help assess the sustainability of the municipal water sources. The models are developed based on the conceptual understanding of the groundwater and surface water systems, and they are refined around wells (and intakes) to a level supported by available data. The models are calibrated to represent typical operating conditions under average (steady state) and variable (transient) climate conditions.

In this Tier Three Assessment, the groundwater and surface water modelling approach was designed to simulate average and drought conditions, represent the detailed hydrologic and/or hydrogeologic conceptual model, and integrate the input and outputs of the surface water and groundwater models (e.g., groundwater recharge, baseflow). A surface water model was constructed, calibrated, and validated using MIKE SHE (DHI 2011a and 2011b), and a groundwater model was constructed and calibrated using the FEFLOW code (Finite Element Subsurface Flow and Transport Simulation System; v5.4, DHI-WASY 2009).

As this Tier Three Assessment examines the water budget for municipal groundwater supplies, the groundwater model was used to examine whether existing and planned groundwater wells are able to sustain their allocated pumping rates under existing and planned rates, and to help predict the resultant impacts to other water uses. The water budget model was used to simulate both steady state and transient flow conditions.

Appendix B describes the development and calibration of the surface water model and Appendix C describes the development and calibration of the groundwater model in detail.

2.6.1 Surface Water Model

A three dimensional, integrated surface and groundwater model was constructed for the Barrie Tier Three Study Area using the MIKE SHE software. The model was calibrated over the time period of 1990-2005 using available streamflow data for three streamflow monitoring gauges:

- Willow Creek above Little Lake (1990-1995);
- Willow Creek at Midhurst (1990-1998); and
- Lovers Creek at Tollendal (2001-2004).

The model was then verified over the time period of 2006-2009 using streamflow data from a fourth stream gauge:

- Willow Creek near Minesing (2006-2008)

An investigation of additional streamflow data at the Barrie Creeks gauges (2004-2009), the Lovers Creek gauge (2005-2009), and at spot flow measurement locations led to the conclusion that these three data sets or subsets were not appropriate for model calibration (Appendix B).

Additional calibration targets included groundwater elevations throughout the Study Area and snow depths from a snow survey in the southern portion of the Study Area. The calibration resulted in a reasonable match between simulated and observed data, which provided confidence that the model output (i.e., groundwater recharge) is appropriate to use in the FEFLOW groundwater model.

The overall water budget and key hydrologic processes were computed and mapped. The mean annual groundwater recharge for the 1990-2009 period was used as input to the steady state FEFLOW groundwater model. Transient recharge rates were computed on a monthly basis from 1953-2009 and were used in the transient calibration of the FEFLOW model.

2.6.2 Groundwater Flow Model

To assess the potential impacts of increased municipal groundwater demands on other water uses, a detailed conceptual model of the geologic, hydrogeologic, and hydrologic systems was developed for the Study Area (Figure 1.1) with particular focus on the areas surrounding municipal well fields.

A FEFLOW groundwater flow model was constructed to represent the groundwater system and the interaction with the surface water system and, as such, was calibrated to hydraulic head measurements, as well as surface water data. A transient model calibration was also undertaken to confirm the performance of the model under transient conditions.

Output of the surface water model was used as input (groundwater recharge) into the groundwater flow model, while the surface water model received hydraulic conductivity and interbasin flow estimates from the groundwater model, in an iterative manner, until both models were satisfactorily calibrated. This coupling was used to examine the impact of future land development on water levels in aquifers and reductions in discharge to streams and surface water features. The groundwater flow model was also used in the Risk Assessment to examine the potential response of aquifers to long-term drought conditions.

3.0 WATER DEMAND

This chapter outlines the consumptive water uses within the Study Area and estimates consumptive water demand for those uses. Consumptive water demand refers to the amount of water removed from a surface water or groundwater source and not returned to that source within a reasonable amount of time. Estimates of consumptive water demand are necessary in water budget assessments to identify areas that may be under hydrologic stress. All municipal takings within the City of Barrie were considered consumptive in this study because water is pumped from groundwater aquifers and discharged to Lake Simcoe via the Water Pollution Control Plant; the pumped water is not returned to the groundwater production aquifers and as such is considered 100% consumptive.

This chapter outlines the consumptive water takers within the Barrie Creeks subwatershed including the municipal (Section 3.2) and non-municipal large permitted and domestic water takings (Section 3.4). These large (permitted) consumptive water takings were simulated as groundwater takings within the groundwater flow model as they have the potential to influence simulated water levels and impact the model calibration.

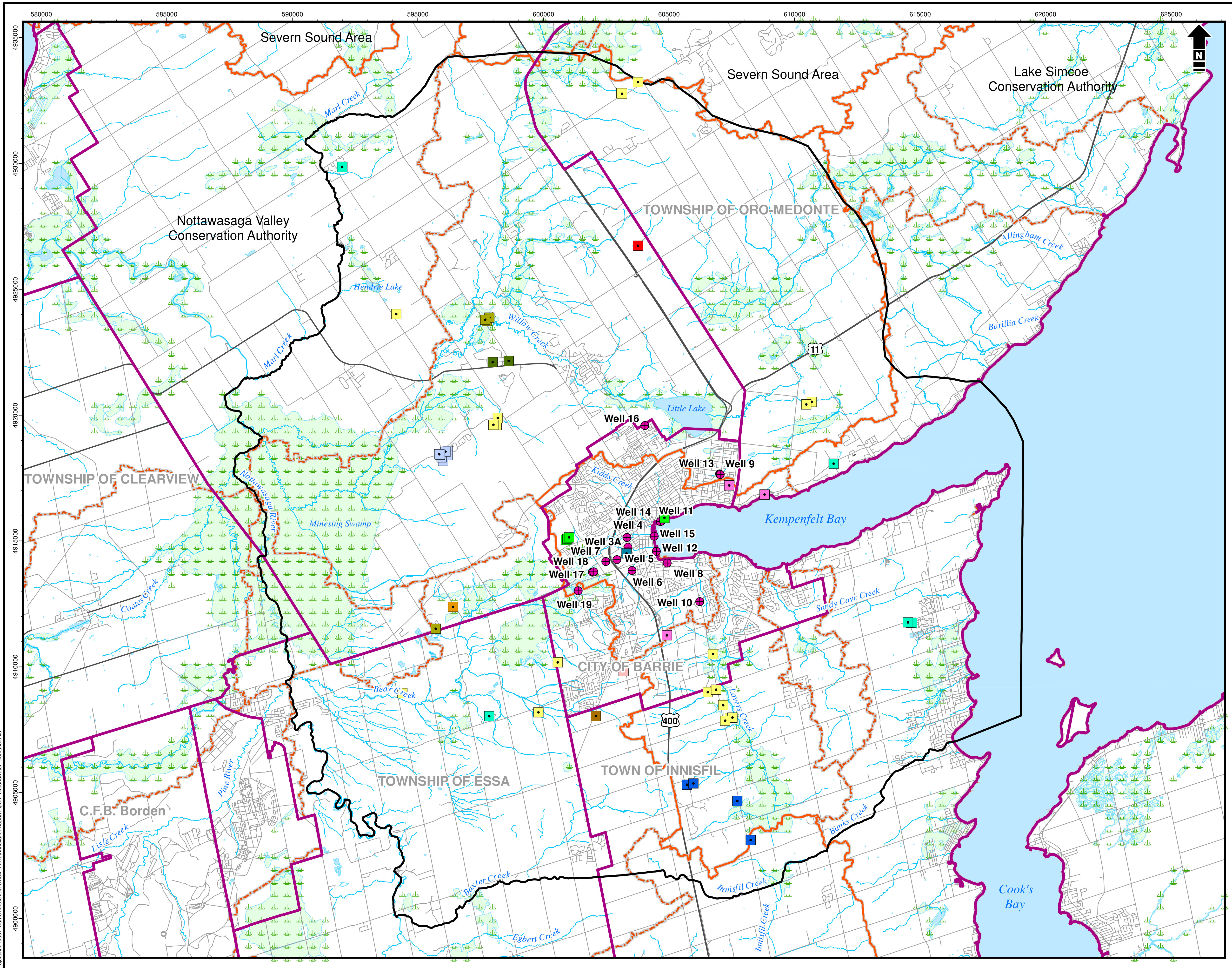
In addition to the groundwater takings, there are several non-consumptive water uses that also rely on the groundwater supplies within the subwatershed (Section 3.4). These include surface water features that rely on groundwater discharge for sustaining coldwater fisheries (and similar environmental/ ecological communities) and for recreational use. These water uses rely on a minimum flow or minimum variation in water levels provided by the groundwater and surface water systems, and therefore are part of the overall risk assessment. Such surface water uses were considered as part of the Risk Assessment (Section 5).

3.1 Municipal Water Systems

The City of Barrie, the Town of Innisfil, and the Townships of Essa, Oro-Medonte and Springwater have municipal water supplies within the Study Area. Not all of the communities within the Study Area rely entirely on groundwater for their municipal drinking water needs; both the City of Barrie and the Town of Innisfil also have surface water supply sources, drawing from Lake Simcoe. The municipal water supply systems for these communities are outlined below.

3.1.1 City of Barrie

Until recently, the City obtained its water supply entirely from groundwater. The municipal system, which has been in operation since 1937, currently consists of 15 wells, of which 14 are operational, and constructed into deep overburden aquifer systems (Golder 2006). Figure 3.1 illustrates the locations of municipal wells in the Study Area. All of the Barrie municipal wells lie within the City of Barrie. Well 19 is not yet operational at the time of this study, but is a planned system under the Clean Water Act as it has undergone a Class EA and has a permit to take water (Golder 2009; IWS 2009). Figure 3.1 also shows the locations of three wells which are no longer in operation; Wells 6, 8 and 10.



City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Groundwater Demand

Date: 15 May 2013	Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 3.1

Municipal water supplies represent the largest water use within the Study Area. Accurate estimates of municipal water use are therefore 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, as well as their maximum permitted capacity and operating capacity. Operating capacity is an alternative to the maximum permitted number, indicative of the limit each well is capable of pumping based on the wellfield operators' experience. Limitations experienced can be caused by adverse conditions within the wells with higher pumping rates (i.e. clogging) or dictated by limitations within the distribution system itself (i.e. booster station or pipe diameter). For instance, Wells 17 and 18, which are located next to each other, share a common discharge pipe that currently supplies Pressure Zone 1. Restrictions in the distribution system dictated that Pressure Zone 1 can only be supplied with the capacity of 10,800 m^3/day at any given time; therefore, the combined pumping of these two wells should not exceed that amount.

TABLE 3.1 City of Barrie Water Supply Wells

Well Name	Pumped Aquifer	Maximum Permitted Capacity (m^3/day)	Operating Capacity (m^3/day)	Operator Comments
Pressure Zone 1 – Core Area				
3A (Anne Street)	A4	6,552	3,888	Due for Rehabilitation
4 (Perry Street)	A3	6,552	0	Currently Offline
5 (John Street)	A4	6,552	5,184	
7 (Tiffin Street)	A3/A4	6,552	6,048	
11 (Heritage Park)	A3/A4	9,100	8,640	
12 (Centennial Park)	A4	9,100	8,986	
14 (Heritage Park)	A3/A4	9,100	8,986	
15 (Centennial Park)	A3/A4	9,100	8,986	Second Yielding Well in System
17 (Cross Street)	A3/A4	11,232	10,800*	Largest Yielding Well in System
18 (Cross Street)	A3/A4	11,232		System Restrictions
19 (Boulton Court)	A3/A4	7,862	0	Currently Not Commissioned
Pressure Zone 2 – North				
9 (Johnson Street)	A3/A4	6,552	6,048	
13 (Johnson Street)	A3/A4	6,552	6,307	
16 (Brownwood)	A3	7,862	7,430	
Total		**113,900**	**81,302**	

* Shared operating capacity between Well 17 and 18

3.2 Municipal Water Demand

As part of the Local Area Risk Assessment, the allocated quantity of water needs to be estimated for each existing and planned groundwater well or intake. The allocated quantity of water is estimated based on the committed and/or planned water demand as well as the existing municipal water demand.

As outlined in the MOE Technical Rules (MOE 2009) the Existing, Committed, and Planned Demand for this assessment needed to be established. The definitions of these terms, as outlined in the MOE Technical Rules, are below.

- **Existing Demand** refers to the average pumping rate during the study year (MOE 2009). For this study the existing demand year was chosen to the 2012 as it represents the time period after the surface water plant was brought on-line. The existing demand was chosen to allow comparison to committed and planned pumping demand

- **Committed Demand** is the increase in the quantity of water provided by a drinking water system that would be required if the area served by the system were developed in accordance with the Official Plans for the area to an extent that would result in the greatest use of drinking water. For example, a portion of the Official Plan that has been approved for development such as a subdivision or commercial block and will be coming online in the near future.

- **Planned Demand** is defined in the Clean Water Act (MOE 2006) as the demand required by a drinking water system that is established, or will be established if a) there is approval to proceed with the establishment of the system or part has been given under Part II of the *Environmental Assessment Act*, b) the establishment of the system or part has been identified as the preferred solution within a completed planning process conducted in accordance with an approved class environmental assessment under Part II.1 of the *Environmental Assessment Act* and no order has been issued under subsection 16 (1) of that Act, or c) the system or part would serve a reserve as defined in the *Indian Act* (Canada; MOE 2006). For example, Planned Demand would be the demand associated with a new well or intake that is connected to a new or existing system that will be used to support a new development specified in the Official Plan. On an average annual basis, Planned Demand may be lower than the Permitted Rate as it is typically not sustainable to pump a well at its Permitted Rate on a continuous basis.

In addition to the above demand periods, simulations of pumping prior to the surface water plant being brought on-line were also performed (i.e., representative of 2010). This time period represents the final full year where the municipal supply was solely groundwater. This year was simulated as a baseline condition as it is representative of conditions for which the safe available drawdown could be calculated (a pumping and water level observation history is not available for the post-surface-water-intake period). As such, all demand scenarios required under the MOE Technical Rules (MOE 2009) were compared to this scenario.

3.2.1 Existing Demand (Post Surface Water Intake)

A surface water intake was brought online in August 2011, which is intended to supply the south pressure zone of the city (~ 50% of the City's total demand). As a result, the demand from the City's groundwater wells under the Existing Demand is not as high as it has been in previous years.

To evaluate the water quantity risk under potential 2012 pumping, the existing demand was estimated, taking into consideration the change to groundwater demands within each pressure zone. The approach followed to estimate the existing demand included the following steps:

1. Rate Adjustment for "potential" demand. Through consultation with City of Barrie well operators, 2007 (Figure 3.2) was determined to be a representative year of pumping, as this was the last year that all wells were in operation, and the first year that Well 18 was brought online. Applying 2007 pumping is considered to be conservatively high, as this data represents the highest pumped volume of recent years (Figure 3.2).

2. Partitioning of pumping between pressure zones. Based on guidance from the City of Barrie, monthly pumping rates (pre-surface water intake) were modified by partitioning the pumped volumes according to the volume distributed to each pressure zone and discounting the portions used to service the south pressure zones of the city.

3. Population factor Adjustment. Pumped volumes from the above steps were multiplied by a population growth factor, which was the ratio of population from 2007 to 2011 within each pressure zone. The population growth by pressure zone, for those pressure zones reliant on groundwater, are shown in Table 3.2. Pressure Zone 3 North is an elevated portion of the City near the landfill, which does not contain any pumping wells.

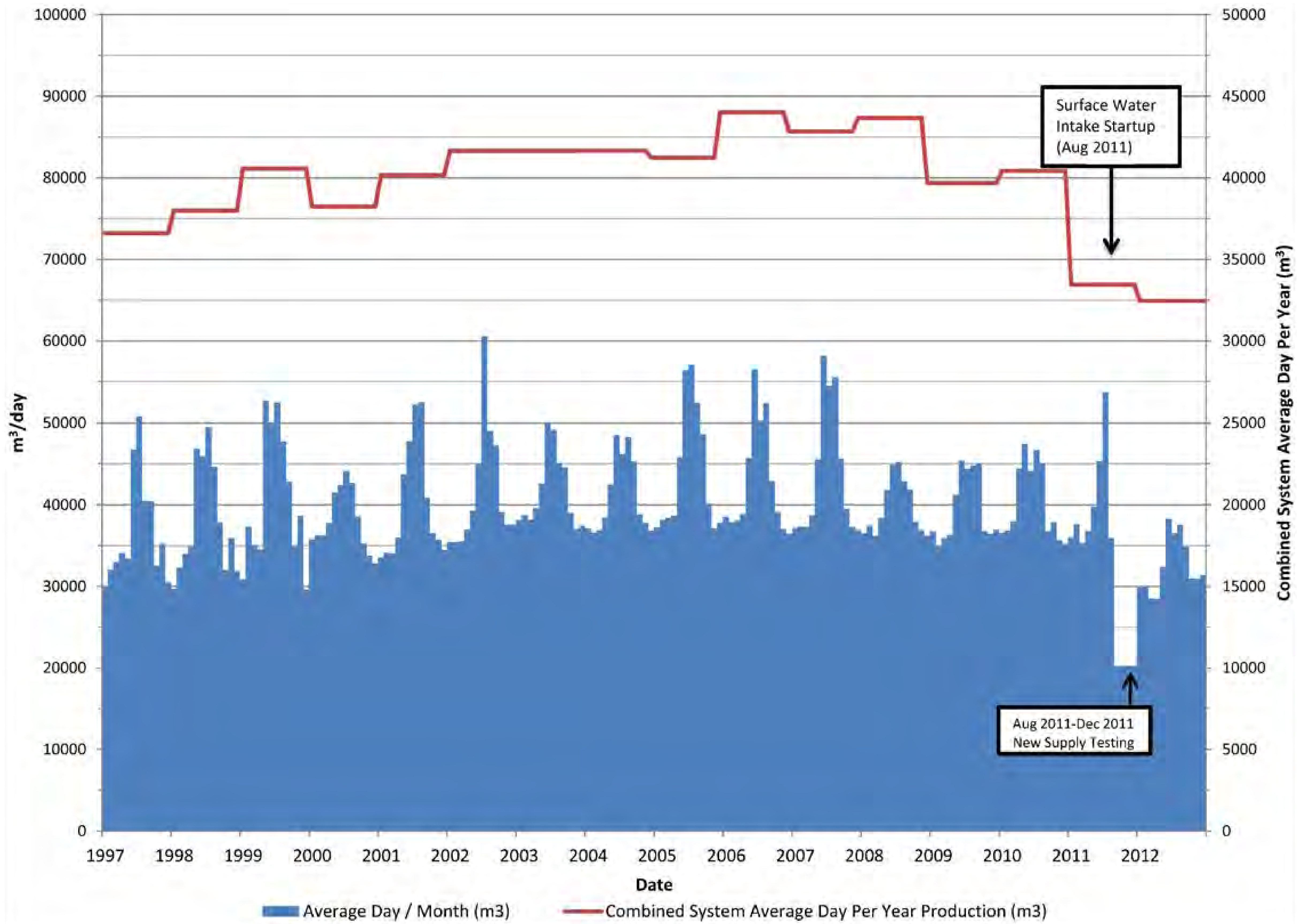
TABLE 3.2 Population 2007, 2011, and-2031

Pressure Zone	2007	2011		2031*	
	Population	Population	Growth Rate (2007-2011)	Population	Growth Rate (2011 – 2031)
1	19,025	20,351	7.0%	31,817	56.3%
2 North	47,306	47,596	0.6%	51,180	7.5%
3 North	10,641	10,560	-0.8%	10,189	-3.5%

*2031 Population based on official plan projections, determined in consultation with City of Barrie

The Existing Demand (post surface water intake - 2012) estimated for each well is presented in Table 3.3 along with the observed pumping rates from the last complete year before the surface water intake was brought on-line (2010).

Transient pumping rates for the drought scenarios were derived from the monthly pumping rates for each well during 2007; as such the monthly pumping rates applied simulate realistic seasonal operation of the wells. The standard deviation of well pumping rates is presented in Table 3.3 and provides an



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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Average Monthly and Average Annual Municipal Water Demands

Date: 20 May 2013	Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 3.2

E:\Projects\2010007_BarrieTier3\GIS\ArcView\MXDs\AnnexationReport\Fig3.2_MunicipalDemands.mxd indication of the monthly variability. Transient well pumping rates vary from a low of approximately 55% of the average rate, to a high of about 140% of the average, with peak demand from June-September.

3.2.2 Committed/Planned Demand (2031)

As part of the Tier Three Assessment, the hydrologic and hydrogeologic response to the increase in municipal pumping associated with Committed and Planned Demands needs to be assessed.

Table 3.3 contains Existing plus Committed plus Planned rates for the City's pumping wells, along with Existing Demand rates (as per Section 3.2.1), and the pre-surface water intake (2010) rates. The pre-surface water intake (2010) rates are provided to illustrate the reduction in demand at individual wells as a result of the surface water intake being brought online.

Committed and Planned rates were estimated from the Existing Demand to reflect population growth projections within each pressure zone (Table 3.2). The total demand was apportioned to individual wells based on their operational capacity (see Table 3.1). The City also indicated that some wells are designed to cycle with others, as indicated in the comments section of the table, and these pumping rates have been shared between each pair. The Existing plus Committed plus Planned pumping rates outlined in Table 3.3 presents the average annual rates that could be sustained by the supply wells as well as the standard deviation of monthly estimated rates. Average pumping rates are within the capacity for each well and are designed to meet the expected needs of Barrie based on the projected population for 2031. Transient monthly rates vary from a low of approximately 60% of the average rate, to a high of about 135% of the average, with peak demand from June-September.

It is recognized that higher daily pumping rates may be temporarily experienced by the wells; however, in some cases, these elevated rates cannot be sustained over the long-term due to operational limitations (See Table 3.1, Operating Capacity).

TABLE 3.3 Municipal Water Demand

Well Name	Demand (m³/day)					Comments
	Pre-Surface Water Intake (2010, Observed)[1]	Existing (2012, Estimate)		Existing Plus Committed Plus Planned Demand (2031, Estimated)		
		Average	Monthly Standard Deviation[2]	Average	Monthly Standard Deviation[2]	
Pressure Zone 1 – Core Area						
3A	2,087	2,091	420	2,898	565	Cycles with Well 12*
4	0	1,535	527	2,150	572	Cycles with Well 14*
5	2,619	1,292	229	1,823	308	
7	5,409	1,922	424	2,670	866	Cycles with Well 15*
11	0	3,637	229	3,900	566	Limited by operators
12	4,800	2,090	644	2,898	565	Cycles with Well 3A*
14	3,761	1,292	420	1,823	308	Cycles with Well 4*
15	4,131	1,922	644	2,670	866	Cycles with Well 7*
17	2,364	2,698	855	3,715	1145	
18	2,888	2,405	740	3,321	998	
19	0	0	0	4,178	0	Planned System
Pressure Zone 2 – North						
9	3,766	4,191	936	4,589	1006	
13	4,130	2,725	689	3,012	740	
16	4,253	4,662	1252	5,095	1347	
Total	**40,208**	**32,465**		**44,746**		

*Existing and Planned demand estimates
[1] 2010 rates provided to illustrate the drop in demand at individual wells when the surface water plant was brought online.
[2] Monthly range presented as a standard deviation. Monthly pumping projections based on historic pumping from 2007.

3.2.3 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 Figure 3.1. The main adjacent municipalities that use groundwater for supply include Midhurst, Angus, Stroud, and Innisfil Heights. These systems are included in Table 3.4**.** The Midhurst wells are within the same vicinity as Barrie's Well 16; however, they are in the Willow Creek Subwatershed, as opposed to the Barrie Creeks Subwatershed.

TABLE 3.4 Municipal Wells within the remainder of the Study Area

Municipal System	Well Name	MOE Number	Aquifer	2009 Reported Pumping Rates (m^3/day)
		Stroud		
Stroud	Well 1	5708340	A3	166
Stroud	Well 2 Standby	5711982	A3	166
Stroud	Well 3	5720924	A3	166
		Angus		
Centre Street (McGeorge)	Well 1	No Record	A3/A4	306
Centre Street (McGeorge)	Well 2	No Record	A3/A4	283
Brownley	Well 4	5739698	A3/A4	0
Brownley	Well 5	5730542	A3/A4	0
Brownley	Well 6	5730543	A3/A4	0
		Midhurst		
Idlewood	Well 2	5711983	A3	129
Idlewood	Well 3	5718775	A3	437
Greenpine	Well 4	DHL0194	A3	210
Carson Road	Well 5*	5725264	A3	304
Paddy Dunn's Circle	Well 1 (Del Trend)	5728243	A3	11.
Paddy Dunn's Circle	Well 2 (Del Trend)	5728671	A3	18
Paddy Dunn's Circle	Well 3 (Del Trend)	5733452	A3	76
		Vespra Downs		
Vespra Downs	Well 1-93	5729945	A3	39
Vespra Downs	Well 1-91	5728338	A3	0.3
		Alcona		
Crossroads	Well 1B	5727974	A2	96
Crossroads	Well 2	5730571	A2	96
Crossroads	Well 3	5728442	A3	0
Crossroads	Well 3B	5729269	A3	196
Crossroads	Well 4R	5730573	A3	98
Crossroads	Well 5	5729737	A2	112
Crossroads	Well 6	5730083	A3	132
		Craighurst		
Craighurst	Well 1	5728783	A1	0.07
Craighurst	Well 2	5728784	A1	11
Craighurst	Well 3	5728785	A2	21
		Minesing		
Minesing	Well 1	5710801	A3	119

Municipal System	Well Name	MOE Number	Aquifer	2009 Reported Pumping Rates (m^3/day)
Minesing	Well 2	5724869	A2	119
Minesing	Well 3	5729291	A2	137
Thornton				
Glen Avenue	Well 1	5723177	A2	107
Glen Avenue	Well 2	5730575	A2	122
Thornton Estates	Well TW1-69	5706712	A1/A2	82.
Thornton Estates	Well TW2-69	5706711	A1/A2	60
Anten Mills				
Anten Mills	Well 1	5712365	A3	0.5
Anten Mills	Well 2	5710898	A3	120
Anten Mills	Well 3	5737379	A3	151
Shanty Bay				
Shanty Bay	Well 1	5712374	A3	43
Shanty Bay	Well 2	5716548	A2	49
Shanty Bay	Well 3	DHL0193	A3	55
Snow Valley				
Snow Valley	Well 3	5738227	A3	176
Snow Valley	Well 4	A011213	A3	0.5
Snow Valley	Well 1	5723284	A3	53
Snow Valley	Well 2	5724900	A3	54
Innisfil Heights				
Innisfil Heights	Well 2	5711853	A2	128
Innisfil Heights	Well 3	5727320	A2	213
*Formerly Well 4				

3.3 Safe Additional Available Drawdown

Safe additional available drawdown (SAAD) is defined as the additional drop in water level within a pumping well that could be sustained and still maintain that well's allocated pumping rate. It is calculated as the additional drawdown that is available over and above the drawdown measured under recent historic pumping conditions. To establish the safe additional drawdown for each municipal pumping well within the Study Area, the following components need to be evaluated or calculated for each municipal well:

1. Safe water level elevations. The lowermost elevation within the municipal pumping well, or adjacent aquifer that must be maintained to safely pump a well: this elevation may be related to the well screen elevation, pump intake elevation or similar operational limitations.

2. Observed water level elevations in the pumping wells, under normal (good) well performance conditions. Water levels within each municipal well were estimated from well hydrographs (see Good Performance water level, Figure 3.3).

3. Observed water level elevations in the pumping wells, under diminished well performance conditions. Water levels within each municipal well were estimated from well hydrographs (see Poor Performance water levels, Figure 3.3).

Tables 3.5 and 3.6 provide the calculation details and the additional available drawdown thresholds to be utilized in the risk assessment. Table 3.5 provides the available drawdown assessment under normal well performance conditions, whereas Table 3.6 provides the assessment under diminished well performance which may occur due to decreases in well efficiency from clogging of well screen and aquifer materials. It is important to note that diminished well performance has historically occurred over the span of months to years (see Figure 3.3) and thus the City's well operators have ample time to temporarily re-allocate pumping and shut a well down for rehabilitation. As a result, the safe water level elevation under diminished well performance is not considered a strict limitation, but rather a precautionary evaluation.

A brief explanation of the table column headings is provided for clarification. The estimated values for each well can be seen graphically in Appendix D.

- Top of Screened Interval Elevation – taken from the well construction information.
- Top of Aquifer Elevation – estimation of top of aquifer from production well log at each well site.
- Typical Non-Pumping Water Level in the Aquifer - Estimated from hydrograph for the pumping well.
- Typical Pumping Water Level in the Aquifer – Estimated from hydrograph in the observation well adjacent to the pumping well under pumping conditions.
- Typical Pumping Water Level in Pumping Well – Estimated from hydrograph in the pumping well under pumping conditions. Pumping water levels were assessed for both normal and diminished well performance conditions.
- Additional Available Drawdown, which is the available water column below the "Typical Pumping" conditions, as defined below.

3.3.1 Additional Available Drawdown Calculation

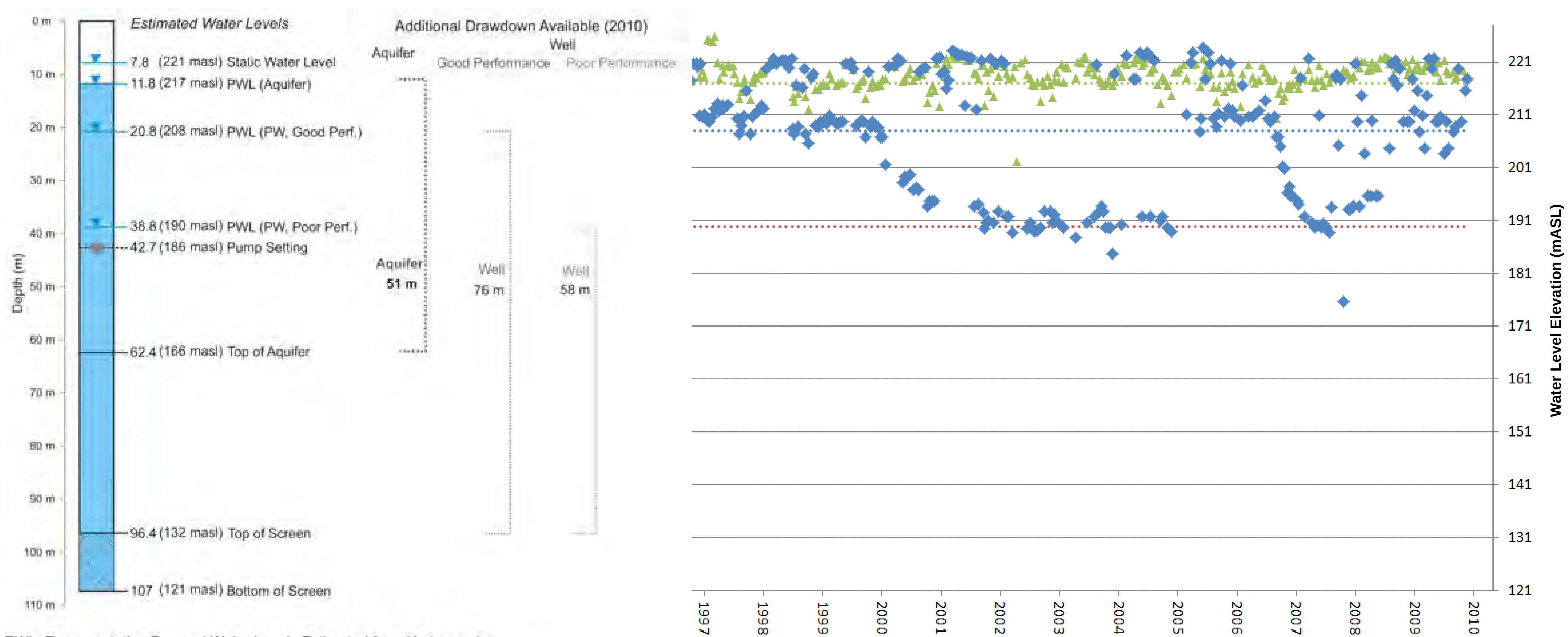
The additional drawdown available was calculated considering the following criteria:

1. The water level in the Aquifer should be maintained above the top of the aquifer where practical to maintain a confined aquifer response to pumping. This water level is obtained from each well's paired monitoring well which are located within 50 m from the pumping well.

2. The water level within the Pumping Well should be maintained above the top of the well screen, to avoid potential redox condition changes and associated precipitation or bio-fouling.

These calculations are illustrated on Figure 3.3 as well as in Appendix D (for each individual well).

The criteria that resulted in the smaller available drawdown was used to establish the Safe Additional Available Drawdown (SAAD) available with the minimum threshold highlighted (i.e., bolded text) for



PWL: Representative Pumped Water Levels Estimated from Hydrographs

Legend

- Observed Water Level: Well 3A
- Observed Water Level: TW1/91
- Pumped Water Level (PWL) - Aquifer
- Pumped Water Level (PWL) - Pumping Well (PW), Good Performance
- Pumped Water Level (PWL) - Pumping Well (PW), Poor Performance

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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Safe Additional Drawdown Calculation (Well 3A)

Date: 17 May 2013	Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 3.3

E:\Projects\2010007_BarrieTier3\GIS\ArcView\MXDs\AnnexationReport\Fig3.3_SafeAdditionalDrawdown_Well3A.mxd each well location. This criteria is used to assess whether additional drawdown during the risk assessment scenarios would violate the most stringent of these available drawdown criteria. Evaluation is done using additional drawdown as the threshold value already considers the drawdown observed under observed pumping conditions. It is important to note that observed conditions were not available for the "Existing Demand"; rather observed conditions reflect the period prior to the surface water intake (i.e., 2010 and earlier). Pump setting was not considered as a criterion because the intake elevation can be lowered within the wells.

TABLE 3.5 Safe Additional Available Drawdown (Normal Performance Conditions: 1997-2010)

Well	Top of Screen (m asl)	Top of Aquifer (m asl)	Typical Non Pumping Water Level in Aquifer (m asl)	Typical Pumping Water Level in Aquifer (m asl)	Typical Pumping Water Level in Pumping Well (m asl)	Additional Available Drawdown (m)	
						Aquifer	Pumping Well
Well 3A	132.5	166.5	221	217	208	**51**	76
Well 4	179.1	187.6	221	217	211	**29**	32
Well 5	144.5	170.1	222	220	216	**50**	71
Well 7	149.3	161.9	222	218	215	**56**	66
Well 9	182.7	198.4	230	225	215	**27**	32
Well 11	173.5	185.6	218	208	192	22	**19**
Well 12	155.5	168.9	218	214	204	**45**	48
Well 13	177.6	193.8	230	225	215	**31**	37
Well 14	178.7	185.6	218	210	196	24	**17**
Well 15	174.7	175.6	218	212	209	36	**34**
Well 16	191.4	202.3	235	233	227	**31**	36
Well 17	148.3	168.4	222	217	212	**49**	64
Well 18	147.7	169.6	222	217	212	**47**	64
Well 19	152.0	165.4	222	217	210	**52**	58

TABLE 3.6 Safe Additional Available Drawdown (Diminished Performance Conditions: 1997-2010)

Well	Top of Screen (m asl)	Top of Aquifer (m asl)	Typical Non Pumping Water Level in Aquifer (m asl)	Typical Pumping Water Level in Aquifer (m asl)	Typical Pumping Water Level in Pumping Well (m asl)	Additional Available Drawdown (m)	
						Aquifer	Pumping Well
Well 3A	132.5	166.5	221	217	190	**51**	58
Well 4	179.1	187.6	221	217	211	**29**	32
Well 5	144.5	170.1	222	220	216	**50**	71
Well 7	149.3	161.9	222	218	212	**56**	63
Well 9	182.7	198.4	230	225	215	**27**	32
Well 11	173.5	185.6	218	208	178	22	**5**
Well 12	155.5	168.9	218	214	198	45	**42**
Well 13	177.6	193.8	230	225	210	**31**	32
Well 14	178.7	185.6	218	210	191	24	**12**

Well	Top of Screen (m asl)	Top of Aquifer (m asl)	Typical Non Pumping Water Level in Aquifer (m asl)	Typical Pumping Water Level in Aquifer (m asl)	Typical Pumping Water Level in Pumping Well (m asl)	Additional Available Drawdown (m)	
						Aquifer	Pumping Well
Well 15	174.7	175.6	218	212	207	36	**32**
Well 16	191.4	202.3	235	233	227	**31**	36
Well 17	148.3	168.4	222	217	212	**49**	64
Well 18	147.7	169.6	222	217	212	**47**	64
Well 19	152.0	165.4	222	217	210	**52**	58

3.4 Other Water Uses

The Local Area Risk Assessment is carried out to assess not only if wells or intakes can meet their allocated rates, but whether committed or planned demand can be met while maintaining the requirements of other water uses in the area. The Tier Three Water Budget should identify all other water uses and compile or estimate water quantity requirements for them where possible. Establishing the quantity of water required by other water uses is difficult as it is not always a unit flow rate of water. As a result, the data gathering exercise may be semi-quantitative. For example, the health and ecological integrity of a Provincially Significant Wetland may be dependent on the water table elevation, or be linked to isolated (perched) portions of the aquifer system. The Tier Three water budget should identify all other uses on a map (MNR and MOE 2011) and provide supporting text and analysis describing the nature of those uses and some estimate of their requirements.

The Technical Rules lists the following uses to be identified in any Tier Three Local Area: wastewater assimilation, other water takings (including agricultural, commercial and industrial), navigation, recreation, aquatic habitat and provincially significant wetlands. In this study, other takings, aquatic habitats and provincially significant wetlands were identified as other uses that may be affected by groundwater takings.

3.4.1 Permitted Water Uses

In addition to the municipal water takers within the Study Area, there are also a number of large permitted water takers within the Study Area with MOE permits. Figure 3.1 illustrates the locations of the non-municipal permitted users in the Study Area (MOE PTTW database; 2010). Table B.3.1 in Appendix B (AquaResource et al. 2011b) outlines the specific details of each permit including the permit number, the location of the water use, the general and specific purpose for the permit, and the average annual consumptive demand. The consumptive demands were originally estimated in the SGBWLS Tier Two project (Golder and AquaResource 2010) and updated with reported rates for this study. A detailed explanation as to how these demands were estimated is contained in Appendix A, Section 3. The consumptive demands are used as they could be considerably less than the permitted water use rates and thus are vital to estimate for inclusion in the model.

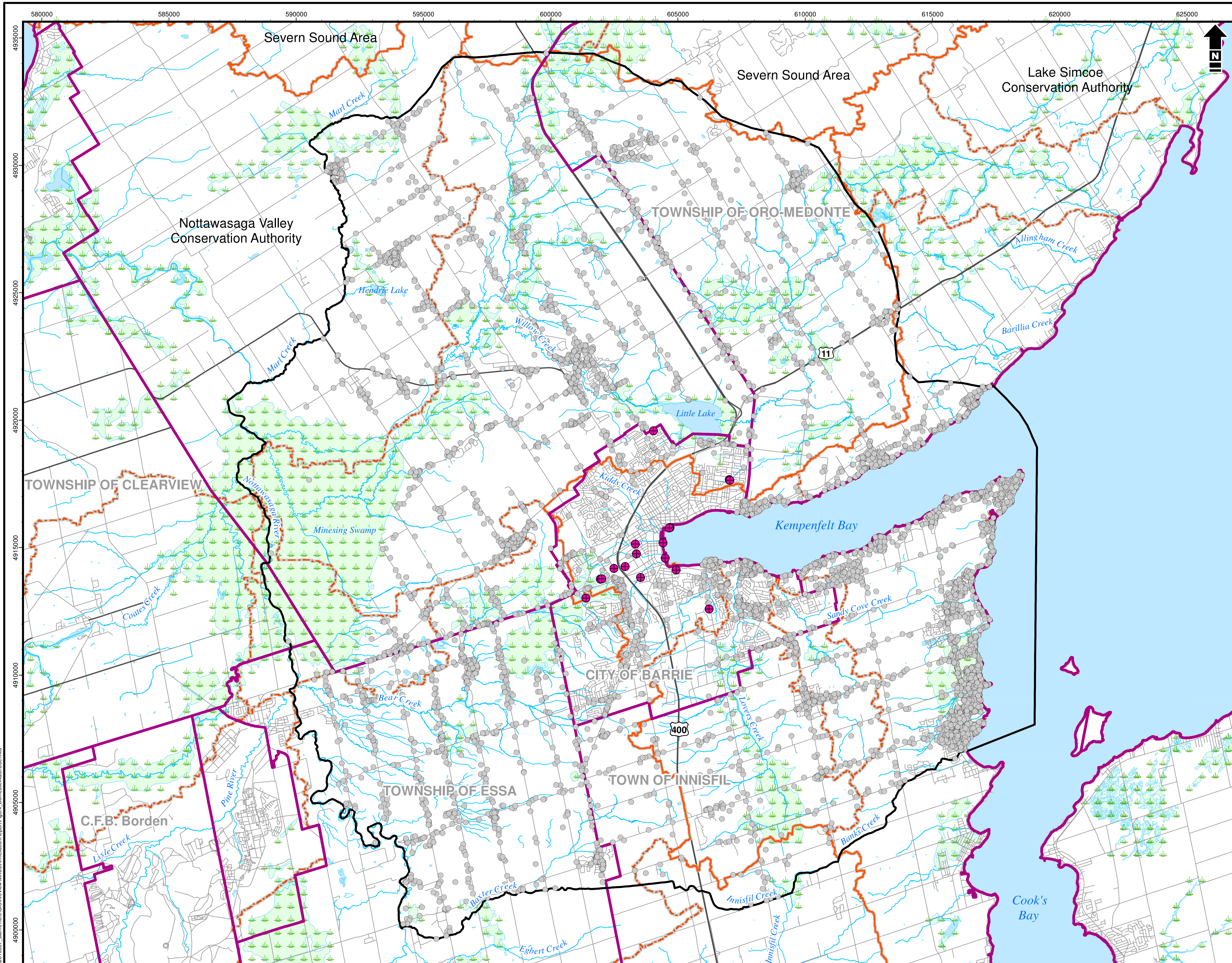
3.4.2 Non-Permitted Pumping

Figure 3.4 illustrates the location of domestic water wells within the Study Area. The locations of the wells were obtained from the MOE water well information system; these wells represent water takings for domestic water use, and in some cases for agricultural water use. Some wells exist within the City of Barrie, and these wells may no longer be in use, or may be used for lawn watering or similar uses. Domestic water takers were not simulated in the groundwater flow model, as their individual takings are relatively insignificant compared to municipal pumping. Consumptive water use from the unserviced domestic wells in the Barrie Creeks subwatershed was estimated (Golder and AquaResource 2010) to be 77 m^3/d. This water use represents approximately 1% of the total municipal water use within the Barrie Creeks subwatershed and less than 1% of the total permitted water use within the subwatershed. As such, these water uses were not simulated in the groundwater flow model or in the Barrie Creeks water budget calculations.

3.4.3 Aquatic Habitat

The Tier Three Assessment process identifies a Local Area as having a Risk Level of Significant in situations where a significant impact to coldwater fisheries or wetlands is predicted as a result of a well or intake pumping at its allocated rate. In Ontario, there has been increasing recognition of the water needs of aquatic ecosystems in legislation and policy. For example, water takings in Ontario are governed by the Ontario *Water Resources Act* and the Water Taking and Transfer Regulation. Section 34 of the Act requires anyone taking more than a total of 50,000 litres in a day from a lake, stream, river or groundwater source, with some exceptions, to obtain a Permit to Take Water (PTTW). The PTTW application process places an emphasis on environmental considerations, such as the potential impact of proposed takings on natural water flows, ecological habitats that depend on water flow and water levels, water availability, and the interrelationship between groundwater and surface water. Another example is the Oak Ridges Moraine Conservation Plan that requires water budgets to include the identification of targets that meet the water needs of affected ecosystems. In general, there is growing awareness of the importance of identifying the water needs of aquatic ecosystems for watershed planning and better linking of design criteria for specific watershed management measures to the ecological responses of receiving waters.

Groundwater discharge requirements for coldwater aquatic habitat are poorly understood, and the impacts of a reduction in groundwater discharge into the aquatic habitat cannot be definitively predicted. Consequently, the Province introduced the use of thresholds to evaluate the impacts of reductions in groundwater discharge into coldwater streams. The Province elected to prescribe specific baseflow reduction thresholds that should be used when assigning a Risk Level associated with predicted impacts to coldwater fish community streams due to increased municipal pumping. For coldwater streams, a Moderate risk occurs when groundwater discharge is estimated to be reduced between a minimum of 10% but not greater than 20% of existing monthly baseflow. Baseflow is defined by the MOE (MOE 2009) as the monthly Qp80 (the flow that is exceeded 80 percent of the time) or



Legend
- Domestic Wells
- Municipal Wells

Transportation Network
- Highways
- Roads

Drainage Network
- River / Stream
- Open Water
- Wetlands

Boundaries
- Barrie Tier 3 Boundary
- Municipal Boundaries
- Conservation Authority
- NVCA and LSRCA Subwatersheds

Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
Produced using information provided by the Ministry of Natural Resources,
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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Domestic Water Use

Date: 15 May 2013	Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 3.4

E:\Projects\2010007_BarrieTier3\GIS\ArcView\MXDs\AnnexationReport\Fig3.4_DomesticWaterUse.mxd average monthly flow. A Risk Level of Significant occurs when groundwater discharge is estimated to be reduced by greater than 20% of the existing average monthly baseflow (MNR and MOE 2011).

Figure 2.2 illustrates the fish community mapping conducted by LSRCA (2010) and NVCA (2009) Authorities within the Study Area, and wetland mapping across the Study Area as mapped by the Ministry of Natural Resources. This figure identifies coldwater streams that would be subject to the Province's groundwater discharge reduction threshold. Within the vicinity of the Barrie wells, Bear Creek, Willow Creek, Lovers Creek and the Barrie Creeks within the city core will all be assessed for baseflow reduction.

3.4.4 Provincially Significant Wetlands

The Technical Rules also identify provincially significant wetlands as other water uses that cannot be significantly impacted by municipal pumping. The wetland systems within the Study Area include swamps, marshes, fens, and bogs. Evaluated wetlands are classified under a standard methodology taking into account the biological, hydrological, and socio-economic features and functions of a wetland. Based on this system, wetlands can be identified as PSWs and these are protected under the wetland component of the Provincial Policy Statement. Three Provincially Significant Wetland Complexes (Figure 2.2) are located near the City of Barrie. These wetlands are the Bear Creek Wetland, Little Lake Wetland and Lover's Creek Wetland, and are described in Appendix A. Evaluation of wetland features is limited to evaluation of water level changes in the vicinity of a wetland and the impact of such water level changes on the function of the wetland (e.g., are discharge conditions maintained).

4.0 TIER THREE WATER BUDGET

One component of the Tier Three Assessment is an improved estimate of the water budget components included in the hydrologic cycle within the Study Area. The surface water and groundwater flow models developed for the Tier Three Assessment were used to estimate average annual values for the various components of the hydrologic cycle. While the MIKE SHE model and FEFLOW model were separate and independent models, the modelling was linked through the groundwater recharge and interbasin flow components (groundwater flow between subwatersheds). Although the MIKE SHE model simulated hourly continuous streamflow, and the FEFLOW model simulated average annual groundwater discharge and baseflow conditions, each of the models estimates important aspects of the same surface water flow system. As such, the two models were calibrated to the same baseflow (component of streamflow assumed to be groundwater discharge) and to some extent, water level, data. The second common aspect shared by the two models is groundwater recharge, which is a parameter that is simulated by the MIKE SHE model as a model output and used as a model input parameter in the FEFLOW groundwater model.

The combined results of the two water budget models produce an improved understanding of the hydrologic and hydrogeologic flow systems. The following sections quantify and outline the water budget components within the Barrie Creeks Subwatershed. Each of the components presented were calculated assuming no net change in stored water over the time period and were based on the limitations and assumptions of the long-term climate dataset discussed in Appendix A.

4.1 Groundwater Flow

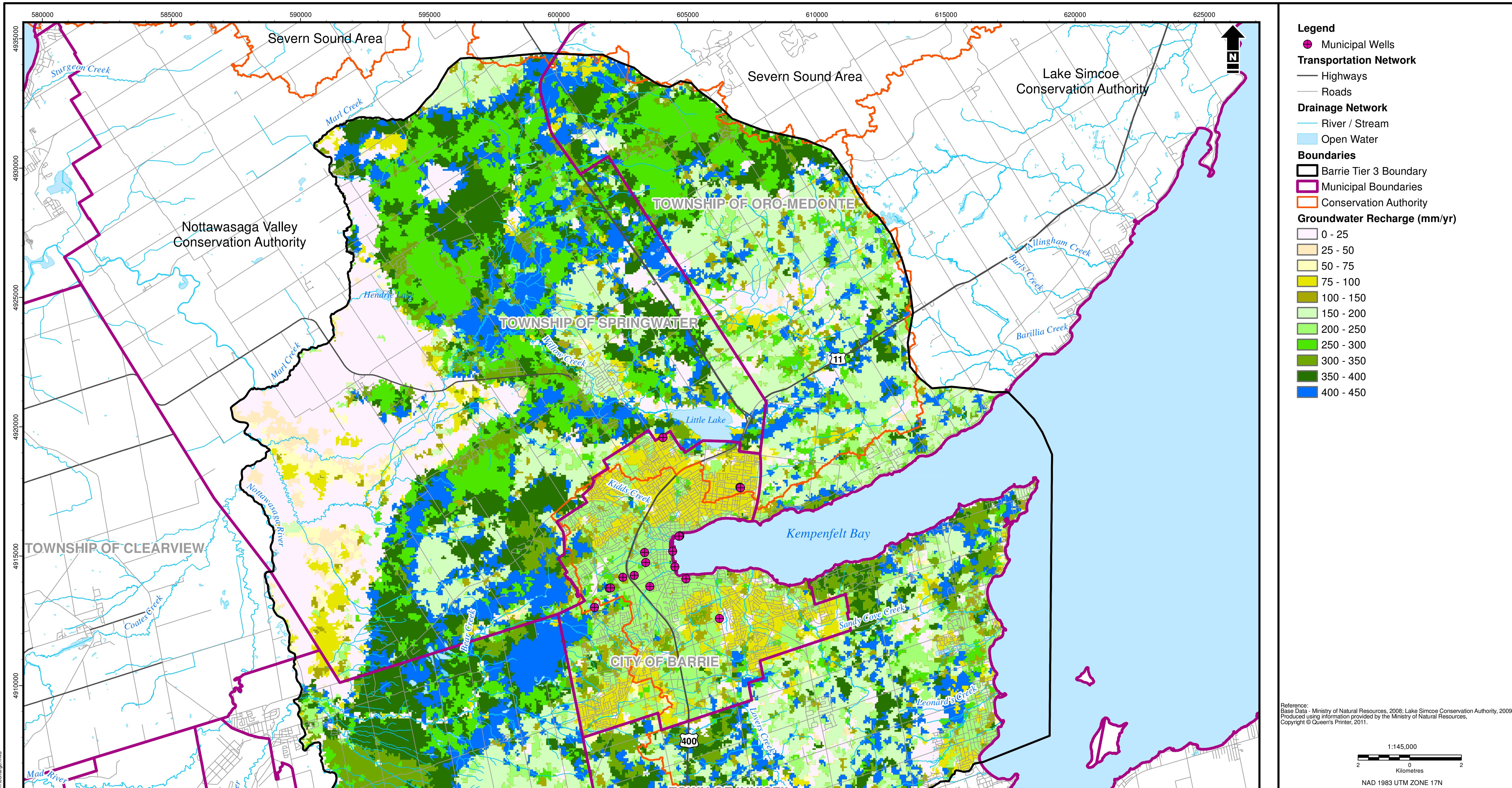
The following section outlines the water budget model results relating to groundwater in the Study Area using the calibrated model presented in Appendix C with 2010 pumping rates.

4.1.1 Groundwater Recharge

Figure 4.1 illustrates groundwater recharge simulated in the calibrated groundwater flow model. As can be expected, groundwater recharge is higher (350 mm/year) in areas with high permeability soils, i.e., sands and gravels, and lower (150 mm/year) in tighter soils, i.e., silts/tills, and clays. The urbanized areas within the City of Barrie have lower recharge rates due to the impervious fraction, which limits the volume of water that can infiltrate. In the Study Area, the groundwater system plays a major role in determining groundwater recharge. In groundwater discharge areas (e.g., wetlands), recharge is zero or very low as the water table is at or near ground surface.

4.1.2 Water Table Contours

Figure 4.2 illustrates the model predicted water table elevation contours produced in the steady state groundwater flow model. As illustrated on the figure, water table contours generally mimic the ground surface topography, and flow converges towards the main streams and wetlands in the Study Area.



Reference:
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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Groundwater Recharge

Date: 15 May 2013	Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 4.1

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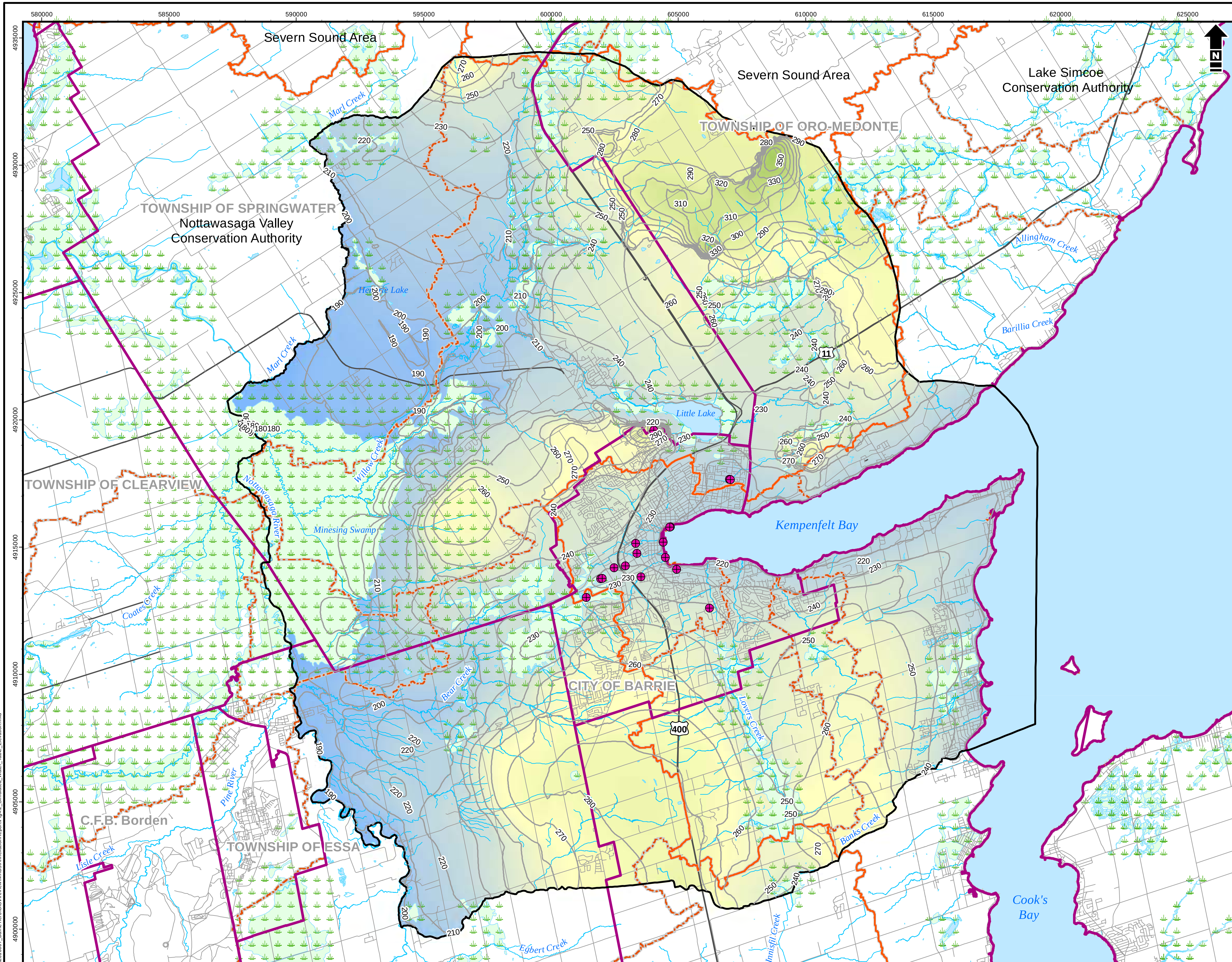

Legend

- Municipal Wells

Transportation Network

- Highways
- Roads

Drainage Network

- River / Stream
- Open Water
- Wetlands

Boundaries

- Barrie Tier 3 Boundary
- Municipal Boundaries
- Conservation Authority
- NVCA and LSRCA Subwatersheds

Water Table Elevation (masl)

High : 360

Low : 175

Contour Interval 10m

Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Simulated Water Table Elevation

Date: 17 May 2013	Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 4.2

The groundwater elevation contours generally compare well with the observed water level contours presented in Appendix A.

The largest horizontal gradients (tightly spaced contours) are observed at regional discharge locations, which include Willow Creek and Bear Creek.

4.1.3 Production Aquifer (A3) Water Level Contours

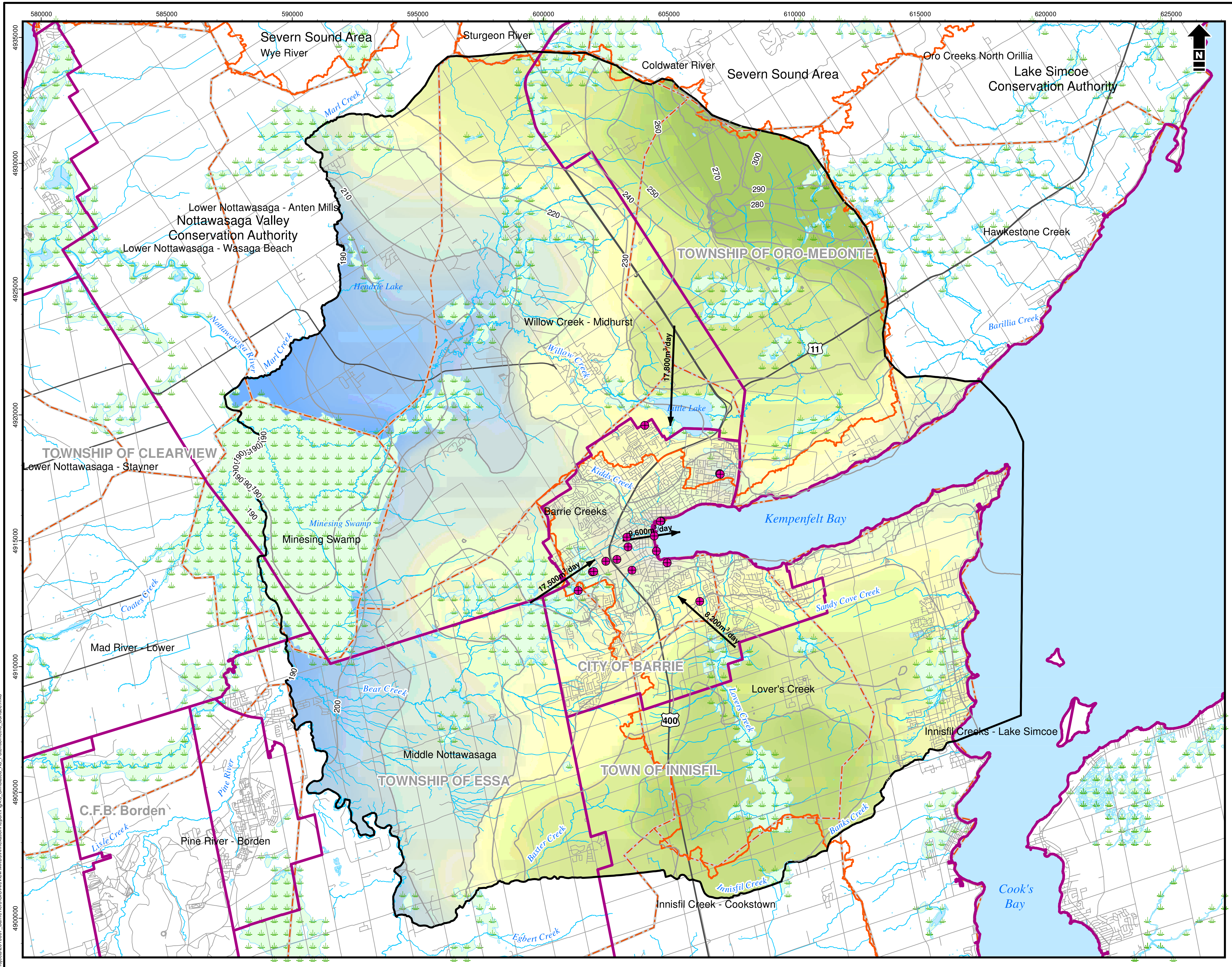
Figure 4.3 illustrates the model predicted A3 potentiometric surface contours within the Study Area. The water level contours are similar to the shallow levels; however, the deep water levels exhibit more subdued hydraulic gradients influenced by groundwater recharge and discharge areas. The Nottawasaga River and the Minesing Swamp wetland complex heavily influence flow in the aquifer where there is some hydraulic connection with the underlying flow system.

Figure 4.3 also illustrates the total cross-boundary groundwater flow between the Barrie Creeks subwatershed and the adjacent watersheds (and subwatersheds) as simulated in the calibrated groundwater flow model. These major cross-boundary flow terms represent the flow through all layers, and are summarized in Table 4.1. Flux crossing the subwatershed boundaries is strongest through the most transmissive layers (in this case, A3).

TABLE 4.1 Summary of Cross-Boundary Groundwater Flow

Boundary	Cross Boundary Flow (m^3/d)
Willow Creek Subwatershed (NVCA) into Barrie Creeks Subwatershed (North)	+17,800
Middle Nottawasaga River Subwatershed (NVCA) into Barrie Creeks Subwatershed (West)	+17,500
Lovers Creek Subwatershed into Barrie Creeks Subwatershed (South)	+8,200
Barrie Creeks Subwatershed to Subsurface Below Kempenfelt Bay	-9,600
Net Cross-Boundary Groundwater Flow	**+33,900**

Cross-boundary flows into Barrie Creeks are significant along the boundaries with the Nottawasaga Valley Watershed to the west and north. The flows across the boundary with the Willow Creek subwatershed are interpreted to be natural, as simulations with no pumping show the same magnitude of interbasin flow. Conversely, flow from the Middle Nottawasaga subwatershed and Lovers Creek subwatershed are shown to be induced by hydraulic gradients resulting from municipal pumping, as simulations with no pumping show that the natural gradient is reversed. Cross-boundary flow out of the subwatershed to the subsurface below Kempenfelt Bay is small, also due to pumping within the city core. It is important to note that this flow does not represent total discharge from the subwatershed to Kempenfelt Bay; discharge to the Bay is accounted for within the water budget by surface water discharge (Section 4.2). Rather, this flow represents only deep groundwater transfer to the subsurface below the Bay.



Legend

- Municipal Wells
- Cross Boundary Flow (all layers)
- Water Table Elevations - Interval 10m

Transportation Network

- Highways
- Roads

Drainage Network

- River / Stream
- Open Water
- Wetlands

Boundaries

- Barrie Tier 3 Boundary
- Municipal Boundaries
- Conservation Authority
- SGBWLS Tier Two Subwatershed Boundary

Deep Potentiometric Surface - Elevation (m)

High : 305

Low : 180

Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
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Simulated A3 Potentiometric Surface

Date: 15 May 2013	Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 4.3

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4.1.4 Vertical Hydraulic Potential

Figure 4.4 illustrates the direction of the simulated vertical hydraulic potential across the Study Area, calculated as the difference between the water table elevation surface and deep potentiometric surface of the deep underlying confined aquifer (A3). The map is shaded to show the upward (green) and downward (blue) hydraulic head differences. Upward gradients exist along the Nottawasaga River and its tributaries and some wetland complexes; a reflection of groundwater discharge to those areas. The largest areas of vertical head difference (potential groundwater discharge) are in portions of the Minesing Swamp, consistent with the existing knowledge of the wetland, as well as Little Lake and Lake Simcoe. The highest downward head differences are present along the crest of the Oro Moraine and along the flanks of the upland areas on either side of the Barrie city core where shallow overburden groundwater recharges the underlying confined aquifers.

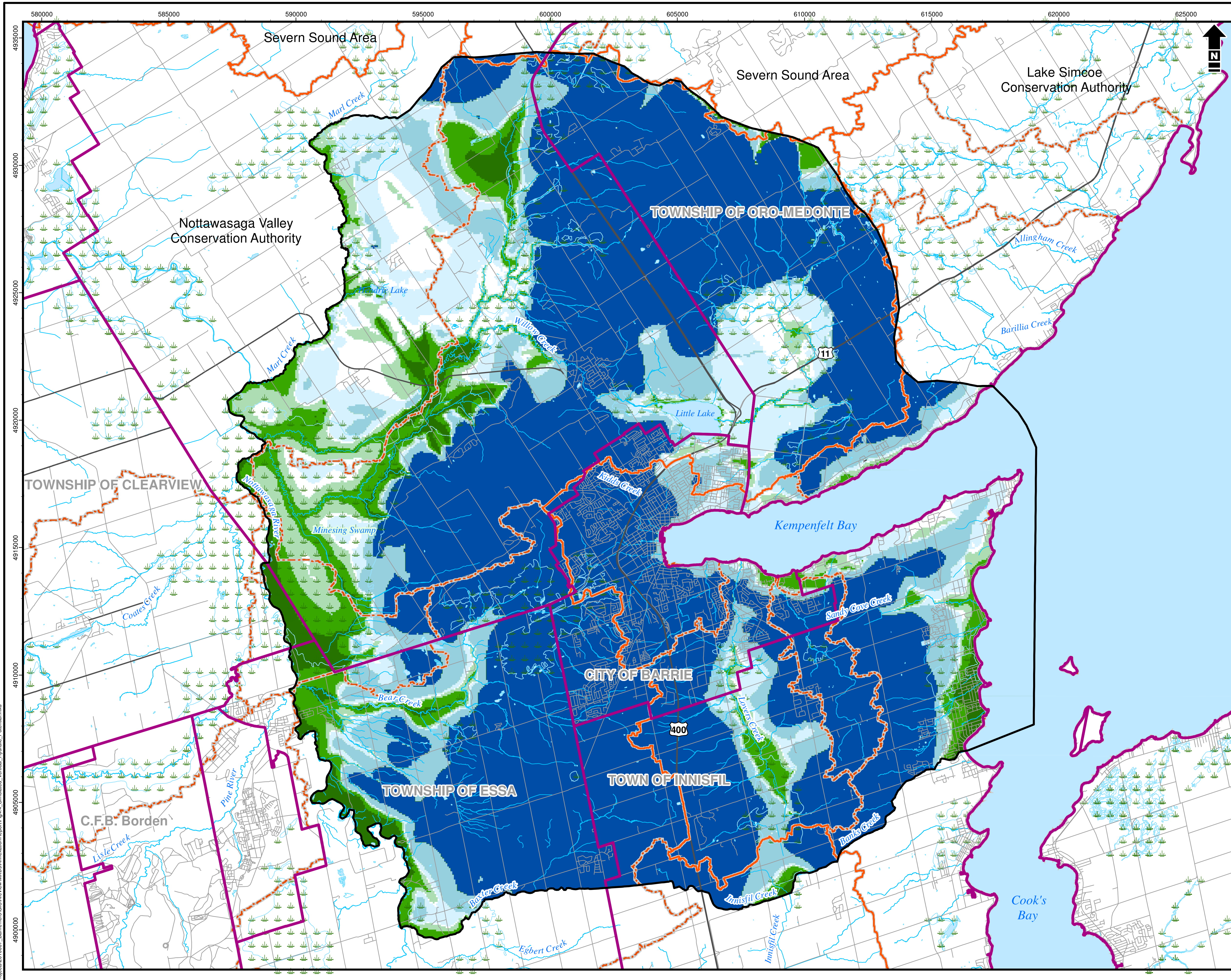
4.2 Barrie Creeks Subwatershed Water Budget

As part of the water budget process, estimates of the water budget component fluxes were examined. Table 4.2 summarizes the estimated overall water budget fluxes for the Subwatershed. The table summarizes watershed inflows including precipitation, interbasin overland flow, and interbasin groundwater flow. Outflows include evapotranspiration, interbasin overland flow, baseflow, overland flow to streams, groundwater pumping, and interbasin groundwater. The groundwater flow terms in this balance include those derived from the groundwater flow model, as well as a small portion of subsurface flow out of the saturated zone within the MIKE SHE model. The water budget parameters are calculated based on information derived from both the surface water and groundwater flow models for the simulation year 2010 and are presented in units of m^3/d and mm/year. The water budget update is presented for 2010 to facilitate comparison to the Tier Two Stress Assessment values as both time periods represent conditions prior to the surface water intake being brought on-line.

Figure 4.3 illustrates the estimated cross-boundary groundwater flow between the Barrie Creeks subwatershed and adjacent subwatersheds. These values are referenced in the following discussion.

TABLE 4.2 Overall Water Balance Table (Barrie Creeks Subwatershed)

Inflows	Flow (m^3/d)	Flow (mm/year)
Precipitation	133,800	910
Overland Flow In	1,000	7
Groundwater Flow In	43,700	297
Total Inflow	**178,500**	**1,214**
Outflows	**Flow (m^3/d)**	**Flow (mm/year)**
Evapotranspiration	68,800	484
Overland Flow to Streams	40,900	278
Baseflow	17,500	119
Overland Flow Out	600	4
Pumping	41,100	280
Groundwater Flow Out	9,600	65
Total Outflow	**178,500**	**1,214**



Legend

Transportation Network
- Highways
- Roads

Drainage Network
- River / Stream
- Open Water
- Wetlands

Boundaries
- Barrie Tier 3 Boundary
- Municipal Boundaries
- Conservation Authority
- NVCA and LSRCA Subwatersheds

Vertical Hydraulic Head Difference
- Strong Upward (> 5m)
- Upward (1 m - 5 m)
- Weak Upward (0.1 m - 1 m)
- Neutral
- Weak Downward (0.1 m - 1 m)
- Downward (1 m - 5 m)
- Strong Downward (> 5 m)

Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
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Simulated Vertical Hydraulic Potential

Date: 15 May 2013		Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1	

Figure 4.4

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As presented in Table 4.2, average annual precipitation the subwatershed is approximately 900 mm/year as measured at the Barrie WPCC climate station. Groundwater modelling results indicate that more than 60% of groundwater flows into the subwatershed across the subwatershed boundaries. Much of the cross-boundary flow is interpreted to be in response to municipal pumping.

Outflows include evapotranspiration, streamflow, groundwater pumping, overland flow and groundwater flow out of the subwatershed. Average annual evapotranspiration is approximately 484 mm/year. Average annual streamflow is 278 mm/year from all streams across the subwatershed. Approximately 9,600 m^3/d of groundwater flows out of the subwatershed to the subsurface under Kempenfelt Bay. This value does not necessarily reflect discharge to (or conversely, induction from) the bay; which is accounted for largely through surface water discharge within the Kempenfelt Bay subwatershed polygon. This flow to the bay is driven by the hydraulic gradient in the shallow layers of the model.

Table 4.3 contains the water balance for groundwater within the subwatershed. The water budget models predict an average annual groundwater recharge rate of 167 mm/year, or 24,500 m^3/d into the subwatershed. Lateral flow into this subwatershed from the surrounding subwatersheds illustrates the convergence of groundwater flow toward this subwatershed; this convergence of flow is partially natural flow toward Kempenfelt Bay (regional discharge area) and partially induced due to local pumping.

TABLE 4.3 Water Balance, Groundwater (Barrie Creeks Subwatershed)

Inflows	Flow (m^3/d)	Flow (mm/year)
Groundwater Recharge	24,500	167
Flow from Willow Creek Subwatershed	17,800	121
Flow from Middle Nottawasaga Subwatershed	17,500	119
Flow from Lovers Creek Subwatershed	8,200	56
Total Groundwater Inflow	**68,100**	**463**
Outflows	**Flow (m^3/d)**	**Flow (mm/year)**
Discharge to Surface Water	17,500	119
Permitted Wells	41,100	279
Flow to Kempenfelt Bay	9,600	65
Total Groundwater Outflow	**68,100**	**463**

Groundwater outflows include discharge to surface water (streams and wetlands), groundwater wells, and groundwater flow out of the subwatershed. The groundwater flow out of the subwatershed includes flow that crosses into the subsurface beneath the bathymetry of Kempenfelt Bay. Total groundwater discharge to surface water is approximately 17,500 m^3/d or 119 mm/year. Groundwater pumping is 41,100 m^3/d, or approximately 60% of the total recharge and cross-boundary inflow into the subwatershed, which has been shown to be induced by the pumping. These values are comparable to those estimated using the Tier Two (watershed-scale) FEFLOW model; however, discharge to streams is considered to be more realistic within the Tier Three model. The difference in water budget estimates between the Tier Three assessment and those from the Tier Two assessment are attributed to the conceptual and numerical model updates made at the local-scale. The Tier Three Assessment water budget estimates should be considered more reliable than those from the Tier Two Assessment for these reasons.

5.0 LOCAL AREA RISK ASSESSMENT

A Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) is completed to evaluate the potential of a municipality's drinking water wells being unable to supply their allocated pumping rates while considering increased municipal water demand, planned land development, drought conditions, and other water uses.

According to the Technical Rules (Part III.2) a Tier Three Assessment must be completed for all Type I, II, and III drinking water systems where:

1. There have been historical issues with water sources meeting demand; or
2. The Tier Two subwatershed stress level is Moderate or Significant.

As described previously in the SGBWLS Tier Two Integrated Water Budget and Subwatershed Stress Assessment Report (Golder and AquaResource 2010), the municipal wells for the City of Barrie are located in the Barrie Creeks Subwatershed which is classified in the Tier Two Study as having a significant potential for stress; this designation reflects the relatively high volume of groundwater demand locally, relative to the flow through the subwatershed. While there are no documented issues with respect to the municipal sources meeting demand, the municipal system is required to undergo a Tier Three Assessment.

The term, "Local Area," was introduced in the MOE Directors Rules (Part III.2) to link the Water Quantity Risk to an area surrounding the drinking water wells or intakes where a competing demand for water (land use development or pumping) may alter the sustainability of the municipal wells. The water budget models are used to delineate the "Local Area" for groundwater wells, which form the basis for the Local Area Risk Assessment. In this assessment, the water budget models are used to estimate the impact to a well in response to a water demand, climate, and land use scenarios. Where these scenarios identify a potential that wells or intakes will not be able to supply their allocated rates, the Local Area is assigned a Moderate or Significant Water Quantity Risk Level. In such a case, consumptive water uses and reductions in groundwater recharge within the Local Area would be identified as Moderate or Significant drinking water threats. The risk scenarios also consider the need to meet the water demand requirements of other surrounding uses, particularly those that are required to be maintained by provincial or federal law such as the ecological flow requirements of a coldwater fish habitat.

Municipalities typically implement physical solutions (e.g., storage reservoirs, peaking / backup intakes) and water conservation measures to reduce the amount of instantaneous water demand required from a primary drinking water source or to reduce the community's overall water demand. These types of measures are implemented to increase a municipality's "tolerance" to short-term water shortages. Tolerance effectively reduces the potential that a municipality will face short or long-term water quantity shortages. The City of Barrie's implementation of a supplementary surface water intake in Kempenfelt Bay is an example of a measure that provides significant tolerance to potential groundwater shortages.

5.1 Methodology

The following steps are recommended (MNR and MOE 2011) when completing a Local Area Risk Assessment:

1. Delineate Vulnerable Areas. The Groundwater Quantity Vulnerable Areas, WHPA-Q1 and WHPA-Q2 should be delineated using the Tier Three Water Budget Model.

2. Define the Local Area based on the delineation of the WHPA-Q1 and WHPA-Q2 areas.

3. Evaluate Risk Scenarios. A series of scenarios take into account the allocated quantity of water for each well and intake, average and drought conditions, and planned land use. The scenarios are evaluated in terms of the ability to pump water at each well or intake along with the impact to other water uses.

4. Assign Risk Level. A Risk Level ranking (low, moderate, and significant) should be assigned to the Local Areas based on the results of the risk scenarios. An uncertainty level (e.g., high, low) will accompany each Risk Level ranking.

5. Identify Drinking Water Quantity Threats and areas where they are significant and moderate. Drinking water quantity threats as consumptive uses or reductions in recharge within the vulnerable areas should be identified.

5.1.1 Delineation of Vulnerable Areas

One of the deliverables of the Tier Three Assessment is the delineation of areas that are vulnerable from a municipal drinking water quantity perspective. Similar to the water quality vulnerable areas, the water quantity vulnerable areas (Wellhead Protection Area for Quantity; WHPA-Q1 and WHPA-Q2) are delineated to protect the quantity of water required by a municipality to meet their current or future water supply needs. The Technical Rules (MOE 2009) require that WHPA-Q1 and WHPA-Q2 areas be delineated for all municipal water supply wells that extract water from a subwatershed assigned a groundwater stress level of Moderate or Significant in the Tier Two Subwatershed Stress Assessment.

The WHPA-Q1 is delineated as the combined area that is the cone of influence of the well and the whole of the cones of influence of all other wells that intersect that area (MOE 2009). The cone of influence for the well(s) was estimated by calculating the difference in the potentiometric heads in the municipal aquifer under allocated (Existing plus Committed plus Planned) municipal demands and current land use versus the potentiometric surface in the municipal aquifer without pumping (Risk Assessment Scenario G(2), Table 5.1). The extent of the cone of influence is determined by selecting an appropriate drawdown threshold, which considers several factors including observed seasonal aquifer water level fluctuations (e.g., 1 to 2 m) and available field observations of pumping induced drawdown around the municipal wells (see Appendix A of the Conceptual Understanding Report for hydrographs of high quality wells).

The WHPA-Q2 is delineated as the WHPA-Q1 plus any area where a future reduction in recharge would have a measurable impact on the cone of influence of the municipal wells. Areas where future reduction in recharge may occur were identified using the Official Plans (Figure 2.6), and the maximum recharge reduction that may result from the land use developments was considered.

5.1.2 Description of Risk Assessment Scenarios

The Local Area Risk Assessment requires that a series of scenarios to be evaluated as listed in the Technical Rules (MOE 2009) and the Water Budget and Water Quantity Risk Assessment Guide (MNR and MOE 2011). These scenarios, summarized in Table 5.1, are designed primarily to assist in identifying the potential impacts from each of the planned water takings, land use, and drought on current hydrogeological conditions. The data required for each of the model scenarios are outlined in Section 5.2.

TABLE 5.1 Risk Assessment Model Scenarios

Scenario	Time Period	Model Scenario Details		
		Land Cover of the Local Area	Water Demand	Model Simulation
C	Climate Data Period	Existing	Existing*	Steady-state, simulate water levels and flows using average annual recharge and pumping
D	Ten year drought period	Existing	Existing*	Transient, using monthly recharge and monthly pumping
G(1)	Climate Data Period	Planned, reduction in recharge	Planned plus Existing* plus Committed	Steady-state, simulate water levels and flows using average annual recharge and pumping
G(2)		Existing	Planned plus Existing* plus Committed	
G(3)		Planned, reduction in recharge	Existing*	
H(1)	Ten year drought period	Planned, reduction in recharge	Planned plus Existing* plus Committed	Transient, using monthly recharge and monthly pumping
H(2)		Existing	Planned plus Existing* plus Committed	
H(3)		Planned, reductions in Recharge	Existing*	

*Existing Demand estimated for 2012, after the start-up of a surface water supply system

The time period within Table 5.1 defines the period of time that each scenario is required to evaluate. The term 'climate data period' implies that the steady state model should be representative of the entire period for which adequate climate and stream flow data are available for the local area.

Existing Demand for Scenarios C and D correspond to estimated 2012 pumping rates (as per Section 3.2.1) and land use under average climate and drought conditions, respectively. Scenarios G and H correspond to future land cover and allocated pumping rates for existing or planned wells under average climate and drought conditions, respectively. As such, the scenarios were interpreted as follows:

- Scenarios representing average climate (i.e., C and G) can be simulated using a steady state approach.
- Scenarios representing drought conditions (i.e., D and H) can be simulated using a transient model to represent the drought period of the 1960s.
- Three versions of scenarios G and H are provided to evaluate the impact of allocated pumping rates separate from impacts of land cover and the cumulative impact of both.
- Impacts to other uses (e.g., wetlands and cold water fisheries) are not evaluated for the drought scenarios (D, H). The drought scenarios only serve to identify the potential for water levels to fall beneath a safe additional drawdown for each municipal well.

5.2 Delineation of Vulnerable Areas

5.2.1 WHPA-Q1

The WHPA-Q1 areas were delineated by examining the change in model predicted heads within the production aquifer between two model scenarios:

1. Steady-state model simulating existing land use, and no pumping. This scenario establishes water levels that would exist without pumping.
2. Steady-state model simulating existing land use, and Existing plus Committed plus Planned municipal pumping rates.

The model predicted heads in each aquifer for both pumping and non-pumping scenarios were subtracted; the maximum change from all aquifers was projected to the surface and contoured (Figure 5.1). It is important to note that the most significant drawdown extent occurs within the main production aquifer, A3. Seasonal water level fluctuations within wells monitoring heads in the production aquifer vary by up to 2 m, and therefore, the 2 m drawdown contour interval was selected for use in delineating the WHPA-Q1 area.

The WHPA-Q1 area lies within the Barrie area (Figure 5.1). This area underlies much of the City of Barrie, and extends north towards Midhurst, west towards Bear Creek and south towards Innisfil. There are 10 non-municipal permits identified within the WHPA Q1 (Figure 5.1), , five of which are dewatering wells that only pump to lower water levels when needed. Two of the 10 wells are screened within the main production aquifer, A3; however, one (Permit 5372-6SYPRA) was reported to be non-pumping, and the other (Permit 1315-6W3QAS) is a dewatering well. The complete list of permitted takers within the WHPA Q1 is shown in Table 6.1.

5.2.2 WHPA-Q2

The WHPA-Q2 is defined in the Technical Rules and Guidance Document (MOE, 2009; MNR and MOE 2011) as the WHPA-Q1 area, plus any area where a future reduction in recharge may have a measurable impact on drawdown at the municipal wells. Proposed land development areas that could reduce the available drawdown in a municipal well, were considered for assessment. Figure 5.2 shows the WHPA Q1 as well as the urban development areas (as discussed in Section 2.5).

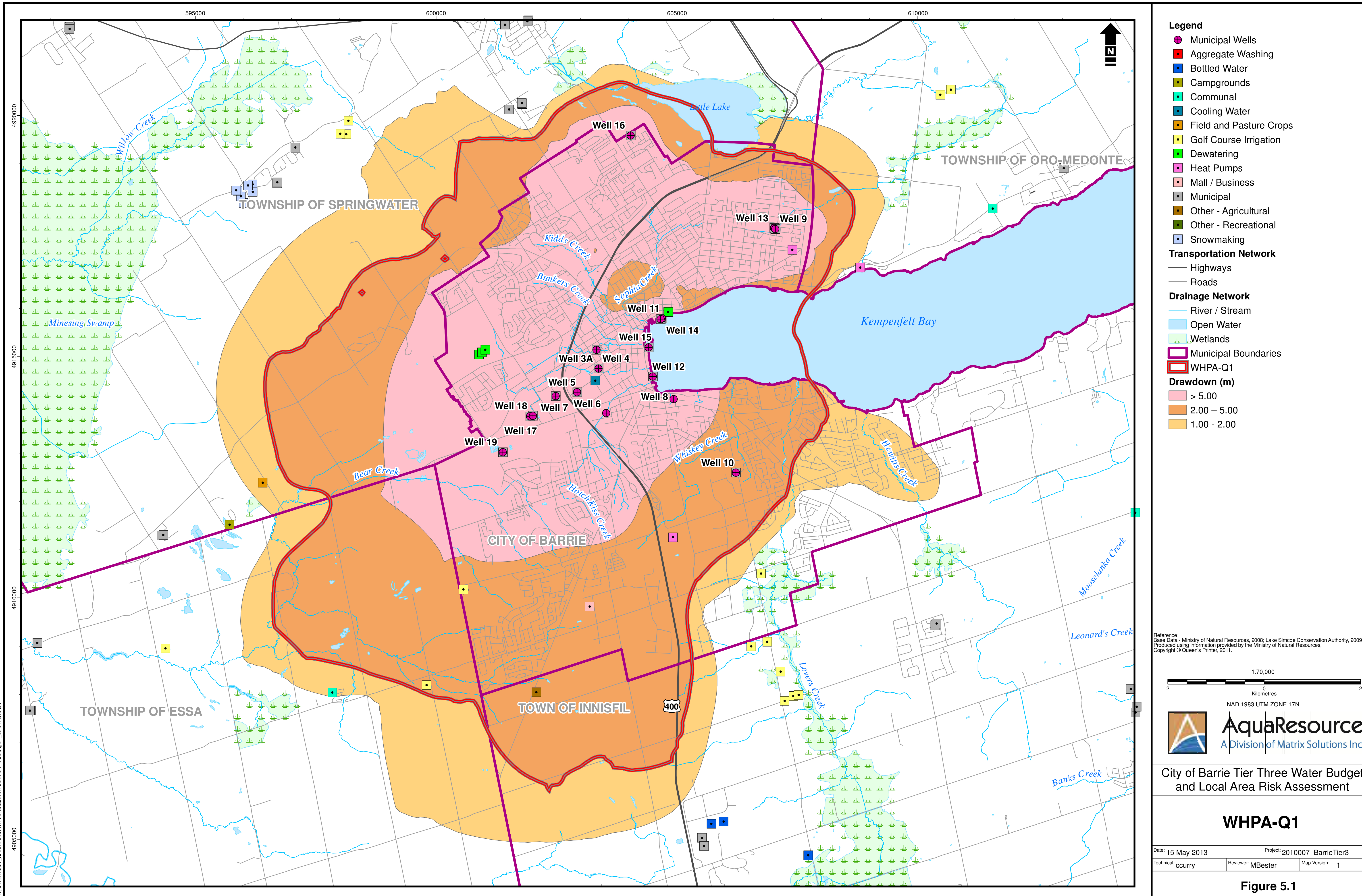
Urban development areas that lie within the WHPA-Q1 area include infilling of high and low intensity urbanized land within the city core. Some of these potential land use developments straddle the extent of the WHPA-Q1 and extend beyond it. To assess the impact of land use changes on the water quantity for the City's wells, the model was run with existing land use and existing pumping, and the head at the municipal wells (in the production aquifer) was noted. The model was then updated to simulate a 50% reduction in recharge for the areas designated for high or low intensity land use changes, and the model was re-run. The reduction in hydraulic head due to the development of residential lands was predicted to be between 0.1-0.13 m in the aquifer at the municipal wells in the city core (Wells 3A, 4, 5, 7, 12, 17, and 18), and between 0.06 and 0.09 m for the other municipal wells (Wells 9, 13, 14, 11, 15, and 16). As this impact is far less than the seasonal fluctuations in the aquifer (1 to 2 m) it is considered immeasurable. Further, considering that the available drawdown at all wells is greater than 17 m, the reduction in recharge outside of the WHPA-Q1 was not considered significant (i.e., the potential drawdown from recharge reduction is < 1% of the available drawdown at each well). As such, the land use changes that lie outside the WHPA-Q1 area were not included in the WHPA-Q2 area; however, the potential impact of the land use changes that lie within the WHPA-Q1, or intersect it, were investigated further.

To investigate further the validity of including these areas, the recharge reduction in these areas was assessed separately to isolate individual contributions to the drawdown at the wells. The simulated drawdown impacts from individual area was found to be minor (i.e., < 0.03 m, which is far less than seasonal fluctuations). As a result, such drawdown is considered negligible and the WHPA Q2 is defined as the same area as the WHPA Q1; there are no planned land use developments that are expected to have a notable impact on the municipal well supply. Appendix E contains a memo summarizing the evaluation of drawdown induced by varying recharge on individual areas of land use change.

5.2.3 Local Area

With respect to groundwater wells, the Local Area is the combination of the following areas:

1. the cone of influence of the well



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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

WHPA-Q1

Date: 15 May 2013		Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1	

Figure 5.1

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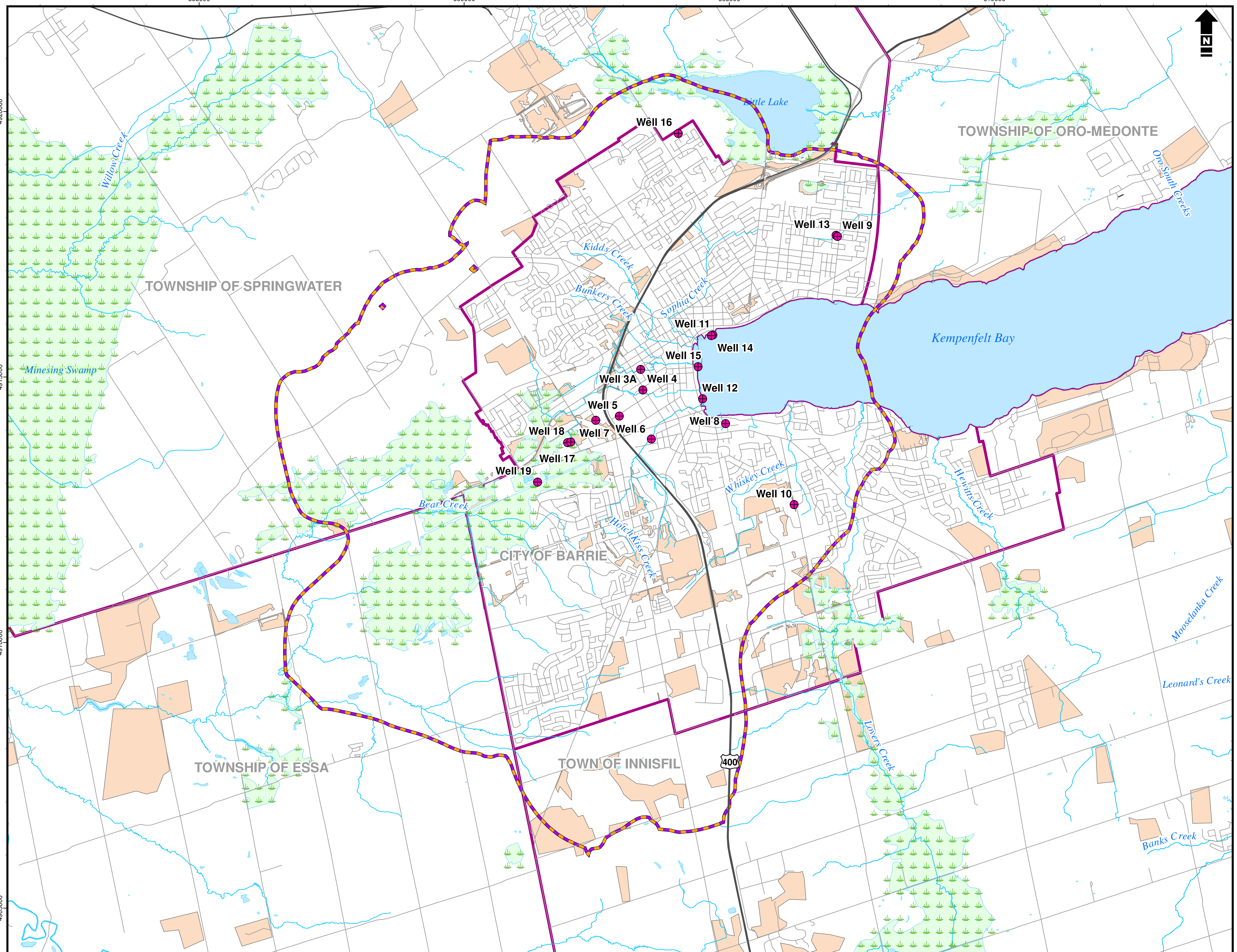

Legend

- Municipal Wells

Transportation Network

- Highways
- Roads

Drainage Network

- River / Stream
- Open Water
- Wetlands
- Municipal Boundaries
- WHPA-Q2/Local Area
- Groundwater Recharge Reduction Activity

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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

WHPA-Q2 and Local Area

Date: 15 May 2013	Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 5.2

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2. the cones of influence resulting from other water takings where those cones of influence intersect that of the well

3. the areas where a reduction in recharge would have a measurable impact on the cone of influence of the well

For one or more wells that draw water from an aquifer, the cone of influence is the projection to ground surface of the depression created in the water table or potentiometric surface when the wells are pumped at a rate equivalent to their allocated rates.

The Local Area for this study is illustrated on Figure 5.2. The Local Area is delineated by combining the cone of influence of the municipal supply wells (WHPA-Q1; Figure 5.1) and the areas where a reduction in recharge would have a measurable impact on the cone of influence of the wells (WHPA-Q2; Figure 5.2). For this study, the WHPA-Q1 and WHPA-Q2 are coincident.

5.3 Development of Risk Assessment Scenarios

Prior to completing the Local Area Risk Assessment, information needed to prepare the models for each of the scenarios was compiled as described in the following sections.

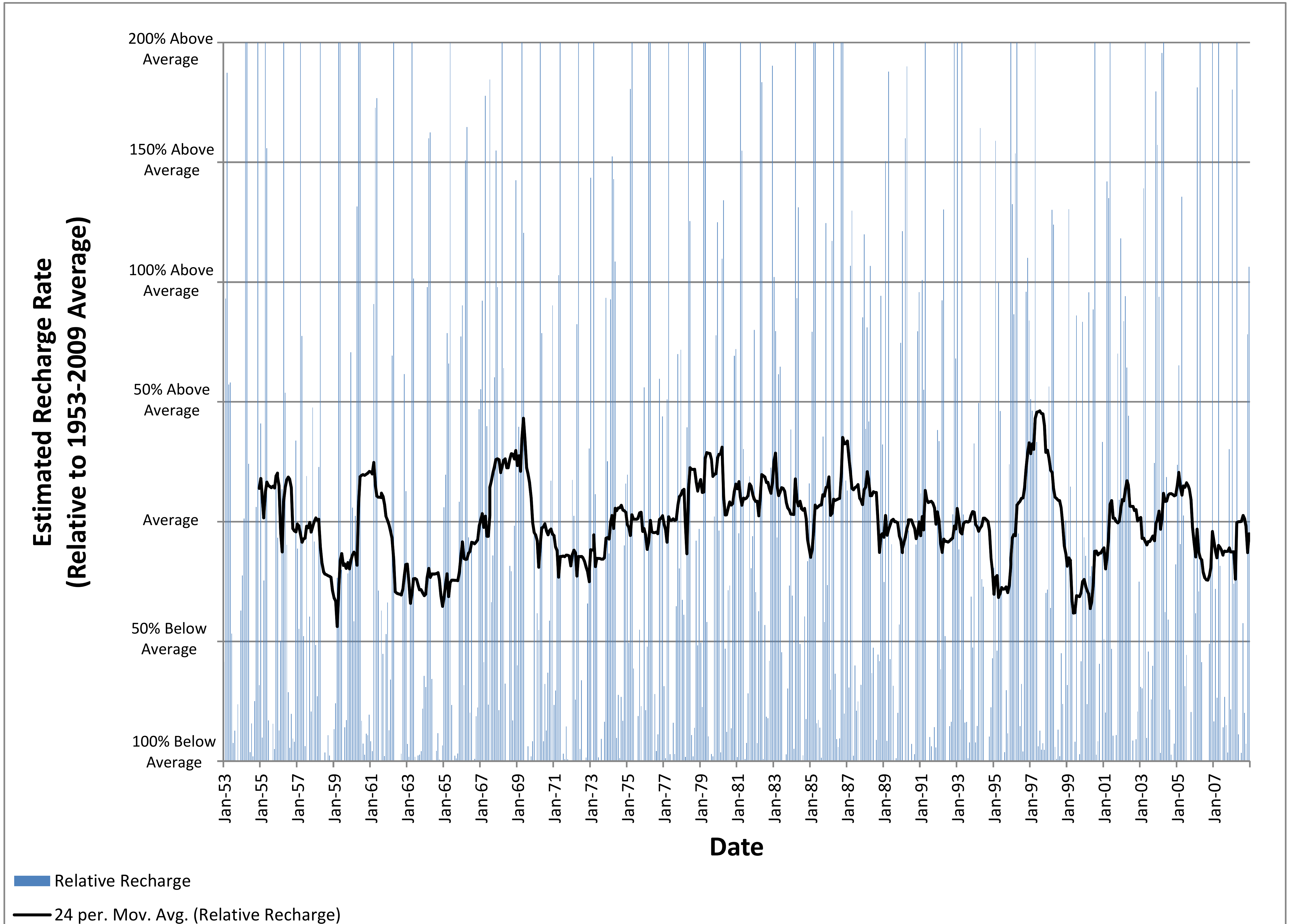
5.3.1 Scenario C – Existing Demand, Average Climate

Scenario C evaluates the ability for existing municipal water supply wells to maintain existing average annual pumping rates under average climate conditions. This scenario was simulated in steady state in the FEFLOW model using the estimated 2012 (Existing) pumping rates (Table 3.3) and the average annual groundwater recharge distribution from the calibrated MIKE SHE model (1953 to 2009 simulation – assumed to be representative in 2012).

The groundwater flow model was applied to predict groundwater levels in the aquifer at the municipal pumping wells, and to predict groundwater discharge rates under existing water demand and average climate conditions.

5.3.2 Scenario D – Existing Demand, Drought

Scenario D aims to evaluate whether each municipal well is able to pump at its allocated rate (Existing Demand – estimated for 2012) during a drought period. This scenario was simulated using the calibrated Tier Three groundwater flow model in time-marching (transient) mode for the period of 1953 to 2009. Average monthly recharge rates from the MIKE SHE model were applied in the groundwater flow model for the duration of the simulation (1953 to 2009), which included several drought periods (i.e., late 1960s and late 1990s droughts). Figure 5.3 illustrates the variability of average monthly groundwater recharge rates from 1953 to 2009 in the Study Area as estimated by the MIKE SHE model. This figure illustrates the average monthly recharge rates as a proportion of the long-term average recharge rate. Figure 5.3 also shows the 24-month moving average of the groundwater recharge rates, which illustrates



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Long Term Recharge Rate Estimate

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Technical: ccurry	Reviewer: MBester · Map Version: 1

Figure 5.3

that while the the drought of the late 1990s provides the lowest average recharge rates; the drought of the 1960s was a longer duration drought.

Average monthly pumping rates, as outlined in section 3.2 (see Table 3.3), were applied to simulate seasonal demand variability (variability based on 2007 trends). Transient well pumping rates for the Existing Conditions scenario vary from a low of approximately 55% of the average rate, to a high of about 140% of the average rate, with peak demand from June-September.

The Technical Rules refer to a 10-year period to define drought conditions for the scenarios. However, this assessment went beyond the requirements of the Technical Rules (MOE 2009) and examined two drought periods that occurred within the 56-year climate period examined (i.e., 1960s and 1990s). The transient model included the two drought periods, and periods where precipitation (and in turn recharge) were above normal.

As outlined in the Technical Rules (MOE 2009), the impacts of municipal pumping on other uses were not considered in this drought scenario. As a result, the main output parameters for this scenario are water levels at each of the municipal wells.

5.3.3 Scenario G – Existing Plus Committed Plus Planned Demand, Future Land Development, Average Climate

Scenario G evaluates the ability for existing and planned wells to maintain Existing plus Committed plus Planned pumping rates under average climate conditions and reductions in recharge. Pumping rates for this scenario are presented in Table 3.4. This scenario was simulated using the calibrated Tier Three groundwater flow model in steady state conditions using groundwater recharge rates that reflect long-term average (1953-2009) climate conditions. Scenario G is subdivided into three scenarios (G(1), G(2), and G(3)). The purpose of multiple scenarios is to isolate the impacts of municipal pumping from recharge reduction due to land developments. The G2 scenario, which independently evaluates municipal pumping changes, is the only scenario considered when evaluating the impact of the scenarios on wetlands and coldwater streams. The G3 scenario, which evaluates the independent impact of land use change, is not evaluated with respect to surface water features; identifying risks or threats to surface water systems based on land development was out of scope from the original intent of the Clean Water Act, and would be more appropriately addressed under the Planning Act. The Water Quantity Risk Assessment is only designed to identify a risk to a water source if land development has an impact on the water source supplying the well.

5.3.3.1 *Scenario G(1) – Cumulative Effects*

This scenario evaluated the cumulative impact of increased municipal pumping rates (Existing plus Committed plus Planned rates) and reductions in recharge (due to increases in imperviousness) due to planned land use changes defined in the Official Plans, on the municipal wells, and other uses. Table 3.4 lists the Existing plus Committed plus Planned water demands applied to evaluate this scenario.

Figure 2.6 illustrates the land areas where recharge was reduced in the models. Recharge reductions were assigned to these land areas according to Table 2.2.

5.3.3.2 *Scenario G(2) – Isolated Pumping Effect*

This scenario evaluated only the impact of increased municipal pumping rates (Existing plus Committed plus Planned rates) on the municipal wells and other water uses. The existing conditions land use was simulated in this scenario to isolate the influence of municipal pumping from land development. Only this scenario is considered when evaluating the impact on wetlands and coldwater streams. Baseflow reductions arising from land use development are independent from increased groundwater pumping, and only those impacts associated with groundwater pumping (e.g., Scenario G(2)) should be used to evaluate the Water Quantity Risk Level relating to the impact to other uses.

5.3.3.3 *Scenario G(3) - Isolated Recharge Effect*

This scenario evaluated only the impact of reductions in recharge (due to increases in imperviousness) due to planned land use changes defined in the Official Plans, on the municipal wells and other water uses. Existing municipal pumping rates were used in this scenario to isolate the influence of land development from Existing plus Committed plus Planned demand.

5.3.4 Scenario H - Existing Plus Committed Plus Planned Demand, Future Land Development, Drought Conditions

Scenario H evaluated the ability for existing wells to maintain allocated municipal pumping rates (Existing plus Committed plus Planned) through a drought period (same temporal period as Scenario D). The groundwater flow model was run transiently to examine the combined impact of drought conditions, land use development, and additional municipal pumping on water levels at the municipal wells. Impacts to other water uses are not considered in Scenario H.

Average monthly pumping rates, as outlined in section 3.2 (see Table 3.3), were applied to simulate seasonal demand variability (variability based on 2007 pumping). Transient well pumping rates for the Planned Demand Scenario vary from a low of approximately 60% of the average rate, to a high of about 135% of the average, with peak demand from June-September.

Similar to Scenario G, this scenario was subdivided into Scenario H(1), H(2) and H(3) to evaluate the relative contribution of municipal water takings and land use development at each municipal well under drought conditions.

5.3.4.1 *Scenario H(1) – Cumulative Effects*

This scenario evaluated the cumulative impact of increased municipal pumping rates (Existing plus Committed plus Planned rates), reductions in recharge (due to increases in imperviousness) due to planned land use developments defined in the Official Plans, and drought conditions on the municipal wells. As noted above, the impact was only evaluated at the municipal wells and not on other water uses.

5.3.4.2 *Scenario H(2)- Isolated Pumping Effect*

This scenario evaluated only the impact of increased municipal pumping rates (Existing plus Committed plus Planned rates) on the municipal wells during a drought period. The existing conditions land use was simulated in this scenario.

5.3.4.3 *Scenario H(3)- Isolated Recharge Effect*

This scenario evaluated the impact of reductions in recharge (due to increases in imperviousness) due to planned land use developments defined in the Official Plans and drought conditions on the municipal wells. As noted above, the impact was only evaluated at the municipal wells and not on other water uses.

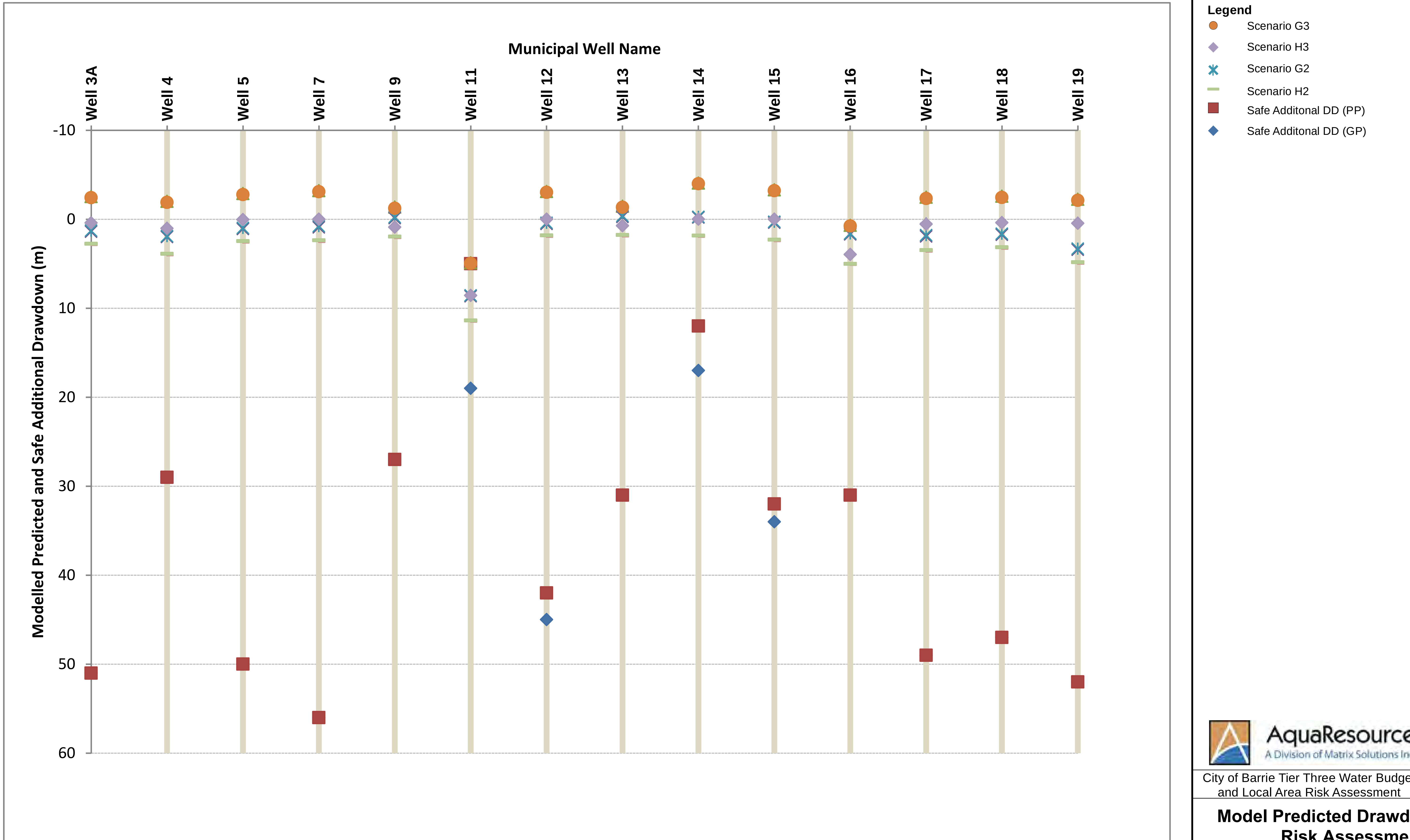
5.4 Model-Predicted Scenario Results

The model scenario results are evaluated with respect to both the estimated drawdown at each municipal well for all scenarios and the impact on groundwater discharge to coldwater streams and Provincially Significant Wetlands for steady state scenarios (C and G).

5.4.1 Drawdown

The drawdown under each of the Risk Assessment model scenarios was calculated and compared to the estimated safe additional drawdown at each municipal well or aquifer. The drawdown for each well is calculated relative to the 2010 conditions (pre-surface water intake). For the steady state models (Scenarios C, G(1), G(2) and G(3)), the difference between the water levels at the well during 2010 and those at the end of each model scenario were recorded as the model scenario drawdown (Table 5.3). For the transient scenarios, the lowest simulated water level elevation was compared to the water level during 2010 conditions and this value was recorded in Table 5.3. Simulations are compared to 2010 pumping conditions to facilitate direct comparison with the safe additional available drawdown values, which are based on the same period (Table 5.3). Comparing conditions prior to the surface water intake and scenarios representing existing 2012 (Scenario C and G) and allocated rates (Scenario D and H) yields negative drawdown, indicating a water table rise due to decreased groundwater demand. However, comparison of scenario drawdown to the safe available aquifer drawdown is appropriate even with negative numbers.

Wells that may not be able to sustain their allocated pumping rate are identified as those where the simulated drawdown is greater than the safe additional aquifer drawdown. Table 5.3 and Figure 5.4 summarize the predicted maximum drawdown for each municipal well under each of the Risk Assessment scenarios.



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Model Predicted Drawdown Risk Assessment

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Figure 5.4

5.4.1.1 *Scenario C*

Scenario C examines the predicted change in water level from before (2010) and after (2012) the start of the surface water intake, at each of the municipal wells under average climate and existing land use conditions. The effect of bringing the surface water intake on-line was a reduction in the groundwater demand; in most cases, this is also simulated to result in a water level rise (negative drawdown). The differences between simulated water levels of this scenario and of the 2010 pumping scenario were tabulated for comparison to the safe additional drawdown estimate at each municipal well (Table 5.3). Where the simulated drawdown is less than the available drawdown, there is low risk that the well would experience problems sustaining its allocated rate. As presented on Table 5.3, the drawdown at each municipal well is less than the estimated safe additional available drawdown for each well.

The model predicted drawdown in the production aquifer for Scenario C, relative to 2010 pumping is illustrated on Figure 5.5. Only the area around Well 16 is expected to experience a decrease in water levels (positive drawdown), while the remainder of the area is predicted to experience a water level rise (negative drawdown).

As such, the wells are predicted to be able to pump sustainably under the Existing Demand (neglecting uncertainty).

5.4.1.2 *Scenario D*

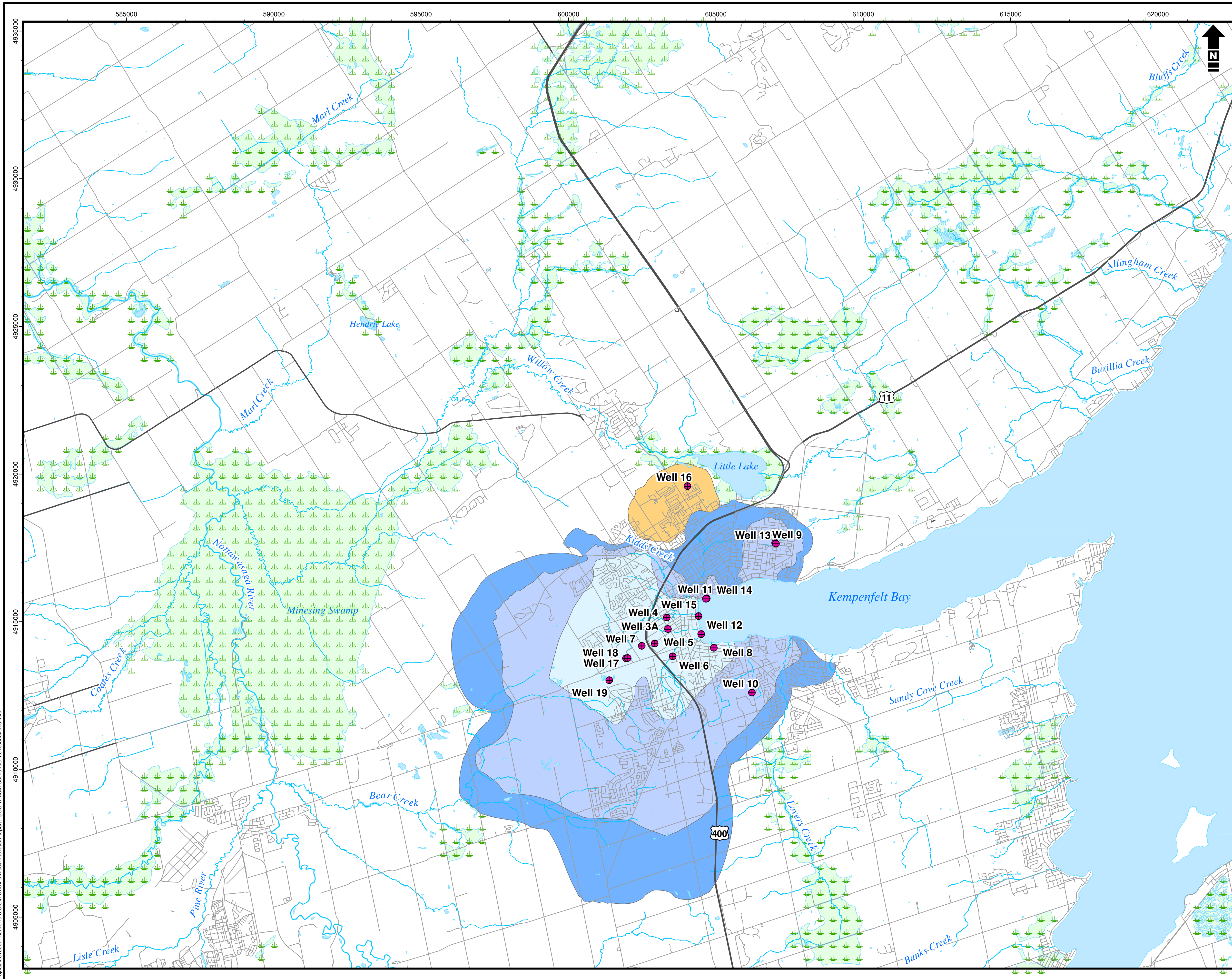
Scenario D examines the predicted water level fluctuations at each of the municipal wells through variable climatic conditions including short and longer term drought; existing land use and pumping conditions are assumed constant. The lowest water level predicted by the model during the scenario was recorded. The differences between the lowest predicted water level and the water level under 2010 pumping were tabulated and compared to the safe additional available drawdown estimated for each municipal well (Table 5.3).

As outlined in Table 5.3 the model predicted drawdown is less than the estimated safe additional drawdown for each of the wells. As such, the wells are predicted to maintain Existing Demand pumping throughout simulated drought periods (neglecting uncertainty); this prediction assumes normal well performance and existing land use.

As noted in Table 5.3, drawdown under this scenario does however have the potential to exceed the available drawdown at Well 11, if that well is experiencing diminished performance. Since rehabilitation is considered part of routine well maintenance, this condition does not present a risk; rather it highlights the requirement for regular well maintenance.

5.4.1.3 *Scenario G*

Table 5.3 contains the model simulated drawdown under Scenarios G(1), G(2) and G(3) for the municipal wells within their production aquifers. The model predicted drawdown arising from the increase in pumping and the reductions in recharge (Scenario G(1)) are less than the available drawdown for all



Legend
- Municipal Wells

Transportation Network
- Highways
- Roads

Drainage Network
- River / Stream
- Open Water
- Wetlands

Drawdown (m)
- -0.50 - -1.00 } Water Level Rise
- -1.00 - -2.00 } Water Level Rise
- -2.00 - -3.00 } Water Level Rise
- 0.25 - 0.50
- > 0.25

Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
Produced using information provided by the Ministry of Natural Resources,

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Drawdown Scenario C (relative to 2010 conditions)

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Figure 5.5

E:\Projects\2010007_BarrieTier3\GIS\ArcView\MXDs\AnnexationReport\Fig5.5_DrawdownScenarioC_2010conditions.mxd municipal wells. The model predicted drawdown in the production aquifer for Scenario G(1) is illustrated on Figure 5.6; note that this drawdown is relative to water levels from the pre-surface-water intake (2010) pumping conditions, and as such exhibits an area of water level rise (negative drawdown) around Wells 9 and 13.

Figure 5.7 illustrates the model predicted reduction in water levels within the production aquifer under Scenario G(3), reductions in recharge arising from land use development outlined in the Official Plans. The figure illustrates the reduction in water level relative to the pre-surface-water intake (2010) pumping conditions, and as such, there are some areas of water level rise (negative drawdown). In some areas, such as around Wells 9 and 13, water levels increase due to a decrease in pumping in Well 13, relative to 2010 conditions.

Under average climatic conditions, the model predicted drawdown is less than the safe additional drawdown for all wells. This suggests that if municipal pumping were to increase to Planned plus Committed plus Existing rates (Scenario G(2)), or reductions in recharge were to take place (Scenario G(3)), or both (Scenario G(1)) all municipal wells would be able to pump sustainably under average climatic conditions (neglecting uncertainty), assuming they are experiencing normal operating conditions (as opposed to wells experiencing diminished well performance).

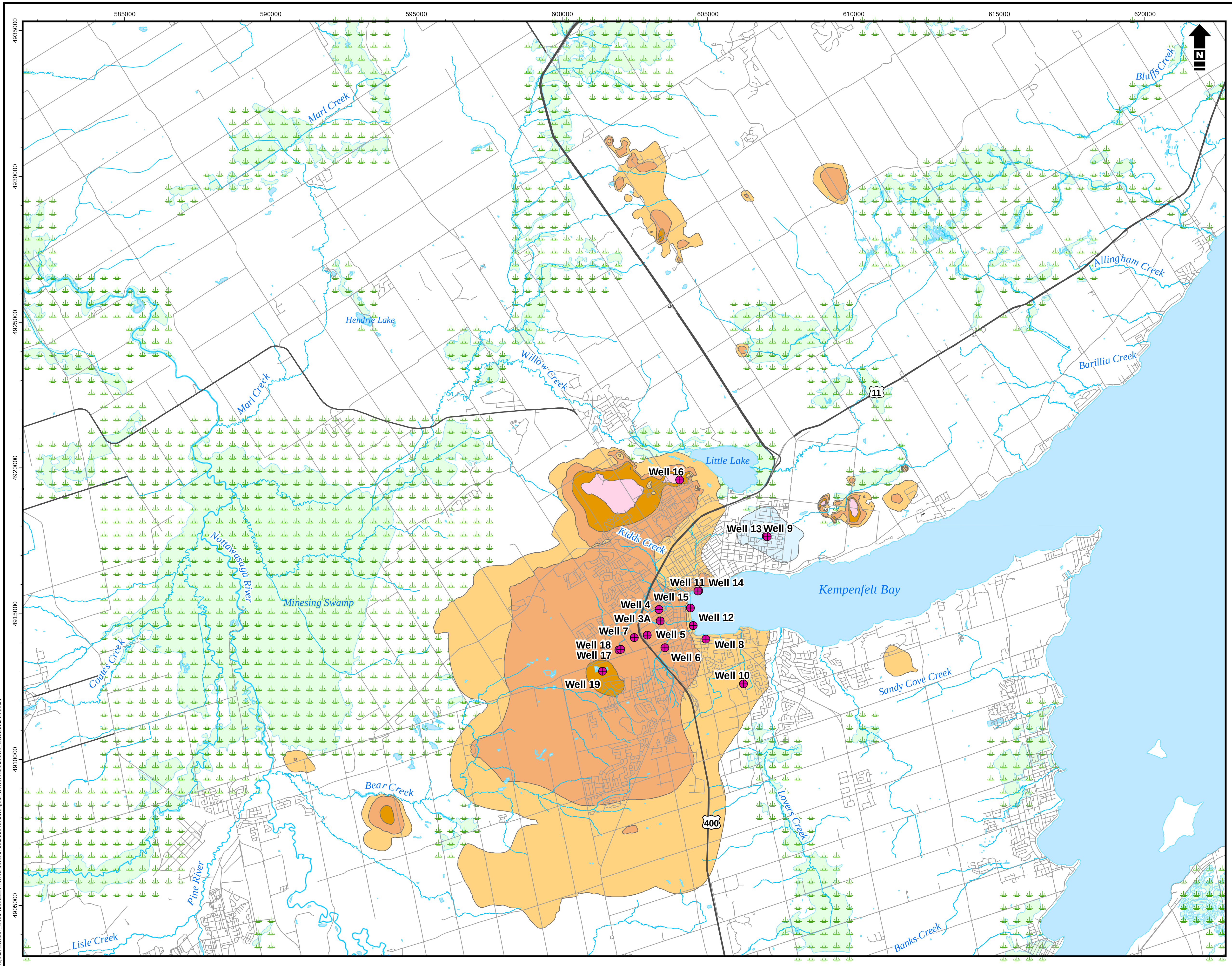
It should be noted that the effects of recharge reduction (Scenario G3) and increased pumping (Scenario G2), are additive and reflected in the cumulative scenario (G1). This is most readily evident if the drawdown is taken relative to the Existing Conditions (2012) scenario (C).

5.4.1.4 *Scenario H*

Scenario H examines the model predicted fluctuations in hydraulic head measurements for each of the municipal wells under drought conditions. Scenario H(1) evaluated the cumulative impact of allocated demand (existing, plus Committed plus Planned) and reductions in recharge, while Scenario H(2) only evaluated the allocated demand (increased pumping), and Scenario H(3) evaluated only the reductions in recharge.

The lowest hydraulic head (in the aquifer at each municipal well) predicted by the model during each of the model scenarios was recorded. The difference between this water level and the water level for each well under Scenario C were tabulated and compared to the safe additional drawdown estimated for each municipal well (Table 5.3).

As outlined in Table 5.3, the model predicted drawdown for each municipal well is less than the estimated safe additional drawdown for each of the wells. As such, the wells are predicted to be able to maintain allocated pumping rates throughout drought periods under normal well performance and planned land use changes (neglecting uncertainty).



Legend

- Municipal Wells

Transportation Network

- Highways
- Roads

Drainage Network

- River / Stream
- Open Water
- Wetlands

Drawdown (m)

- 0.00 - -0.50 Water Level Rise
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- >3.00

Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
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Drawdown Scenario G1 (relative to 2010 conditions)

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Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 5.6

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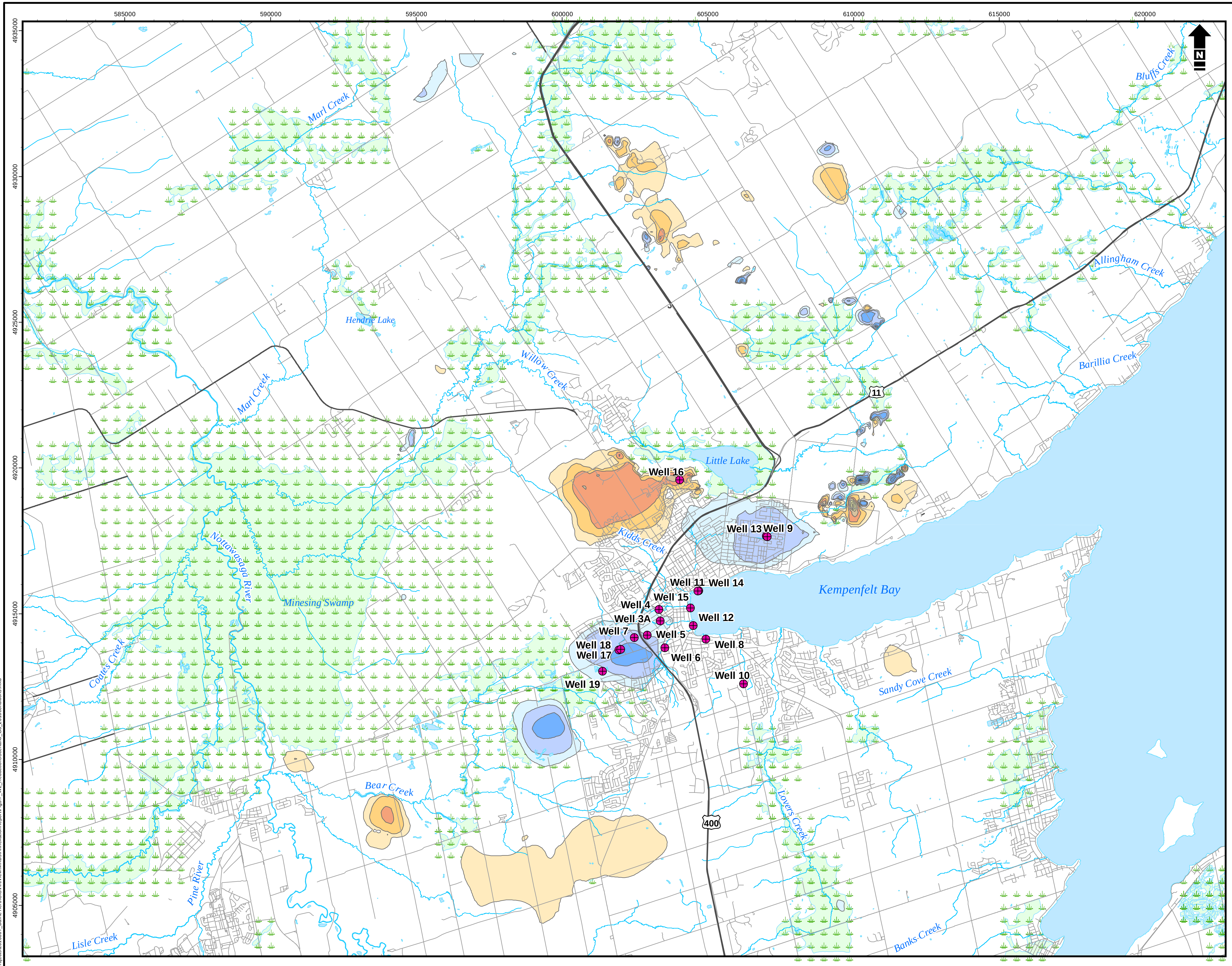

Legend

- Municipal Wells

Transportation Network

- Highways
- Roads

Drainage Network

- River / Stream
- Open Water
- Wetlands

G3 Water Level Reduction (m) (from 2010)

- < -3.00
- -3.00 - -2.00
- -2.00 - -1.00
- -1.00 - -0.50
- -0.50 - -0.25
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- 3.00 - 4.00
- > 4.00

Water Level Rise (< -3.00 to -0.50 - -0.25)

Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
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Water Level Reductions-Scenario G(3) (relative to 2010 conditions)

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Technical: ccurry	Reviewer: MBester		Map Version: 1

Figure 5.7

5.4.1.5 *Diminished Well Conditions, All Scenarios*

In the case of poor well performance, the predicted drawdown within all scenarios is within the tolerance of safe additional available drawdown with the exception of Well 11 (Table 5.3). In this case, poor well performance could lead to exceedance of the safe additional available drawdown criteria in the case of a drought (Scenarios D and H) or increased demand (Scenarios G1 and G2) or both. Only the drawdown during Existing conditions (Scenario C) is within the safe additional available drawdown threshold for Well 11.

The safe additional available drawdown threshold for Well 11 under diminished well performance represents a worst case scenario in which the well performance is decreasing in efficiency due to clogging of the well screen and adjacent aquifer materials. In this case, the additional safe drawdown is the difference between the typical pumped water level immediately before Well 11 would be rehabilitated and the top of the well screen. Historically, when the pumped water level reaches this level, which is just slightly above the pump setting, the well has been taken offline and rehabilitated, while other wells in the system have compensated for this loss of supply by marginal increases in their pumping rates distributed among the remainder of the wells. For example, the well was offline for most of 2010 and 2011 for rehabilitation. Since rehabilitation is considered part of routine well maintenance, this condition does not present a risk; rather it highlights the requirement for regular well maintenance. Further, this well has been successfully rehabilitated in the past, and the system has been proven to be able to temporarily pump the total volumes necessary without this well.

TABLE 5.3 Risk Assessment Drawdown Results

Well Name	Safe Additional Available Drawdown (2010) Pre- Surface Water Intake	Safe Additional Available Drawdown (2010) Diminished Well Conditions	Average Climate (Steady State) Drawdown (m)				Drought (Transient) Maximum Drawdown (m)			
			C[1]	G(1)	G(2)	G(3)	D	H(1)	H(2)	H(3)
			Existing Demand (2012)- Post Surface Water Intake	Recharge Reduction, Increased Demand	Increased Demand	Recharge Reduction	Existing Demand / Recharge, Post-SW Intake	Recharge Reduction, Increased Demand	Increased Demand	Recharge Reduction
Well 3A	51	51	-2.5	1.4	1.3	-2.4	0.4	2.8	2.7	0.4
Well 4	29	29	-2.0	2.0	1.9	-1.9	1.0	4.0	3.9	1.0
Well 5	50	50	-2.9	1.1	1.0	-2.8	0.0	2.5	2.5	0.0
Well 7	56	56	-3.2	0.9	0.8	-3.1	0.0	2.4	2.4	0.0
Well 9	27	27	-1.4	-0.1	-0.2	-1.2	0.8	2.0	1.9	0.9
Well 11	19*	5*	4.9	8.6	8.6	5.0	8.5	11.4	11.4	8.6
Well 12	45	42*	-3.1	0.5	0.4	-3.0	0.0	1.9	1.8	0.0
Well 13	31	31	-1.5	-0.3	-0.4	-1.3	0.7	1.8	1.8	0.7
Well 14	17*	12*	-4.1	-0.2	-0.3	-4.0	0.0	1.9	1.8	0.0
Well 15	34*	32*	-3.3	0.4	0.3	-3.2	0.0	2.4	2.3	0.0
Well 16	31	31	0.7	1.7	1.6	0.8	3.9	5.0	5.0	3.9
Well 17	49	49	-2.5	1.9	1.8	-2.3	0.5	3.5	3.5	0.5
Well 18	47	47	-2.6	1.7	1.6	-2.5	0.3	3.2	3.2	0.4
Well 19	52	52	-2.2	3.4	3.3	-2.1	0.4	4.9	4.8	0.5

(light blue)	Pumped drawdown close to, or greater than, the safe additional available drawdown under diminished well conditions
(dark red)	Pumped drawdown close to, or greater than, the safe additional available drawdown under normal operating well conditions
*	Additional drawdown available is calculated using the water levels within the well (Criteria 2 in Section 3.3.1) rather than aquifer
1	Existing Demand included here to compare expected drawdown conditions post-surface water intake with those prior to the surface water intake (2010). This is important as the safe additional available drawdown is representative of conditions prior to the surface water intake. The safe available additional drawdown post surface water intake would be safe additional drawdown in 2010 plus the simulated water level rise post-surface water intake (e.g., SAAD for Well 3A post 2012 would be 51+2.5 = 53.5m).

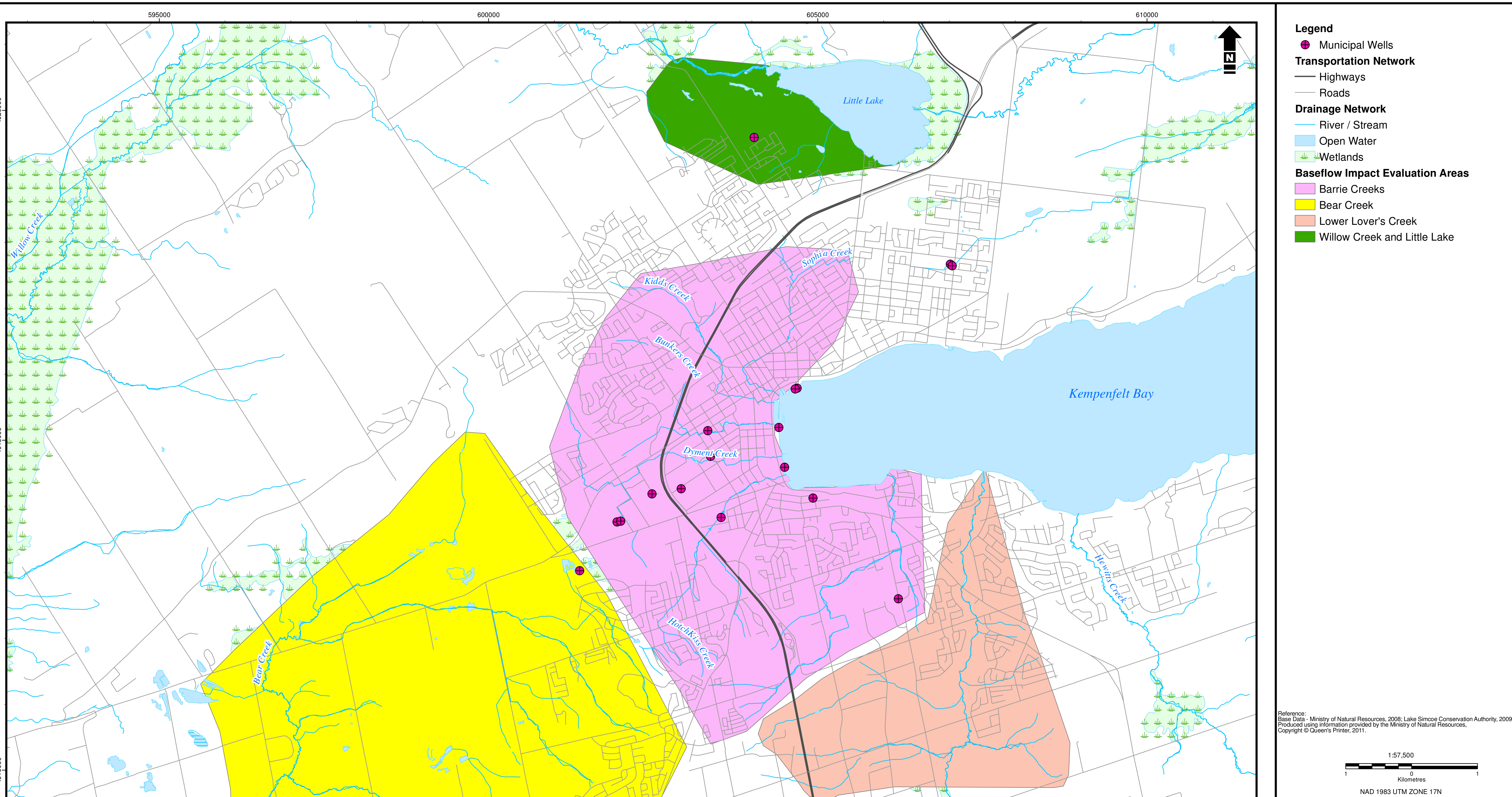
5.4.2 Impacts to Groundwater Discharge

The simulated impact on groundwater discharge to rivers, streams and wetlands of interest within the WHPA Q1 was assessed for Scenarios C, G(1), G(2) and G(3) by comparing the simulated groundwater discharge to the groundwater discharge simulated under 2010 Pumping Conditions. Figure 5.8 delineates the areas within the model where impacts to groundwater discharge were assessed under each model scenario. The impacts of enhanced groundwater recharge from individual septic systems and/or leaky municipal infrastructure (sanitary, storm or pressure mains) within and surrounding Barrie were not simulated in the groundwater flow model. This enhanced recharge may increase groundwater discharge to some local streams and wetlands, and may offset some baseflow reductions predicted to occur with future increased pumping or groundwater recharge reduction activities.

The Barrie Creeks (Sophia, Hotchkiss, Dyments, Kidds, Bunkers and Whiskey) were combined for this assessment due to several reasons. First, the local details of these creeks in terms of groundwater/surface water interaction are not well characterized – stretches of several of the creeks have both warm and cold classifications, however there is limited characterization data to represent such changes in conditions at such a fine scale. Secondly, the total baseflow for each creek is so small that error arising due to the rounding of the sums would be large in proportion to the baseflow amount. Lastly, some stretches of the streams are in urban concrete-lined channels running through the downtown city core, and the locations where streams can discharge or recharge into the groundwater system are not well characterized. For these reasons, it is appropriate to group the streams as one entity, noting that the important focus is to calculate the total combined effect on these streams which are in close proximity to each other.

The modelled average annual groundwater discharge to each reach is contained in Table 5.4 and also plotted on Figure 5.9. Table 5.4 contains the simulated values for each of the following scenarios; pre-surface-water-intake demand (2010), Existing Demand (post surface-water intake), and the G (1,2,3) planned system scenarios. The percentage reduction in groundwater discharge, as compared to 2010 Conditions is also contained in this table. Note this value is a cumulative impact for comparison to conditions prior to the surface water intake being brought on-line; for incremental percent changes, you must subtract the values between the simulations.

Figure 5.9 also plots the groundwater discharge rate calculated for each scenario. This figure indicates that reductions in baseflow were experienced under each of the Scenarios, with the greatest impacts to baseflow occurring in Scenario G(1) (reductions in recharge and increases in municipal pumping to Existing plus Committed plus Planned rates).



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Model Simulated Baseflow Impact Areas

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Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 5.8

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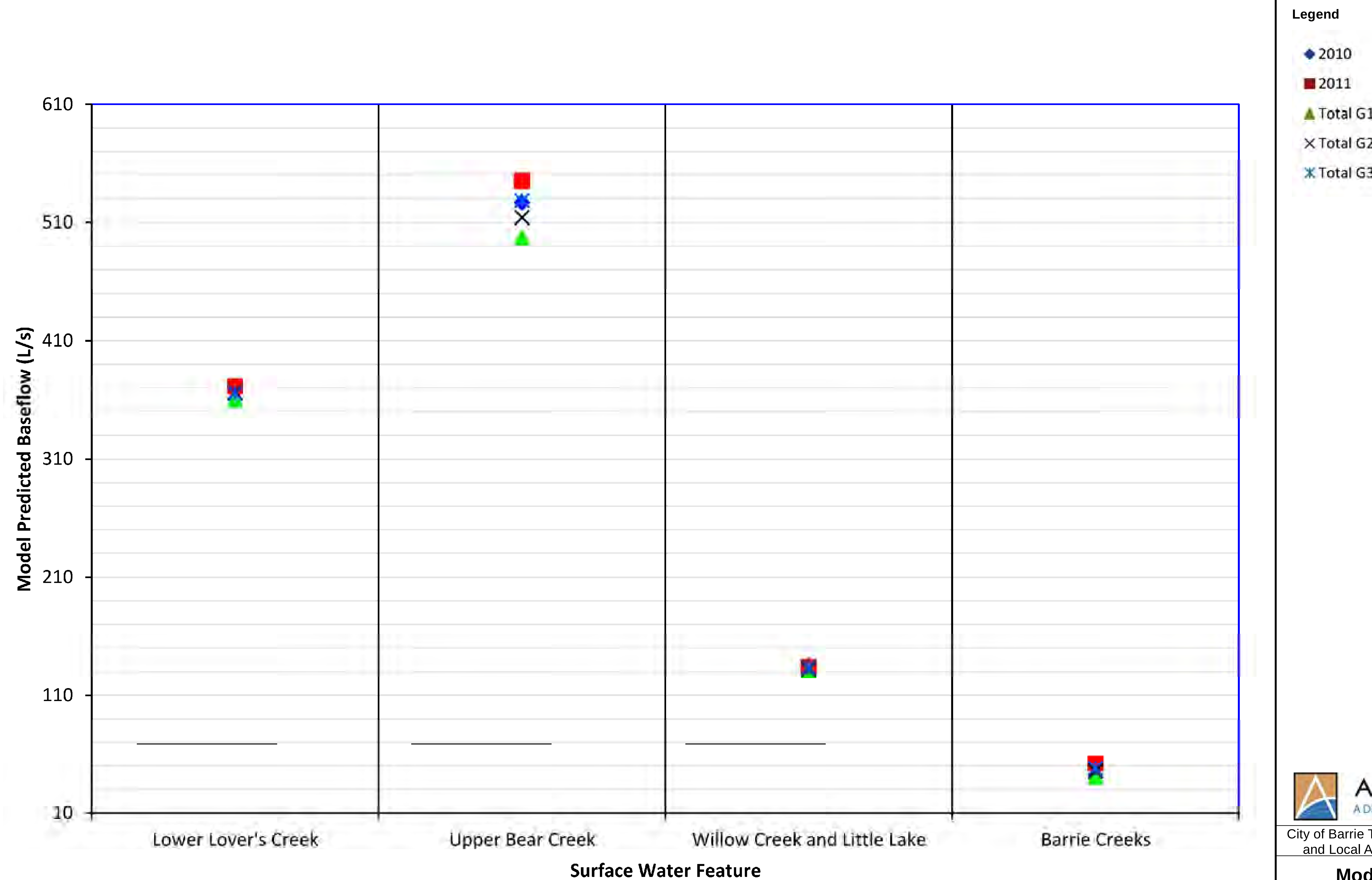

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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Model Simulated Baseflow

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Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 5.9

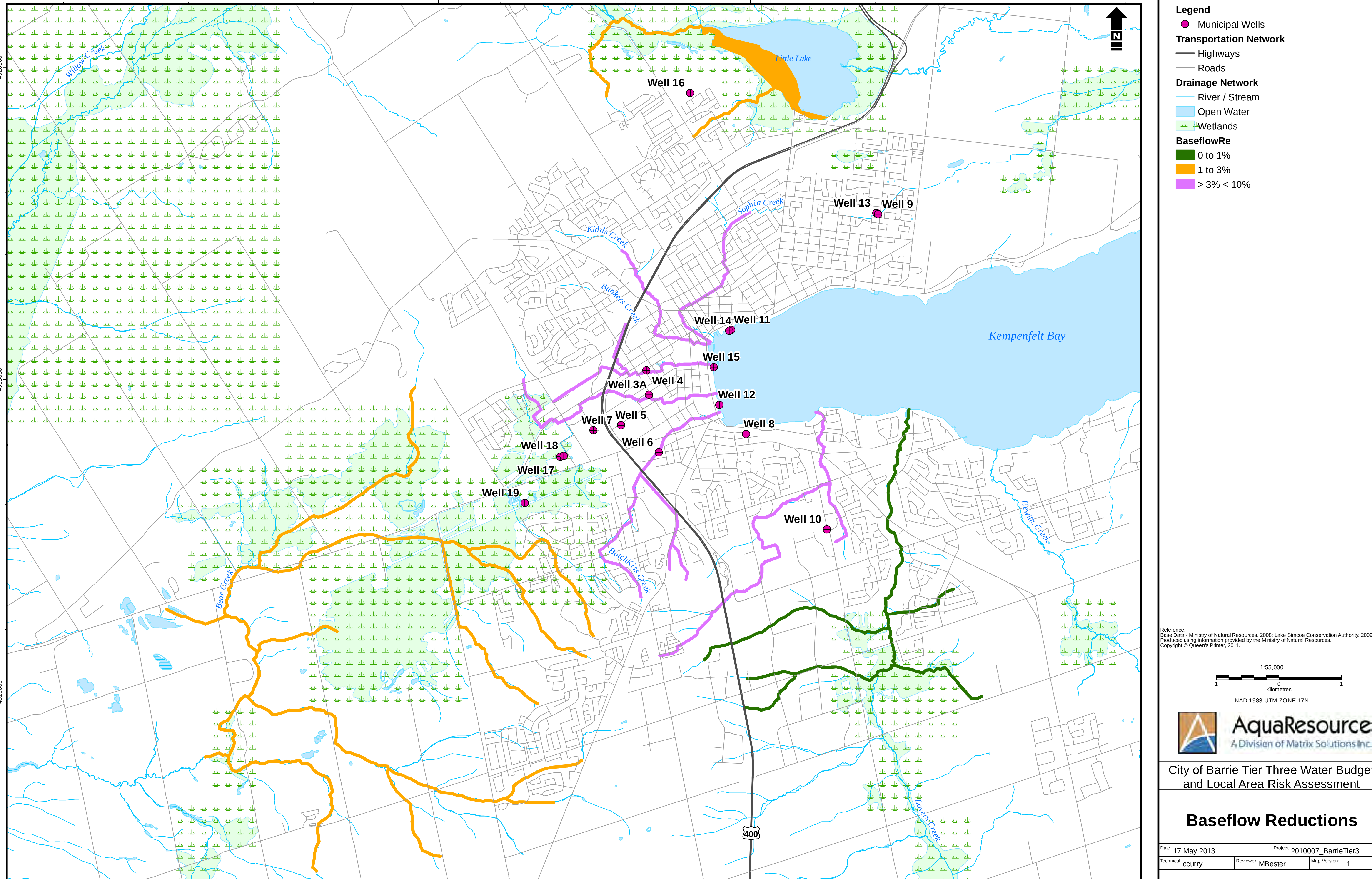
TABLE 5.4 Impacts to Groundwater Discharge[1] – Scenarios C and G

Stream/ Reach	Pre Surface Water Intake Demand	Scenario C – Existing Demand (Post SW Intake)		Scenario G(1)		Scenario G(2)		Scenario G(3)	
	2010			(Increased Demand and Recharge Reduction)		(Increased Demand)		(Recharge Reduction)	
	GW Discharge (L/s)	GW Discharge (L/s)	Percent Reduction (%)	GW Discharge (L/s)	Percent Reduction (%)	GW Discharge (L/s)	Percent Reduction (%)	GW Discharge (L/s)	Percent Reduction (%)
Upper Bear Creek	992	1007	Increase	971	2%	982	1%	996	Increase
Lower Lover's Creek	669	672	Increase	656	2%	667	0%	661	1%
Willow Creek and Little Lake	626	626	No Change	617	1%	623	<1%	619	1%
Barrie Creeks	62	65	Increase	57	8%	60	3%	62	No Change

[1] Impacts to groundwater discharge are presented relative to conditions prior to commencement of pumping from the surface water intake (e.g., 2010 conditions)

While Table 5.4 summarizes baseflow impacts for Scenarios G(1), G(2) and G(3), the Tier Three Assessment only considers baseflow impacts associated with Scenario G(2) when evaluating the Risk Level placed on the Local Areas. This is due to the fact that baseflow reductions arising from land use development are independent from increased groundwater pumping, and only those impacts associated with groundwater pumping (e.g., Scenario G(2)) should be used to evaluate Water Quantity Risk Level.

Figure 5.10 illustrates the model simulated reduction in groundwater discharge relative to 2010 conditions for Scenario G(2). Figure 5.11 illustrates the water table reduction predicted under Scenario G(2) as compared to the water table predicted under 2010 conditions. The increase in municipal pumping to the Existing plus Committed plus Planned rates is predicted to cause a water table reduction greater than 1 m in the area surrounding Barrie Wells 18 and 19, with lesser impacts in the surrounding areas. Reductions of up to 0.5 m are expected beneath some of the wetlands associated with the Bear Creek Wetland, however discharge conditions to the wetland are predicted to be maintained in all scenarios (as a result, the wetland function would be maintained). It should be noted that the water table elevations in this model represents the saturated water table (as opposed to any perched systems) within the top Aquifer (A1), which may be confined in some places. Therefore, Figure 5.12 has been included to illustrate the modelled extents of the riparian wetlands relative to 2010, as this reflects a better measure of the actual impact as it relates to wetland features. These modelled extents represent areas in the model that have simulated hydraulic heads above ground surface, which ultimately discharge to the surface water boundary condition that they are associated with. In all cases, the



Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
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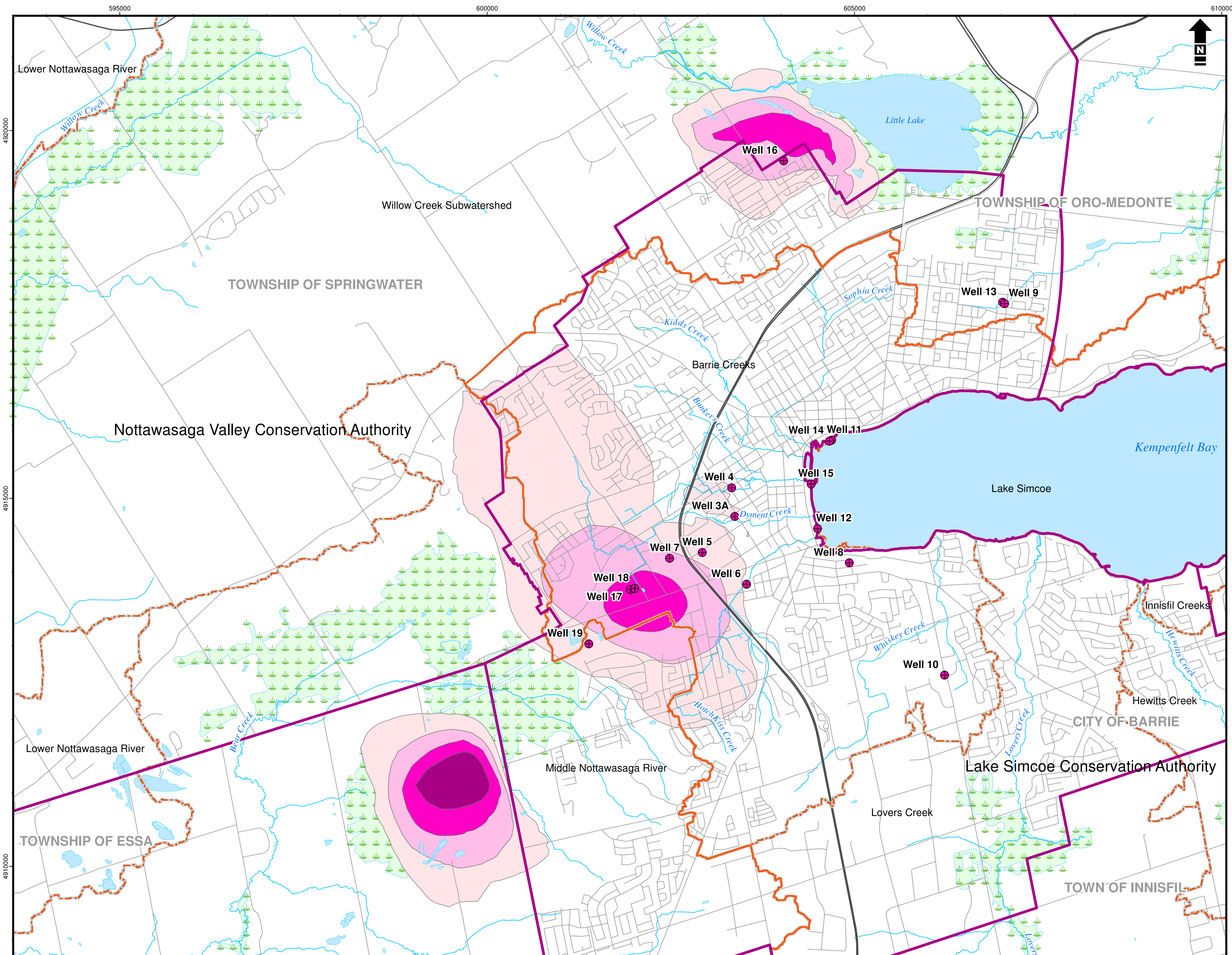
City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Baseflow Reductions

Date: 17 May 2013	Project: 2010007_BarrieTier3

Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 5.10



Legend

- Municipal Wells

Transportation Network

- Highways
- Roads

Drainage Network

- River / Stream
- Open Water
- Wetlands

Boundaries

- Barrie Tier 3 Boundary
- Municipal Boundaries
- Conservation Authority
- NVCA and LSRCA Subwatersheds

Water Table Drawdown (m)

- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- > 1.00

Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Water Table Reduction (Scenario G2)

Date: 15 May 2013 | Project: 2010007_BarrieTier3
Technical: ccurry | Reviewer: MBester | Map Version: 1

Figure 5.11

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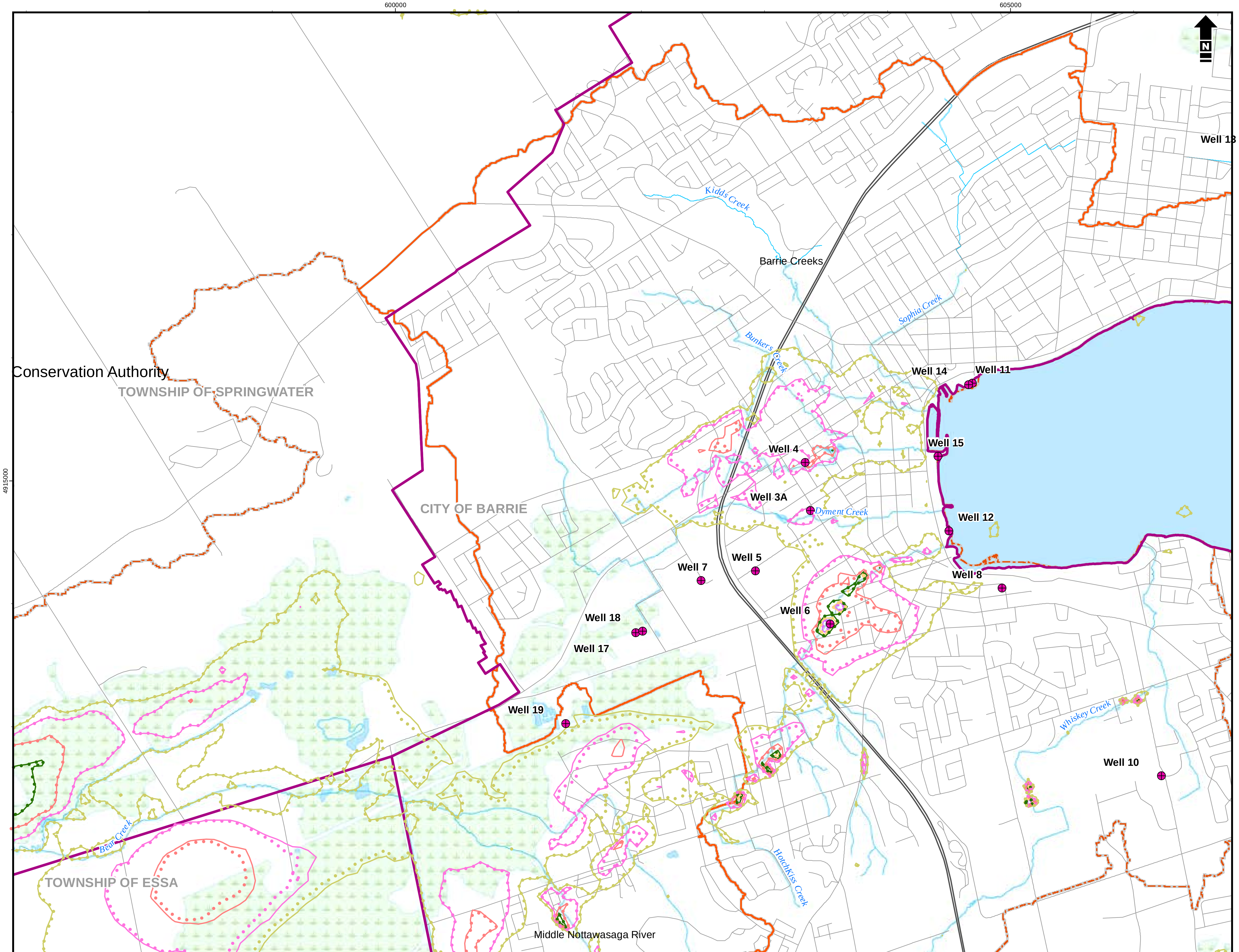

Legend

- Municipal Wells

Hydraulic Head Above Ground Surface (2010) (m)

- -10
- -8
- -6
- -4
- -2
- 0

Hydraulic Head Above Ground Surface (G2) (m)

- -10
- -8
- -6
- -4
- -2
- 0

Transportation Network

- Highways
- Roads

Drainage Network

- River / Stream
- Open Water
- Wetlands

Boundaries

- Barrie Tier 3 Boundary
- Municipal Boundaries
- Conservation Authority
- NVCA and LSRCA Subwatersheds

Reference:
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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Areas of Expected Groundwater Discharge

Date: 17 May 2013	Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 5.12

E:\Projects\2010007_BarrieTier3\GIS\ArcView\MXDs\AnnexationReport\Fig5-12_Areas_of_Expected_Groundwater_Discharge.mxd discharge function to the wetlands is simulated to be maintained; as such, there is no additional risk associated with impacts on these wetlands.

When completing the Local Area Risk Assessment, any baseflow reductions to coldwater streams between 10% and 20% will result in a Water Quantity Risk Level classification of Moderate for the Local Area (MNR and MOE 2011). Baseflow reductions greater than 20% will result in a Water Quantity Risk Level of Significant (MNR and MOE 2011). As highlighted in Table 5.4, simulated groundwater discharge reductions all of the streams for the G(2) scenario is 3% or less.

The potential baseflow reductions associated with recharge reductions are minor (less than 2%). The model scenarios did not consider the influence of stormwater best management practices, and groundwater recharge was reduced proportionally to the imperviousness assumed for areas where land use changes might occur. While these scenarios are conservative, they indicate where groundwater discharge is slightly sensitive to increased pumping, but not sensitive to land use development alone.

The baseflow reduction results for Bear Creek agree with earlier assessments that Bear Creek is essentially isolated from the lower aquifer and would not be impacted by increased pumping nearby. This conclusion was based on the hydrogeologic setting, which shows separation of the surficial features by a consistent clay-rich confining unit in this area. The results of a pumping test (IWS 2009), which showed no response in the surficial aquifer water levels, and a creek bed piezometer in Bear Creek showed a significant separation of water levels between the surficial aquifer/surface water system and the lower aquifer, A3 (IWS 2008) confirm this conclusion as well. Earlier modelling of the area has shown a 4% decrease of baseflow to Bear Creek; however, this was experienced with a combined pumping rate for wells 17 and 18 (which are the closest to Bear Creek) that is more than twice the operational rate that was used in this Assessment.

5.5 Uncertainty Analysis of Scenarios

The structure, input parameters, and calibration of the groundwater flow model applied in the Risk Assessment are documented in the Numerical Model Development Report (Appendix C). The representation of the groundwater flow system was manually calibrated to available hydraulic head data and baseflow measurements using a set of parameters (e.g., recharge and hydraulic conductivity) that are consistent with the conceptual model; however, this set of parameters is non-unique, as discussed in Appendix C, and other parameter sets may produce an equally well-calibrated model.

This section presents an uncertainty analysis, which completes the following:

1. Determine which parameters could be adjusted and still be considered to be acceptably calibrated.
2. Create multiple sets of model input files each containing different combinations of suitable model parameters that are considered to be acceptably calibrated.
3. Evaluate a scenario for each of the model input files and predict the result in terms of water level drawdown and baseflow reduction. From these results, it is possible to estimate conservatively, if

the water level or groundwater discharge reduction criteria will be violated (or satisfied) by the model.

5.5.1 Uncertainty/Data Gap Analysis Results

The base case model presented in Appendix C is one realization of a set of parameters that produced a calibrated model. The model and the input parameters are a generalized representation of a complex hydrogeological system, and the assumptions used to generalize the model have associated uncertainty. Throughout the calibration process, parameter combinations that had little impact on the model calibration were noted. This type of parameter insensitivity can lead to uncertainty in model predictions; such parameters were examined through this uncertainty assessment.

Care was taken throughout calibration to distinguish between 1) field-verified high quality observations and testing; 2) zones where this information was absent; and 3) areas where potential parameter ranges discovered through calibration did not agree with observed properties. In the last case, these areas are rare within the Barrie core and in most cases, implementing the conductivities and observing gradients found through various hydraulic testing of the municipal wells resulted in a very good match with observed water levels in high quality wells.

Capitalizing on the experienced gained throughout the calibration of the groundwater model, as well as knowledge of present day data gaps, it was determined that the most significant, uncertain parameters (for both additional drawdown and baseflow reduction) are the high permeability “windows” within the confining aquitards that overlie and protect the municipal aquifer. These aquitards separate the deep system and shallow system; however, the degree of connectivity between the two is uncertain in some areas. These areas include: the aquitard window to the west of Barrie Well 6 (now out of service due to water quality issues); the aquitard window over Barrie Wells 9 and 13 (documented by pumping test results which imply that the aquifer has some connectivity to the surface); a zone south west of Well 19 beneath the Bear Creek wetland and the connectivity of Kempenfelt Bay with the deep aquifer. For example, it was found that simultaneously, decreasing the conductivity of one window while increasing the conductivity of the other would result in similar average water level results. Baseflow to the nearby streams, however, varied significantly with these changes, and without year round baseflow monitoring of these streams, a base case model (Appendix C) was achieved through professional judgement and local knowledge of stream flow, rather than a hard calibration target. However, alternative conceptual models are also feasible, as there is a possibility that the streams receive discharge from nearby perched systems, which are not explicitly represented in the model, and whose contributions to the streams are not well known.

Because baseflow to the creeks is uncertain, a “worst case” scenario was chosen in which the permeability of the aquitard windows overlying the municipal wells was increased as much as possible (up to four orders of magnitude) while maintaining calibrated water levels. To account for the change, the permeability of the C2 aquitard, directly underlying Kempenfelt Bay, was decreased by one to three orders of magnitude. The results of this scenario are conservative in that the connection of the municipal production aquifer to the surface is high, and the opportunity for the aquifer to be replenished via a deep connection with Kempenfelt Bay is low which would result in a more pronounced impact on both baseflow and water levels throughout the scenarios. The data gap below Bear Creek was not adjusted within this alternative conceptual model, as the aquitard "window" is already present in the base case model.

5.5.1.1 *Model Predictions- Hydraulic Heads*

The municipal pumping rates in the conservative "worst case" model were updated to the Existing plus Committed plus Planned rates to represent the conditions in Scenario G(2). The model was run and the output was compiled to provide insight into how the uncertainty associated with the model input parameters may affect the model predictions. The initial objective was to identify if these conditions would cause the hydraulic head in the aquifer at the municipal well to violate the safe additional drawdown at the well. Table 5.5 outlines the results of these simulations. As outlined In Table 5.5, most of the model predicted drawdown at the wells does not exceed the safe additional drawdown levels. Well 11 is the only well that exceeds the additional aquifer drawdown, and only under diminished well conditions. These results are consistent with the results of the base case model scenario where the model-simulated drawdown exceeded the safe additional available drawdown for that well.

TABLE 5.5 Data Gap/Uncertainty Alternative Calibration Model Drawdown Results

Well Name	Safe Additional Available Drawdown (2010)	Safe Additional Available Drawdown (2010) Diminished Well Conditions	FEFLOW Groundwater Model Scenario Drawdown (m)							
			Average Climate				Drought			
			C Existing Demand	G (1) Recharge Reduction, Increased Demand	G (2) Increased Demand	G (3) Recharge Reduction	D Existing Recharge, Demand	H (1) Recharge Reduction, Increased Demand	H (2) Increased Demand	H (3) Recharge Reduction
Well 3A	51	51	-3.8	1.9	1.7	-3.6	0.0	3.3	3.3	0.0
Well 4	29	29	-3.2	2.5	2.3	-3.1	0.6	4.5	4.4	0.4
Well 5	50	50	-4.1	1.6	1.4	-3.9	0.0	3.0	2.9	0.0
Well 7	56	56	-4.4	1.4	1.2	-4.2	0.0	2.9	2.8	0.0
Well 9	27	27	-1.3	-0.1	-0.3	-1.2	0.8	2.0	2.0	0.7
Well 11	19*	5*	4.2	9.1	9.0	4.3	8.4	12.0	12.0	7.4
Well 12	45	42*	-4.5	1.0	0.9	-4.4	0.0	2.5	2.4	0.0
Well 13	31	31	-1.4	-0.3	-0.4	-1.3	0.7	1.9	1.8	0.6
Well 14	17*	12*	-4.8	0.3	0.2	-4.7	0.0	2.5	2.4	0.0
Well 15	34*	32*	-4.7	0.9	0.7	-4.5	0.0	3.0	2.9	0.0
Well 16	31	31	0.7	1.7	1.6	0.8	4.0	5.1	5.1	3.9
Well 17	49	49	-3.6	2.4	2.2	-3.5	0.1	4.0	3.9	0.0
Well 18	47	47	-3.7	2.2	2.1	-3.6	0.0	3.7	3.6	0.0
Well 19	52	52	-3.4	4.0	3.8	-3.2	0.0	5.3	5.2	0.0
(light blue)	Pumped drawdown close to, or greater than, the safe additional available drawdown under diminished well conditions									
(dark red)	Pumped drawdown close to, or greater than, the safe additional available drawdown under normal operating well conditions									
*	Additional drawdown available is calculated using the water levels within the well (Criteria 2 in Section 3.3.1) rather than aquifer									

5.6 Local Area Risk Assessment Results

The Local Area for the City of Barrie is illustrated on Figure 5.2. The Water Quantity Risk Level classification is made to the Local Area based on the ability to meet peak demand ("Tolerance") as well as the results of the scenarios listed above (Risk Level).

5.6.1 Tolerance

Municipalities typically implement physical solutions (e.g., storage reservoirs, peaking / backup wells) and water conservation measures to reduce the amount of instantaneous water demand required from a primary drinking water source. These types of measures are implemented to increase a municipality's "tolerance" to short-term water shortages. Tolerance effectively reduces the potential that a municipality will face short or long term water quantity shortages. A municipality's existing water supply system may be designed such that the wells or intakes alone cannot meet peak water demands, but existing storage systems are in place for this purpose.

The Technical Rules (Part IX.1) specify that if the municipality's system is able to meet existing peak demands, the tolerance level for the existing system is assigned as high; otherwise, the tolerance is low. Since the City of Barrie has never experienced water shortage issues, has a redundancy of supply (multiple wells) with a capacity that exceeds demand, and has existing storage systems (two reservoirs and three elevated tanks) in place to meet peak demand, the tolerance of the Barrie systems is high. The recent addition of the surface water intake from Kempenfelt Bay adds significant tolerance to the water supply.

5.6.2 Risk Level Circumstances

If any of the following circumstances is present, the Local Area is assigned a Significant Risk Level:

- The Existing or Planned System wells are not able to meet their Existing, or Existing plus Committed plus Planned demands, determined when the drawdown at a municipal well exceeds the safe additional drawdown.

- The Tolerance is "Low" and the drinking water system is not able to meet peak water demands in drought scenario. This may identified where an existing municipal system has had historical issues meeting peak demands.

- The municipal demands result in measurable and unacceptable impacts to other uses in Scenario G. For coldwater streams, an unacceptable impact is defined by a circumstance where groundwater discharge is reduced by more than 20% of existing monthly baseflow (MNR and MOE 2011). Baseflow would be defined as the monthly Qp80 (the flow that is exceeded 80 percent of the time) or by another method. In situations where another threshold has been defined, that threshold would be used to identify a Significant Risk Level (MNR and MOE 2011).

The Local Area for a groundwater system is assigned a Moderate Risk Level if municipal pumping in Scenario G results in measurable and potentially unacceptable impacts to other uses. For coldwater streams, this circumstance occurs when groundwater discharge is reduced between a minimum of 10% but not greater than 20% of existing monthly baseflow.

The Technical Bulletin: Part IX Local Area Risk Level (Appendix; MOE and MNR 2010) lists a series of circumstances, where if one of these circumstances is present, the Local Area is assigned a Significant Risk Level classification. These circumstances are summarized below in Table 5.6.

TABLE 5.6 Risk Assessment; Significant Risk Level Circumstances

Scenario	Circumstances	Results
Planned or Existing plus Committed System with future land use and average annual climate (G) or 10-year drought (H)	The quantity of water that can be taken from groundwater in the Local Area would not be sufficient to meet the allocated quantity of water for those wells	None
Planned or Existing plus Committed System – average annual climate (G)	The quantity of water that can be taken from groundwater in the Local Area would be sufficient to meet the allocated quantity of water for those wells and one or more of the following circumstance exists: (i) the reduction in existing groundwater levels and/or flows results in unacceptable impacts to existing regulated water levels and/or flows or permits. (ii) the reduction in existing groundwater discharge into a coldwater watercourse by a threshold calculated as greater than 20 percent as compared to the existing estimated monthly streamflow Qp80 (the flow that is exceeded 80 percent of the time) or the average monthly baseflow of the watercourse or another threshold that has already been defined as a condition in an existing permit. (iii) the reduction in existing groundwater levels and/or flows results in unacceptable impacts to provincially significant wetlands.(MOE 2009)	None

The Local Area was assigned a “Low” Risk Level based on circumstances that all of the wells are simulated to be able to meet their Allocated Quantity of Water without affecting other uses. This Risk Level is further supported by the system tolerance provided by the surface water intake to Kempenfelt Bay.

5.7 Uncertainty Assessment

The uncertainty analysis examined the range of potential hydraulic conductivity that would produce calibrated models. The predictions made by the alternate model with acceptable ranges of parameters produced consistent model results. The assigned Risk Levels to the Local Area is considered appropriate. Consequently, the uncertainty associated with the Risk Levels applied to the Local Area is Low.

6.0 WATER QUANTITY THREATS

As outlined in the MOE Technical Rules (MOE 2009), for local vulnerable areas classified as having a Significant or Moderate Risk Level, drinking water quantity threats that may limit the sustainability of the municipal water supply wells are identified. The definition of a drinking water quantity threat is 1) an activity that takes water from an aquifer or a surface water body without returning the water taken to the same aquifer or surface water body or an activity that reduces the recharge of an aquifer.

6.1 Consumptive Water Demands

For each vulnerable area identified under clause 15 (2) (d) or (e) of the Clean Water Act (2006), drinking water threats that are or would be classified as Moderate or Significant, need to be identified within each vulnerable area. The Local Area was assigned a Risk Level of Low; as such, all consumptive demands lying within the Local Area are not classified as Significant Water Quantity Threats.

Table 6.1 illustrates the permitted and non-permitted consumptive water uses within the Local Areas. All non-permitted water uses, including rural domestic water uses that lay within the Local Area, are also not classified as water quantity threats.

TABLE 6.1 Consumptive Water Uses

Local Area Risk Level	Permitted Consumptive Demand (Threat)	Threat Classification
Low	Well 3A (Barrie Municipal)	-
	Well 13 (Barrie Municipal)	-
	Well 4 (Barrie Municipal)	-
	Well 5 (Barrie Municipal)	-
	Well 7 (Barrie Municipal)	-
	Well 9 (Barrie Municipal)	-
	Well 10 (Barrie Municipal)	-
	Well 11 (Barrie Municipal)	-
	Well 12(Barrie Municipal)	-
	Well 14 (Barrie Municipal)	-
	Well 15 (Barrie Municipal)	-
	Well 16 (Barrie Municipal)	-
	Well 17 (Barrie Municipal)	-
	Well 18 (Barrie Municipal)	-
	00-P-1210 (Agricultural Dugout Pond)	-
	03-P-1069 (Agricultural Dugout Pond)	-
	1315-6W3QAS (3 Wells, Dewatering/Remediation)	-
	2677-63PK84 (Heat Pump)	-
	5006-7CVGHZ (2 Wells, Dewatering/Remediation)	-
	5372-6SYPRA (Commercial, Business)	-
	6313-5Z4NC5 (Cooling Water)	-
	7455-6QPLB5 (Golf Course Irrigation)	-
	7542-6P8M92 (Golf Course Irrigation)	-
	92-P-3093 (Heat Pump)	-

6.2 Reductions in Recharge

The Technical Rules (MOE 2009) specify that reductions in groundwater recharge are a potential water quantity threat within the Local Area. The Tier Three Scenarios considered the impact of existing and planned land development on groundwater recharge and the resulting impact on water levels in the municipal aquifer at the wells. Proposed land use developments (or groundwater recharge reduction activities) include employment areas, industrial and institutional areas, and undifferentiated suburban lands; however much of this land use development is infilling within the City of Barrie, or not within areas of significant recharge, and as such do not significantly impact the water levels in the municipal aquifer.

7.0 SIGNIFICANT GROUNDWATER RECHARGE AREAS

7.1 Introduction

The MOE's Technical Rules (MOE 2009; MNR and MOE 2012) require that Significant Groundwater Recharge Areas (SGRAs) be delineated for each source protection area. The role of SGRAs is to support the protection of drinking water across the broader landscape. SGRAs delineated using the water budget tools are one of four types of vulnerable areas that are used in water quality vulnerability assessments; the other vulnerable areas are wellhead protection areas, intake protection zones, and highly vulnerable aquifers.

Recharge is the hydrogeologic process described by the flow of water moving from the ground surface through the unsaturated zone to the underlying saturated groundwater zone. Groundwater recharge occurs across a watershed at a range of rates depending on soil type, land use, slope, and climate but does not occur in areas of groundwater discharge. As described in Appendix A, within the Tier Three Study Area, the MIKE SHE surface water model was developed using these components, before it was calibrated and applied to estimate groundwater recharge.

The Technical Rules (MOE 2009) provide a straightforward methodology to delineate SGRAs from the MIKE SHE simulation results. This chapter follows this methodology with several enhancements.

7.2 Methodology Used to Delineate SGRAs

The Technical Rules (MOE 2009) provide the following instructions for the delineation of SGRAs:

> ***Part V.2 - Delineation of significant groundwater recharge areas***
> *44. Subject to rule 45, an area is a significant groundwater recharge area if,*
>
> *(1) the area annually recharges water to the underlying aquifer at a rate that is greater than the rate of recharge across the whole of the related groundwater recharge area by a factor of 1.15 or more; or*
>
> *(2) the area annually recharges a volume of water to the underlying aquifer that is 55% or more of the volume determined by subtracting the annual evapotranspiration for the whole of the related groundwater recharge area from the annual precipitation for the whole of the related groundwater recharge area.*
>
> *45. Despite rule 44, an area shall not be delineated as a significant groundwater recharge area unless the area has a hydrological connection to a surface water body or aquifer that is a source of drinking water for a drinking water system.*
>
> *46. The areas described in rule 44 shall be delineated using the models developed for the purposes of Part III of these rules and with consideration of the topography, surficial geology, and how land cover affects groundwater and surface water.*

This Assessment follows rule 44(1) to define the thresholds for SGRAs; a review of estimated recharge distribution across the watersheds provide further justification of the threshold value used. The “related groundwater recharge area” identified in Rule 44(1) was taken as the entire area covered by the MIKE SHE model. This methodology was used to delineate SGRAs in the SGBWLS Tier Two Assessment (Golder and AquaResource, 2010) across the Nottawasaga Valley Watershed.

7.3 Significant Groundwater Recharge Area Delineation Results

7.3.1 Tier Two Assessment SGRAs

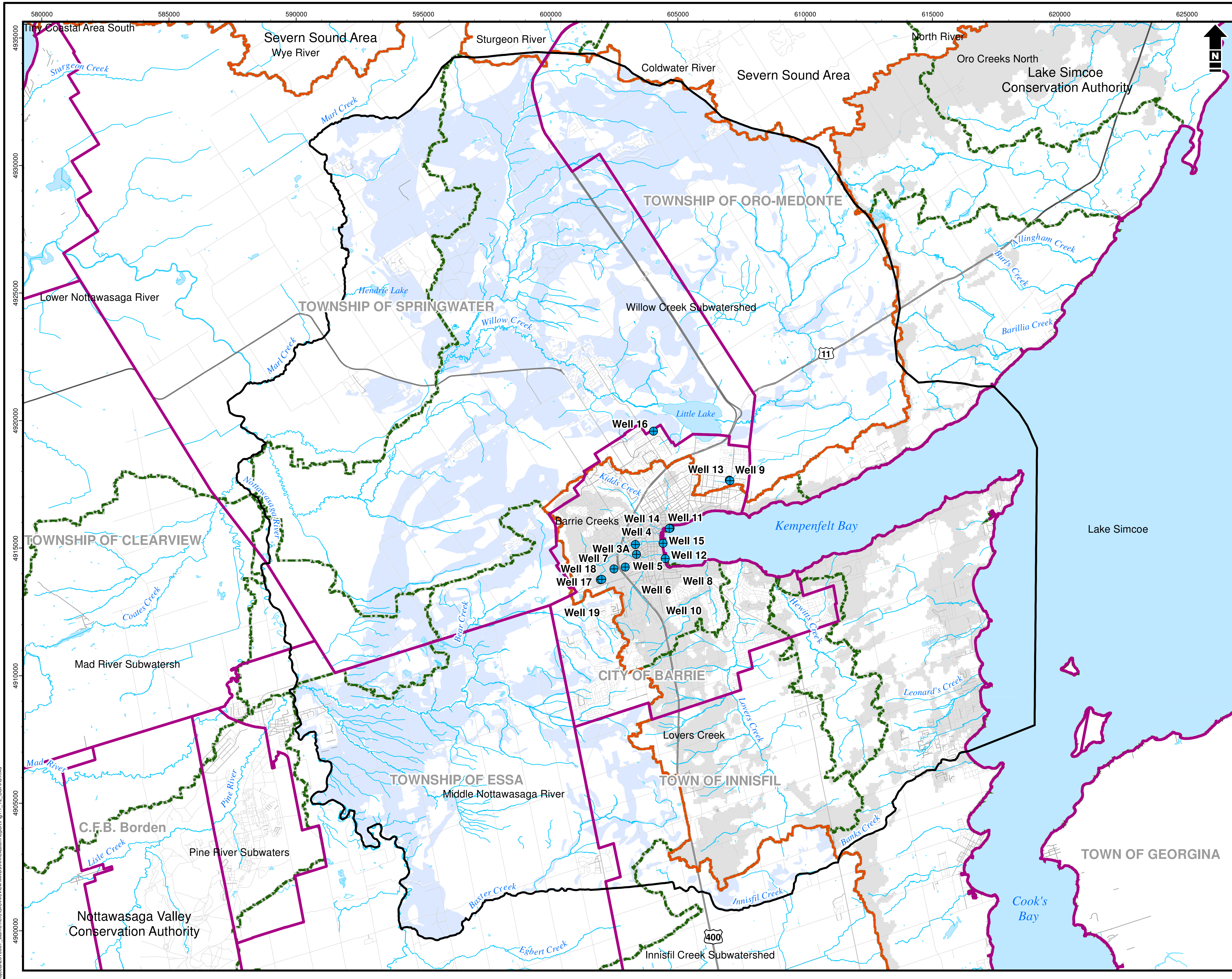
SGRAs were delineated in the Tier Two Assessment (Golder and AquaResource 2010) across the Nottawasaga Watershed and Severn Sound portion of the Tier Two Study Area using the methodology outlined above and illustrated on Figure 7.1. The average annual recharge across the entire Watershed was calculated by HSP-F to be 202 mm/year; consequently, the SGRA threshold for all subwatersheds within the NVCA Watershed was calculated to be 232 mm/year (1.15 times the average as per MNR and MOE 2012).

SGRAs for the Lake Simcoe Watershed portion of the Tier Two Study area were not completed using the HSP-F model. Instead, these SGRAs were delineated as part of the surface water modelling for the Lake Simcoe Watershed (EFX 2010), using the two different methodologies identified within the MOE Technical Rules (Rule 44(1) and 44(2); (MOE 2009)). The two approaches reportedly resulted in similar results. Although the report does not specify the thresholds used for the recharge mapping, it was calculated from the supplied recharge mapping that accompanied the report. Across the West portion of the Lake Simcoe Watershed, the average annual recharge was estimated by the PRMS runoff model as 136 mm/year, resulting in a lower threshold than that applied in the adjacent watershed.

Within the Tier Three Study Area, the SGRAs estimated from both the PRMS and HSP-F models cover a large portion of the area and are absent along groundwater discharge areas including lakes, ponds and wetlands. There is some significant urban recharge within the City of Barrie, as calculated with the PRMS model, as well as in the Snow Valley region of the model, and west of Lovers Creek, as calculated with the HSP-F model.

7.3.2 Tier Three Assessment SGRAs

As SGRAs are delineated on a watershed-scale to protect the broader landscape, the NVCA Watershed SGRA threshold of 232 mm/year (from the Tier Two Assessment) was considered in the Tier Three Assessment. However, this threshold was estimated from a regionally extensive area that spanned from the Niagara Escarpment to Severn Sound, and did not include the recharge directly within the city of Barrie, which lies in the Lake Simcoe Watershed. As well, a consistent surface water model for recharge development over both watersheds within the Study Area was refined in the Tier Three Assessment; this was particularly important, as the cross boundary flows between the two watersheds is a significant portion of the water balance. Therefore, the SGRA mapping was updated in this Tier Three Assessment.



Legend

Municipal Wells

Status

- Current

Transportation Network

- Highways
- Roads

Drainage Network

- River / Stream
- Open Water

Boundaries

- Barrie Tier 3 Boundary
- Municipal Boundaries
- Conservation Authority
- NVCA and LSRCA Subwatersheds
- Nottawasaga Watershed Significant Groundwater Recharge Areas (Golder and AquaResource, 2010)
- Lake Simcoe Watershed Significant Groundwater Recharge Areas (EFX 2010)

Reference:
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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Tier Two Assessment SGRAs

Date: 15 May 2013	Project: 2010007_BarrieTier3	
Technical: ccurry	Reviewer: MBester	Map Version: 1

Figure 7.1

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The MIKE SHE surface water model produces a surface of spatially distributed groundwater recharge estimates that are based largely on surficial soils, topography and land use cover. As a fully integrated model, MIKE SHE is one of the few approaches that will simulate rejected potential recharge within groundwater discharge zones (such as the Minesing or Bear Creek Wetlands). The recharge distribution computed using the calibrated MIKE SHE model was used to calculate an average annual recharge over the Study Area of 222 mm/year, resulting in an SGRA threshold of 255 mm/year. Figure 7.2 illustrates the areas within the Study Area where recharge was simulated to be greater than 255 mm/year.

Technical Rule 46 provides for the ability to evaluate the reasonableness of this threshold recharge value. Figure 7.3 illustrates the distribution of recharge rates as well as the volume and area exceeding each recharge rate for the Study Area. The cumulative exceedance curves are calculated as follows:

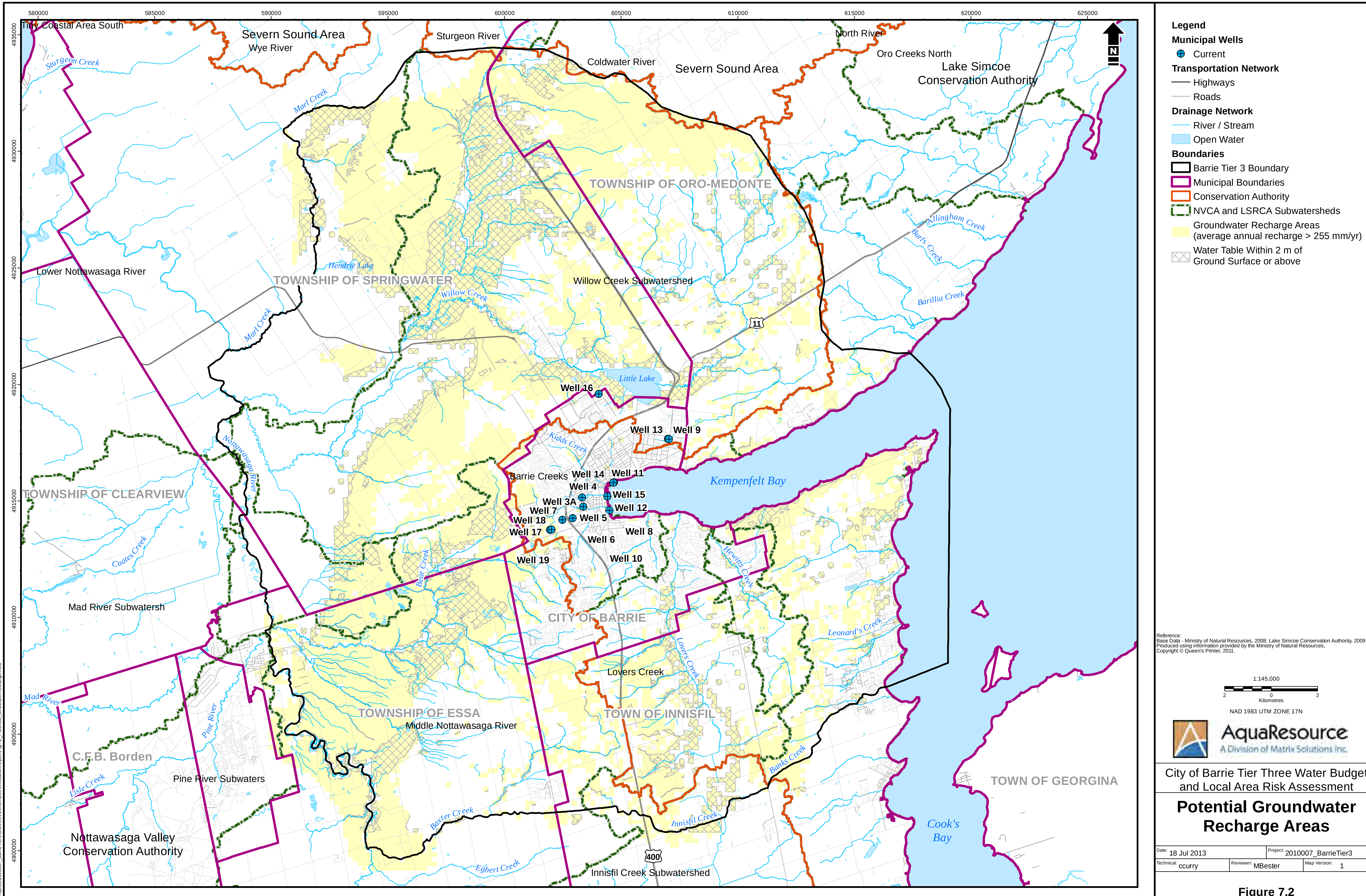
The cumulative exceedance curves are calculated as follows:

- % Volume Exceeding Recharge Rate. This curve is calculated as the sum of the total recharge flux for all unit response functions with a recharge rate equal to or above the value on the horizontal axis, divided by the total recharge flux;

- % Area Exceeding Recharge Rate. This curve is calculated as the sum of area associated with all hydrologic response units having a recharge rate equal to or above the value on the horizontal axis, divided by the total area;

Using these calculations, this figure illustrates how much volume or area would be identified as exceeding a given recharge rate. Inflections in these curves may illustrate natural divisions within the distribution and reflect the variation in surficial geologic conditions and land use within the watersheds.

Figure 7.3 shows the distribution of recharge and indicates the different physiographic regions or geologic materials, land use, and topography within the area. The figure illustrates that the computed threshold value (255 mm/year) using the MIKE SHE model lies within a “plateau” of the % volume curve (red line) and % area curve (blue line); the implication of this is that the areas identified as significant recharge would not change appreciably if the threshold was as low as 215 mm/year or as high as 260 mm/year. Both the NVCA Tier Two (232 mm/year) and the Tier Three (255 mm/year) thresholds are within this range, and thus using either threshold results in very similar mapping. This analysis provides additional confidence that the SGRA mapping is not sensitive to reasonable uncertainty in the threshold value. These recharge thresholds results in identifying 50% of the area and 72% of the recharge volume as significant.



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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Potential Groundwater Recharge Areas

Date: 18 Jul 2013 | Project: 2010007_BarrieTier3
Technical: ccurry | Reviewer: MBester | Map Version: 1

Figure 7.2

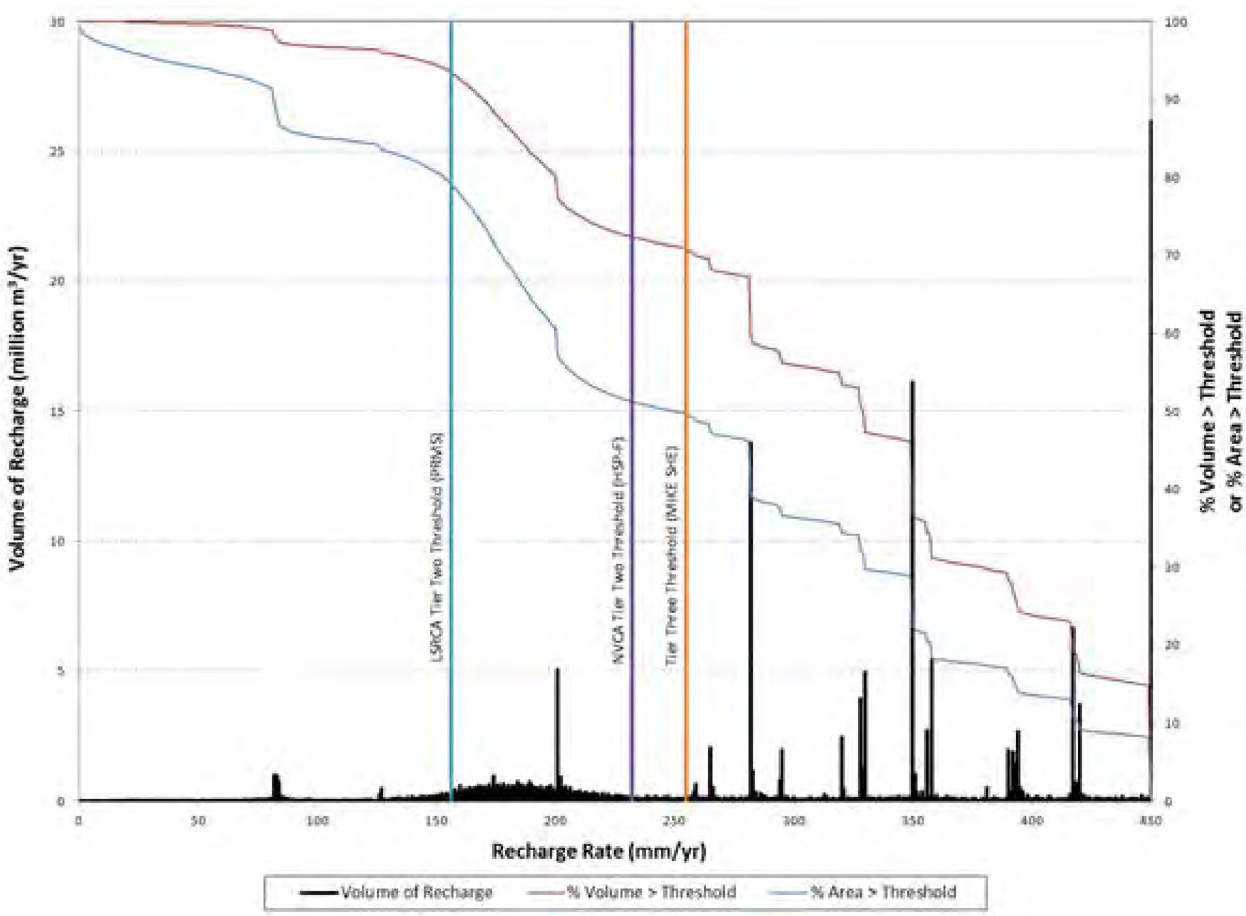
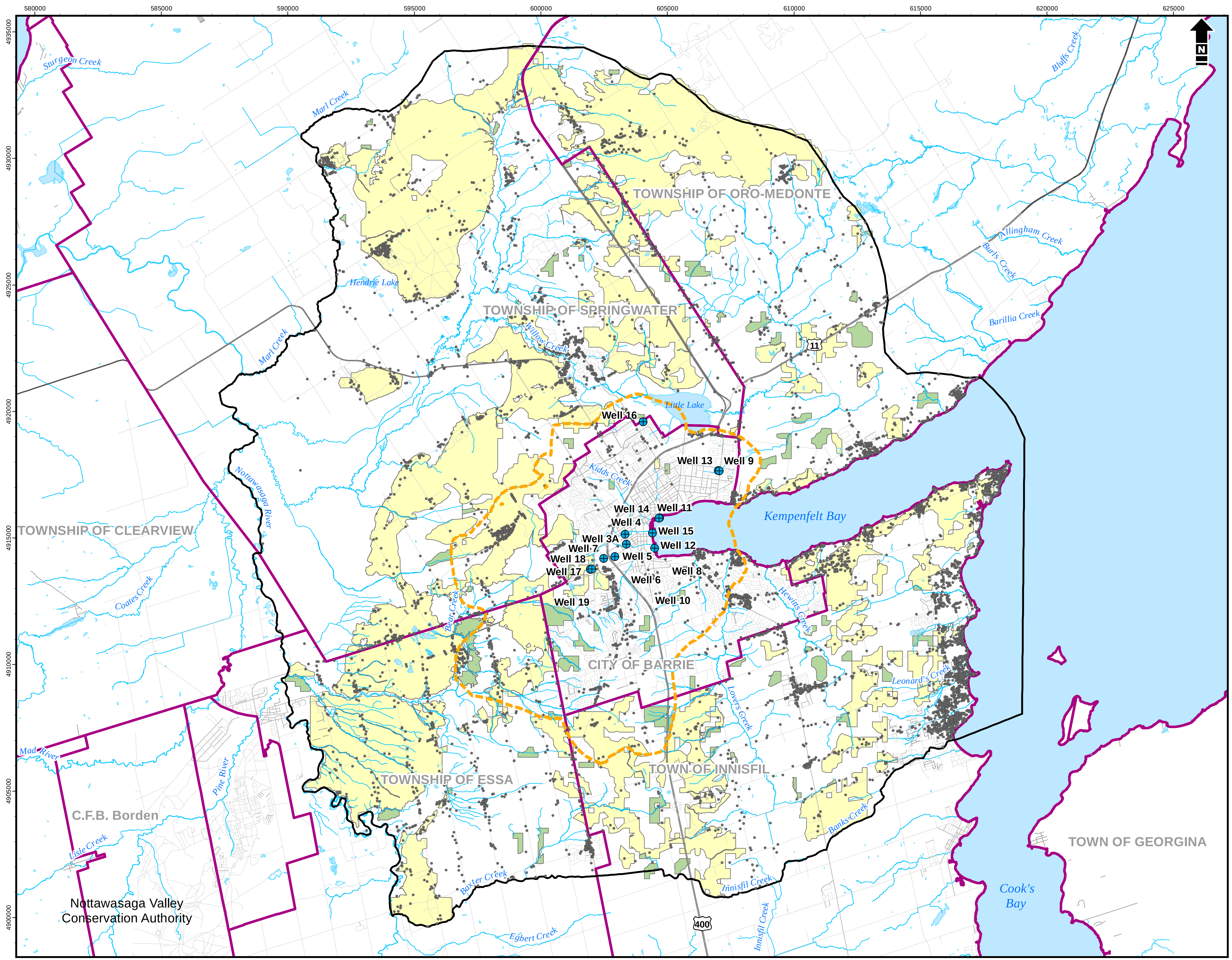


FIGURE 7.3 Recharge Distribution for Study Area

Areas where the model simulated water table is less than 2 m below ground surface were removed from the mapping as there is a high potential for groundwater discharge in these areas. Figure 7.2 shows the spatial distribution of these areas within the subwatershed. The two metre threshold was chosen to account for seasonal water level fluctuations not captured by the steady state groundwater flow model.

Figure 7.4 illustrates the final SGRA mapping within Study Area. As stated above, potential groundwater discharge locations were removed and the locations of private and municipal drinking water wells were added to identify areas where the SGRAs contribute to domestic drinking water sources. The WHPA Q1 (see hatched portion of figure 7.4) was also overlain to further identify those areas that may contribute to municipal groundwater supplies. Some groundwater recharge areas (see green portion of Figure 7.3) are no longer considered Significant Groundwater Recharge Areas as they do not appear to contribute to domestic or municipal groundwater supplies. In addition, small isolated areas less than or equal 40,000 m^2 were removed to create mapping that focuses the delineated SGRAs to larger geologic and physiographic feature that are considered more representative of mapped surficial geology features.

As illustrated on Figure 7.4, the significant groundwater recharge areas include large portions of the upland regions to the North and South of the city and areas where coarse-grained sediments are mapped at surface. Within the urban areas, there are few significant groundwater recharge areas as



Legend

- Municipal Wells
- Drinking Water Wells

Transportation Network

- Highways
- Roads

Drainage Network

- River / Stream
- Open Water

Boundaries

- Barrie Tier 3 Boundary
- Municipal Boundaries
- WHPA Q1
- Significant Groundwater Recharge
- Recharge Areas (not SGRAs)*

*Not classified as SGRA as the areas do not appear to support a private or municipal drinking water supply system

Reference:
Base Data - Ministry of Natural Resources, 2008; Lake Simcoe Conservation Authority, 2009
Produced using information provided by the Ministry of Natural Resources,

1:145,000

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Kilometres

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City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Significant Groundwater Recharge Areas

Date: 18 Jul 2013	Project: 2010007_BarrieTier3
Technical: ccurry	Reviewer: MBester / Map Version: 1

Figure 7.4

E:\Projects\2010007_BarrieTier3\GIS\wc\View\MXDs\AmeriationReport\Fig7.4_SignificantGroundwaterRechargeAreas.mxd these areas have a high percentage of impervious cover associated with roads, buildings, paved areas, etc.

The SGRA mapping completed in the Tier Two for the Nottawasaga Watershed (Figure 7.1) has a slightly lower threshold (232 mm/year) compared to the Tier Three Assessment (Figure 7.2, 255 mm/year) due to the difference in surficial geology that spans from the Severn Sound area to the Niagara Escarpment compared to that found in the Barrie Tier Three Study Area. Coarse-grained outwash or ice-contact sediments are widespread at surface across a larger percentage of the Tier Three study area and this leads to the higher average recharge condition. Both assessments identify large portions of the Subwatershed outside the urban areas as high recharge areas. Finally, the final Tier Three Assessment SGRA mapping (Figure 7.4) reduces the percentage of the Subwatershed designated as an SGRA by removing the areas where the water table lies close to ground surface.

The SGRA mapping completed in the surface water modelling for the Lake Simcoe Watershed (EFX 2010) has a lower threshold within the Study Area than that of both the Nottawasaga SGRA Mapping and the Tier Three SGRA Mapping. This resulted in delineating areas with high urban density, such as the Barrie downtown core, as being SGRA areas. The lower average recharge predicted by EarthFX (2010) appears to have resulted from an underestimation of infiltration in the sandy tills around Lovers Creek and Innisfil Creeks subwatershed.

8.0 DATA AND KNOWLEDGE GAPS

During the Tier Three Assessment, a number of data and knowledge gaps were encountered. Data and knowledge gaps that pertained specifically to the design and construction of the groundwater and surface water flow model are discussed in Appendices B and C and those gaps that pertain to the Risk Assessment contained in this document are presented below.

The first data gap relates to the permeability of the aquitards overlying the municipal aquifer. Over most of the wells, the existence of a low permeability unit has been well documented through multi-level wells, water level differences between the deep and shallow aquifers, and other hydraulic testing. “Windows” in this aquitard have also been inferred through observed data, including water quality observations suggesting a connection to the surface. Despite this knowledge, the extent and range of conductivities within these aquitard windows are not well known.

There is a knowledge gap related to the percentage imperviousness (and in turn the reduction in recharge) that may arise due to development of land as outlined on the Official Plans. It was estimated that the imperviousness due to planned development would be similar to the imperviousness from prior development; however, the actual imperviousness (without best management practices) may be higher or lower than those used in the Risk Assessment scenarios.

There is a knowledge gap related to the loss of water from municipal infrastructure beneath the urban portions of the Study Area due to leaky pipes (i.e., storm sewers, sanitary pipes, etc.). Leaky underground pipes can recharge the groundwater flow system and may locally increase water levels above those interpreted by the groundwater flow model.

There is a lack of continuous flow gauging stations on sensitive creeks such as Bear Creek and the Barrie Creeks. The lack of long term gauged flow data limits the ability to examine the long term trends in these surface water features.

The elevation of the water table in some of the model scenarios was predicted to decrease by 0.5 to 1.0 m beneath the Bear Creek wetland (however, groundwater discharge at this location is simulated to be maintained). The potential causes of this reduction in flux to portions of the wetland are currently a knowledge gap. Information gaps also exist with respect to the gradients within/surrounding the wetlands and installation of staff gauges or piezometers would shed light on the recharging or discharging nature of the wetland seasonally and over time. It is believed that much of Bear Creek is fed by perched water from the upland regions south of the city; however, very little data is available. Characterization of the wetland type could also assess whether the wetland is surface water or groundwater fed, and this information could also be used to enhance the calibration in the area, and reduce the uncertainty associated with the model predictions.

Despite the knowledge and data gaps presented above, the approach undertaken in this study enabled the assignment of an appropriate Risk Level to the Local Areas.

9.0 SUMMARY AND CONCLUSIONS

The Province of Ontario introduced the Clean Water Act (Bill 43) to ensure that all residents have access to safe drinking water. Under the Clean Water Act, Source Protection Authorities are required to conduct technical studies to identify existing and potential water quality and quantity threats to municipal drinking water. Through the development of community-based Source Water Protection Plans actions will be implemented to reduce or eliminate any significant drinking water threats.

Under the requirements of the Clean Water Act, municipalities may be required to complete a Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) to assess the ability of the municipal water sources to meet committed and planned water demands. Municipalities that are predicted to be unable to meet their allocated demands will be required to identify the significant threats that are preventing them from meeting their allocated demands.

This report details the Tier Three Water Budget and Local Area Risk Assessment carried out for the City of Barrie. The report summarizes background information relating to the geology and hydrogeology of the area, current and planned water demands, and the process and results of the Local Area Risk Assessment. Companion reports (Appendix A, Conceptual Understanding, Appendix B, Recharge Estimation and Appendix C, Numerical Model Development) summarize the development of the conceptual and numerical hydrologic and hydrogeologic models used to complete this Tier Three Assessment.

9.1 Summary of the Water Budget Tools and Results

The Tier Two Assessment completed for the South Georgian Bay West Lake Simcoe Source Water Protection Region (Golder and AquaResource 2010) identified the Barrie Creeks subwatershed as having a significant potential for groundwater stress. The identification of a significant stress potential lead to the requirement of a Tier Three Assessment for the City of Barrie, as most of its municipal wells are located within this subwatershed. To date, Barrie has not had any issues meeting their water quantity requirements.

The Tier Three Risk Assessment undertook a detailed review and representation of the physical system within the Barrie Area. The conceptual model used within the Tier Two Assessment was used as the basis to develop the Tier Three understanding. The Tier Three understanding was enhanced through a detailed review of the background data and the hydrogeological setting. The Tier Two surface water model was considered too broad in scale for this assessment and therefore an integrated model (using MIKE SHE) was developed to evaluate surface water conditions and the partitioning of precipitation into overland flow, evapotranspiration and groundwater recharge. The watershed-scale FEFLOW groundwater flow model that was used in the Tier Two Assessment was considered too broad in scale to be used in the Tier Three Assessment to adequately assess impacts at a well field scale. As such, a new groundwater flow model was developed building on data compiled for the Tier Two model as well as the geological characterization used to define model layers for that model. The two models were calibrated in conjunction with one another, exchanging results such as recharge and cross boundary flows.

Specific updates undertaken in the Tier Three Assessment included the interpretation of local-scale cross sections across the study area to refine the subsurface geology, and the assignment of hydrogeologic parameters consistent with local hydraulic testing results within the subwatershed and surrounding areas. The groundwater flow model was calibrated to a finer level of detail with close attention to observations at high quality monitoring wells. The Tier Three model was calibrated at the municipal well field-scale to both steady state (long term average) and transient (time-varying) conditions. It was also verified using long term (10 years) monitoring data to further increase the confidence in the model and its ability to simulate the groundwater flow system within the Study Area. The groundwater model used in the Tier Two Assessment was calibrated to steady state (average annual conditions). As such, the groundwater flow model developed for the Tier Three Assessment represents a refined tool compared to that used in the Tier Two Assessment.

The study included an in-depth compilation of current and historical groundwater pumping and monitoring data. This assessment of monitoring data indicated that the city has never experienced problems pumping the allocated quantities of water from their respective municipal pumping wells, and the only issues have been from poor well performance or water quality, in which case the wells have been rehabilitated or replaced. When this occurs, the city has always been able to supplement from other wells. Since August 2011, the municipal supply capacity has been improved further with the addition of a surface water supply intake at Kempenfelt Bay.

Following the development of the conceptual model, a continuous surface water flow model and three-dimensional groundwater flow model were developed to assess the water budget components in the area and to complete the Water Quantity Risk Assessment scenarios. These models were calibrated to observed steady state and transient water levels and flows and can be considered as reliable tools for water budget estimation.

9.2 Water Budget Summary

A detailed water budget for the Barrie Creeks Subwatershed was developed. Approximately 910 mm/year of precipitation falls within the subwatershed (average annual precipitation at the MOE Barrie climate station). Of this, approximately 50% leaves the subwatershed as evapotranspiration, 30% leaves as overland flow, and the majority of the remainder recharges the groundwater system. Groundwater modelling results indicate that groundwater flow into the Barrie Creeks subwatershed across the subwatershed boundaries is significant with approximately 35,300 m^3/d flowing into the subwatershed from the NVCA Watershed, and an additional 8,200 m^3/d flows in from Lovers Creek subwatershed to the southeast. Much of the cross-boundary flow is induced by municipal pumping.

9.3 Local Area Risk Assessment Summary

A Local Area was delineated surrounding the municipal supply wells in the Study Area (Figure 5.2). The area was delineated following the Province's Technical Rules (MOE 2009) based on a combination of the cone of influence of each municipal well as well as land areas where recharge has the potential to have a measurable impact on the municipal wells.

A set of Risk Assessment scenarios consistent with the Technical Rules (MOE 2009) were developed to represent the municipal allocated quantity of water (existing plus committed plus planned pumping rates); and current and planned land uses. The calibrated surface water and groundwater flow models were used to estimate both the changes in water levels in the municipal supply aquifer and the impacts to groundwater discharge and baseflow under average and drought climate conditions. The Risk Assessment scenarios showed that there is Low Risk associated with the operation of the Barrie wells. Under poor well performance conditions, such as well screen clogging, the ability of Well 11 to supply its existing plus committed pumping rate may be compromised; however, historically, this well has been temporarily taken offline for rehabilitation to restore capacity with no adverse effects on supplying the City's water needs.

The Low Risk Level is considered appropriate for the Barrie system because the increase in takings from the Existing rates to Existing plus Committed plus Planned rates is minor. In addition, the allocated (Existing, plus Committed, Plus Future) demand is similar or lower than the pumping rates that have previously been used for a number of years without any adverse impacts on the wells, Bear Creek wetland, or other surface water features.

9.4 Conclusions

Based on the results of the Risk Assessment modelling scenarios, the Local Area was classified as having a Low Risk Level.

Following the Technical Rules, all consumptive water users and potential reductions to groundwater recharge within the Local Area are **not** classified as significant water quantity threats. These consumptive water users include the permitted water demands (e.g., municipal pumping) and non-permitted water demands (e.g., domestic water wells).

The potential groundwater discharge reductions associated with recharge reductions vary from minor to moderate. The model scenarios did not consider the influence of stormwater best management practices, and the groundwater recharge was reduced proportionally to the imperviousness assumed for areas where land use changes are expected to occur. While these scenarios are conservative, they indicate where groundwater discharge is predicted to be most sensitive to land use change, and where the City of Barrie and LSRCA may wish to direct efforts to maintain groundwater recharge in the future.

9.5 Recommendations

The following recommendations are made based on results of this Tier Three Water Budget and Local Area Risk Assessment:

1. Maintain and Enhance Monitoring Programs.

    a. Monitoring and reporting programs associated with Permits to Take Water are already in place and should be continued. Monitoring data should be reviewed and maintained on an ongoing basis recognizing the relationship between municipal groundwater withdrawals and surface water discharge. Additional shallow monitors throughout the City would also be beneficial in understanding and further characterizing the aquitards windows.

b. Flow gauging and other assessments of key surface water features such as Bear Creek and the Barrie Creeks should be enhanced to monitor the long term trends in surface water features. This data could be used to better characterize the stream and its interaction with the groundwater flow system. It could also be used in future updates to the groundwater flow model to support the model calibration, as it would provide baseline operational field data to better understand the role of groundwater discharge to stream ecology.

2. Rehabilitate and maintain wells routinely. The Risk Analysis Scenarios showed that safe drawdown can be exceeded when wells are experiencing deteriorated well performance; these conditions have been avoided in the past with routine rehabilitation efforts and it is recommended that the City continue their efforts to this end. Alternative pumping scenario plans using current pumping rates (since the supplementation provided by the surface water supply) should be established to allow for periods when a well needs to be offline for maintenance and to develop guidelines as to how many wells can be offline at any given time.

3. Update Regional Water Budget Models. The Lake Simcoe Region Conservation Authority maintains water budget modelling tools to help manage and protect the water resources across the watershed. Hydrogeologic, hydrologic and operational insights gained from this Tier Three Assessment should be incorporated into the regional scale models developed by the LSRCA. These modelling tools should be updated periodically as new information is gathered and insights evolve within the watershed.

4. Maintain and Enhance Water Conservation Programs. Although the City of Barrie can meet municipal water demands under average climate conditions, current water conservation programs should be maintained to ensure that per-capita water demand does not increase and to encourage decreases. Opportunities to reduce water demand within the City should be considered. Any reduction in the per capita water use will enhance local ecosystem health.

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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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DISCLAIMER

We certify that we supervised and carried out the work as described in this report. The report is based on and limited by circumstances and conditions referred to throughout the report and on information available at the time of the site investigation. AquaResource has exercised reasonable skill, care and diligence to assess the information acquired during the preparation of this report. AquaResource believes this information is accurate but cannot guarantee or warrant its accuracy or completeness. Information provided by others was believed to be accurate but cannot be guaranteed.

This report is prepared for the sole benefit of Lake Simcoe Region Conservation Authority, and is solely warranted for the purposes outlined in this report. Any uses which a third party makes of this report, or any reliance on decisions made based on it, are the responsibility of such third parties. AquaResource, a Division of Matrix Solutions Inc. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

AQUARESOURCE
A Division of
MATRIX SOLUTIONS INC.

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Water Resources Modelling Specialist

reviewed by
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Principal Hydrogeological Engineer

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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

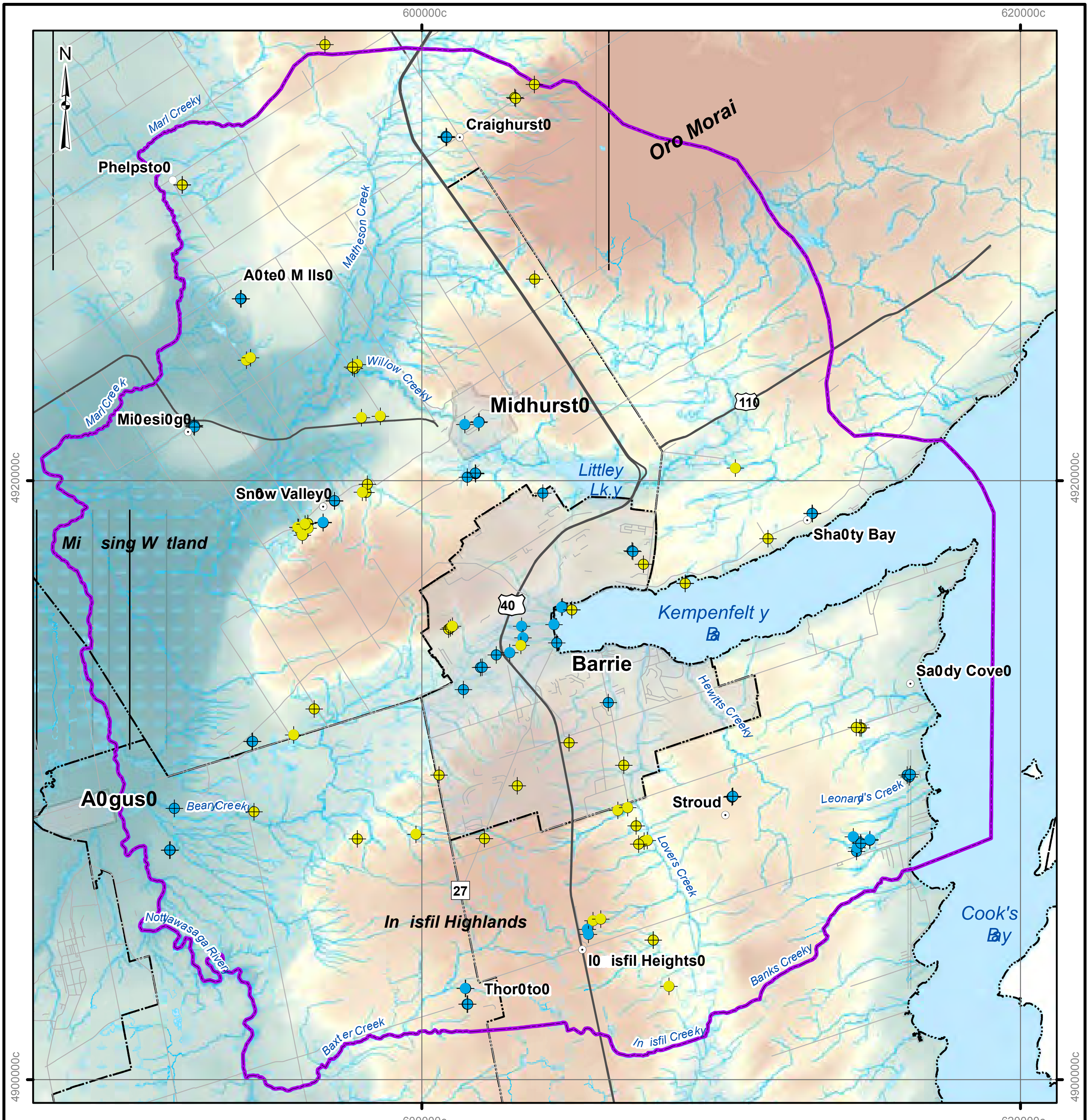
The City of Barrie is located at the western end of Kempenfelt Bay of Lake Simcoe, in the center of the Study Area (Map 1.1). The current (2010) population is approximately 135,000 persons (City of Barrie Planning Services), almost all of whom are serviced by the municipal water supply. The municipal 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



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- Municipal Watcr Supplyc
- Highwaysc
- Roadsc
- Rivcr / Strcamc
- Opcn Watc
- Wctlandsc
- Barric Ticr 3 Bounda yc
- Urban Ccntrcsc
- Township Bounda y

REFERENCESc
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Map 1.10

Study Area

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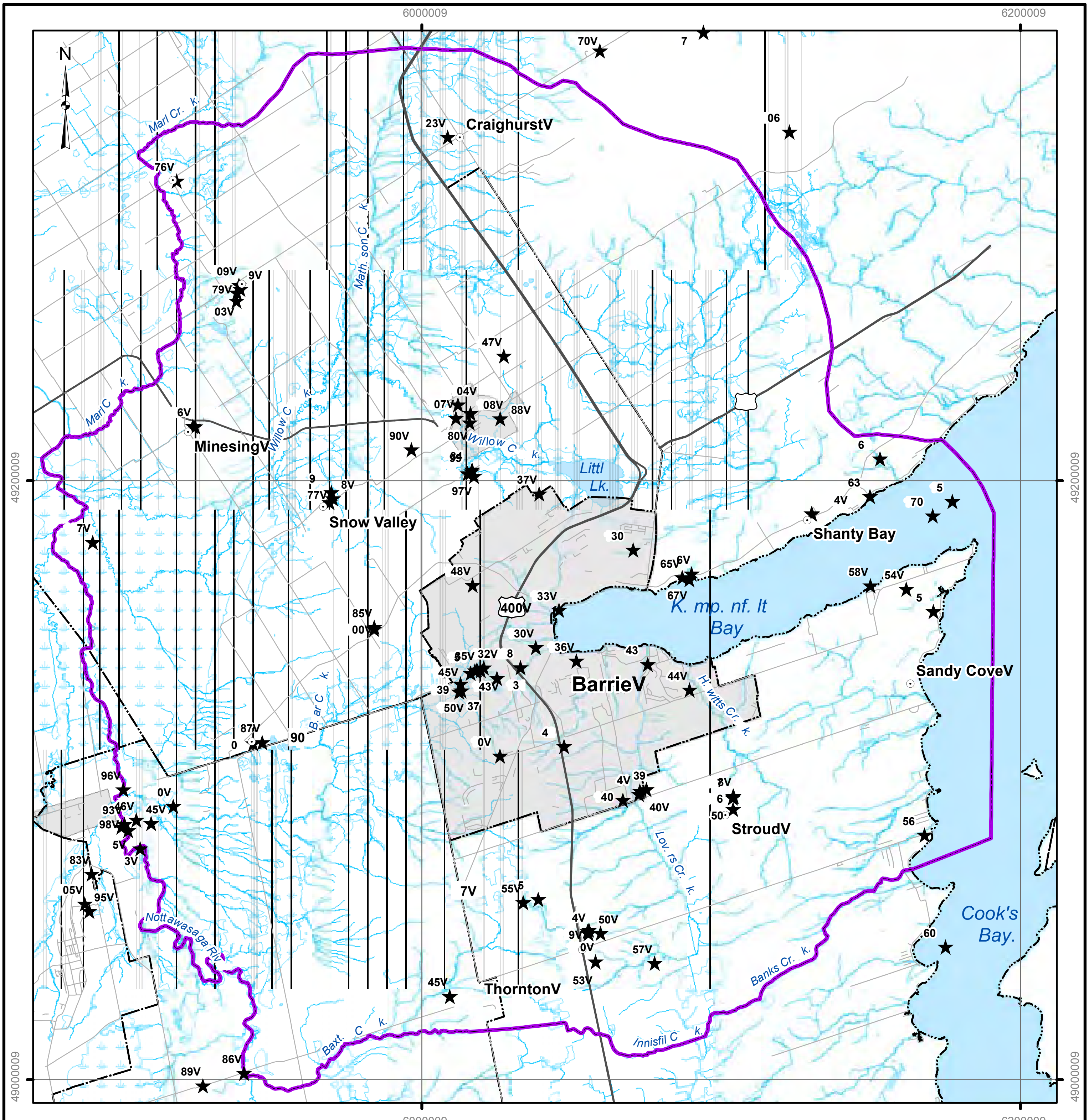

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- Township 9oundary9

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Map 2.2

References by Location

REFERENCES9
ase Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 839
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(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.

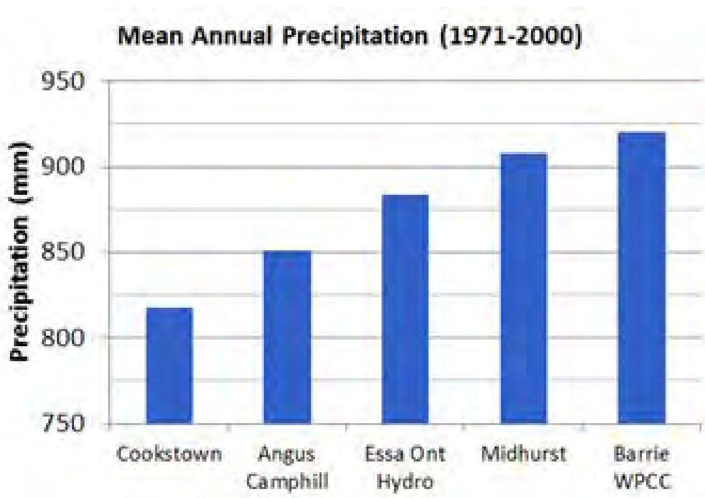

FIGURE 2.1 Mean Annual Precipitation for Five Meteorological Stations in the Study Area (Land Information Ontario 2008)

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- N CA Climate Stations
- Ground Surface Contours - Interval 10mV
- HighwaysV
- RoadsV
- River / StreamV
- Open Water
- WetlandsV
- Barrie Tier 3 Boundar
- Watershed Boundar
- Urban CentresV
- Township Boundar

Ground Surface Elevation (m)

High : 411.797V

Low : 173.093V

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Map 2.1

Topography Drainage and Climate Stations

REFERENCESV

Base Data - N CA, 2009; DEM - LSRCA 2010V
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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.

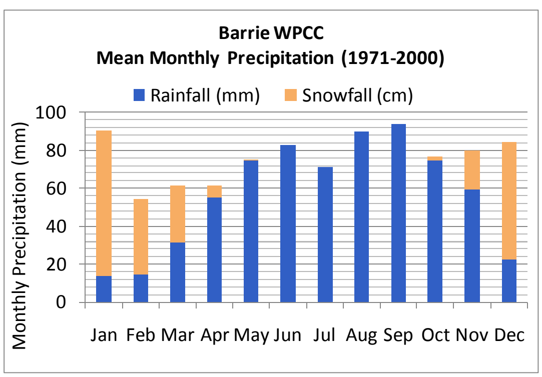


FIGURE 2.2 Mean Monthly Precipitation as Snowfall and Rainfall for Barrie WPCC Station

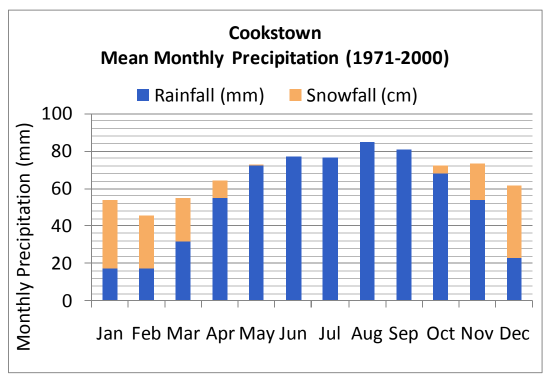
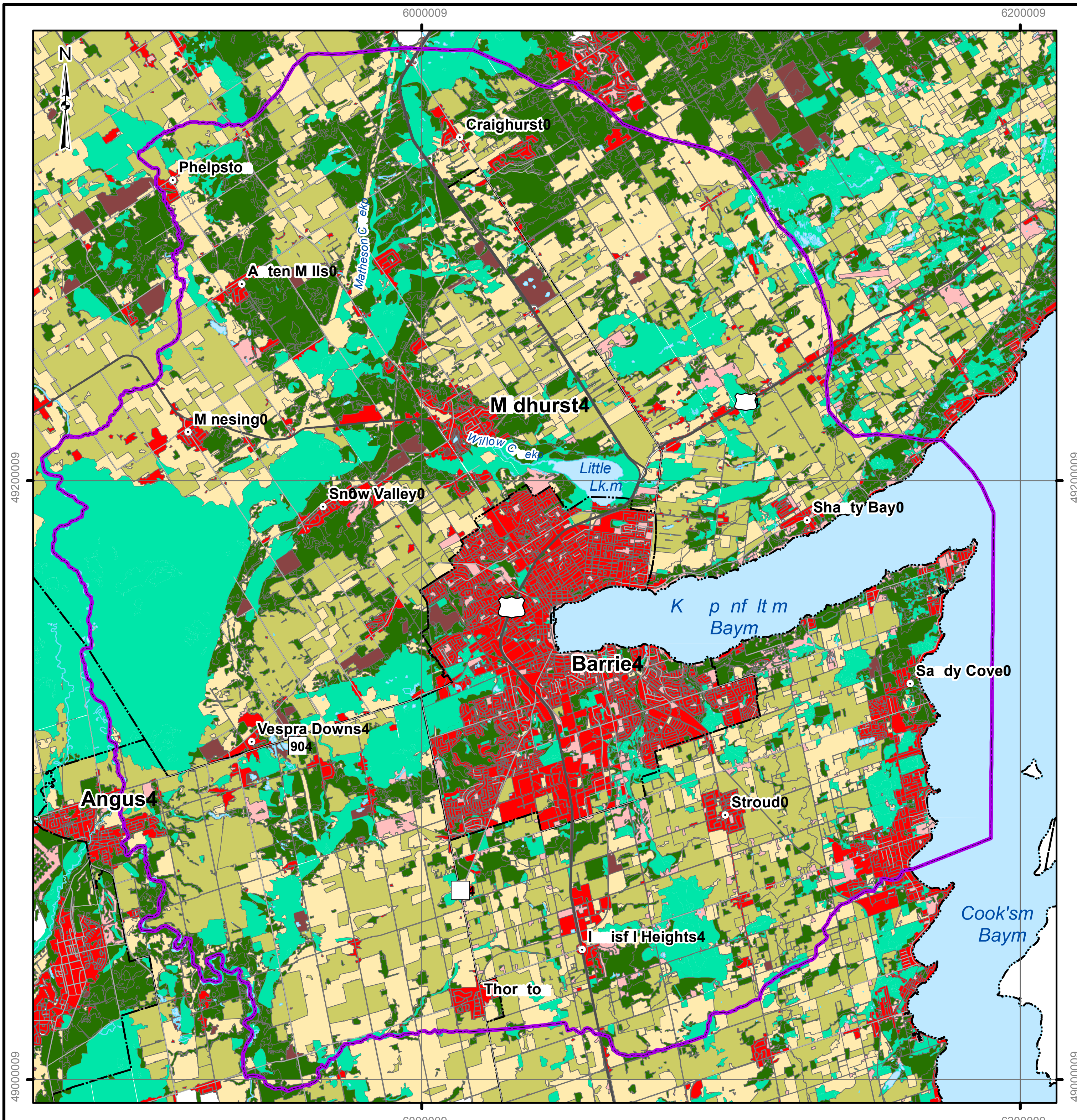


FIGURE 2.3 Mean Monthly Precipitation as Snowfall and Rainfall for Cookstown Station

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



LEGEND4

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- Township Boundary9

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- High Intensity Developed9
- Hay / P sture9
- Row Crop9
- Coniferous Woodland9
- Woody Wetl nd9
- Qu rries9

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Map 2.24

Present nduse

REFERENCES9

B se D t - NVCA, 2009; L nduse - SRCA nd NVCA, 20109
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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).

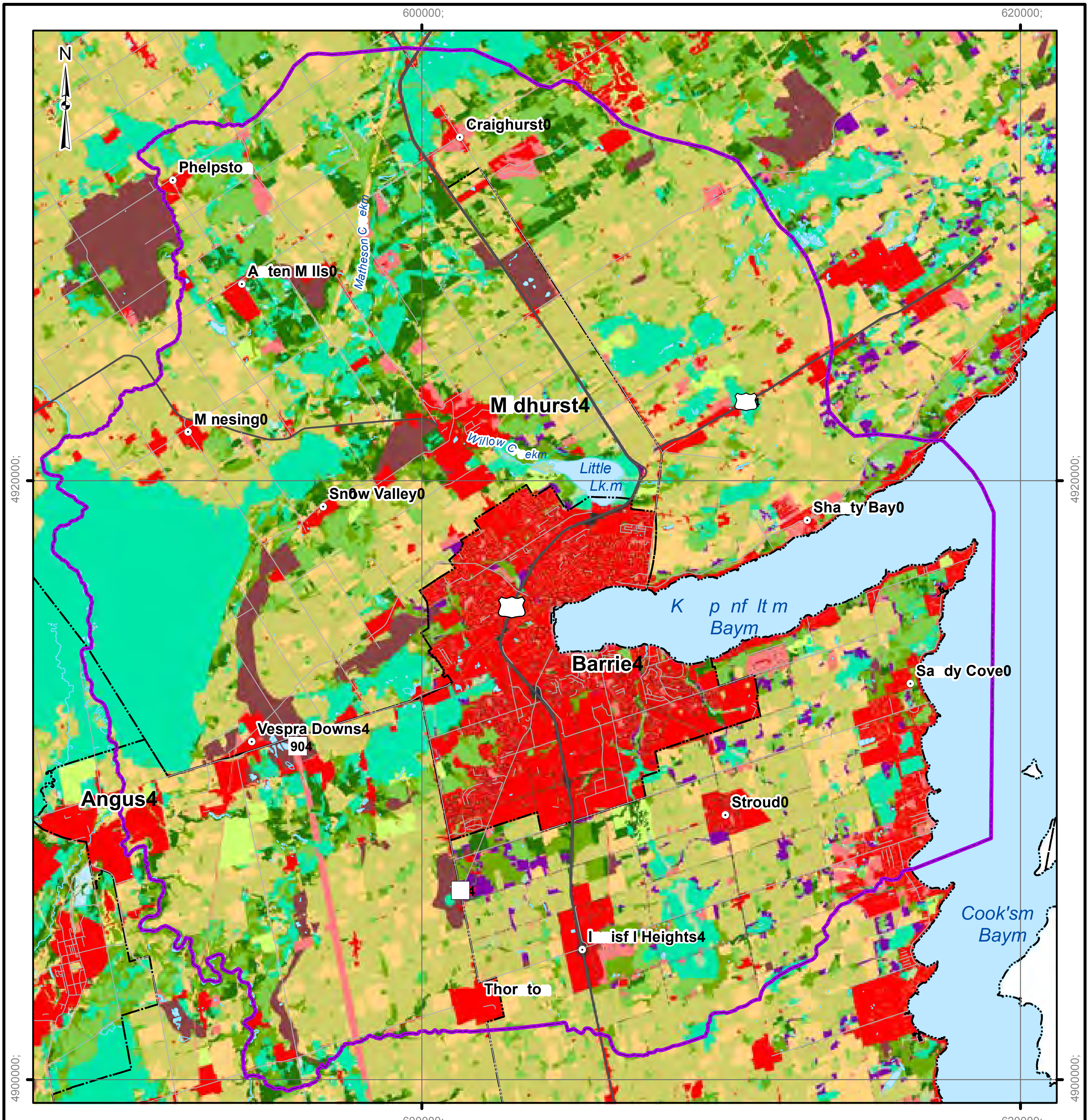
2.5 Surface Water

2.5.1 Overview

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



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- Towns/Villages;
- Highways;
- Roads;
- River / Stre m;
- Open Water;
- Wetl nds;
- B rrie Tier 3 Boundary;
- Township Boundary;

Future La duse4

- Water;
- Low Intensity Developed;
- High Intensity Developed;
- Hay / Pasture;
- Row Crop;
- Coniferous Woodland;
- Mixed Woodl nd;
- Deciduous Woodland;
- Woody Wetl nd;
- Emerge t Wetl nd;
- Qu rries;
- Transitio l;
- Sod F rm / Golf Course;
- Road;

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Map 2.34

Future Land Use

REFERENCES;
Base D t - NVCA, 2009 Future L nduse - LSRCA nd NVCA, 2010;
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Projection: UTM Zo e 17N, NAD 83;
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- Cool Water StreamsV
- Cold Water StreamsV
- River / StreamV
- Open WaterV
- etlandsV
- Barrie Tier 3 BoundaryV
- SubwatershedsV

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Map 2.4c

Surface Water Hydrology

REFERENCESV
Base Data - N CA, 2009; Thermal Regime - N CA 2009, LSRCA 2010.
Produced using information provided by the Ministry of Natural Resources, Copyright © Queen's Printer, 2010.V
Projection: UTM Zone 17N, NAD 83
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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*

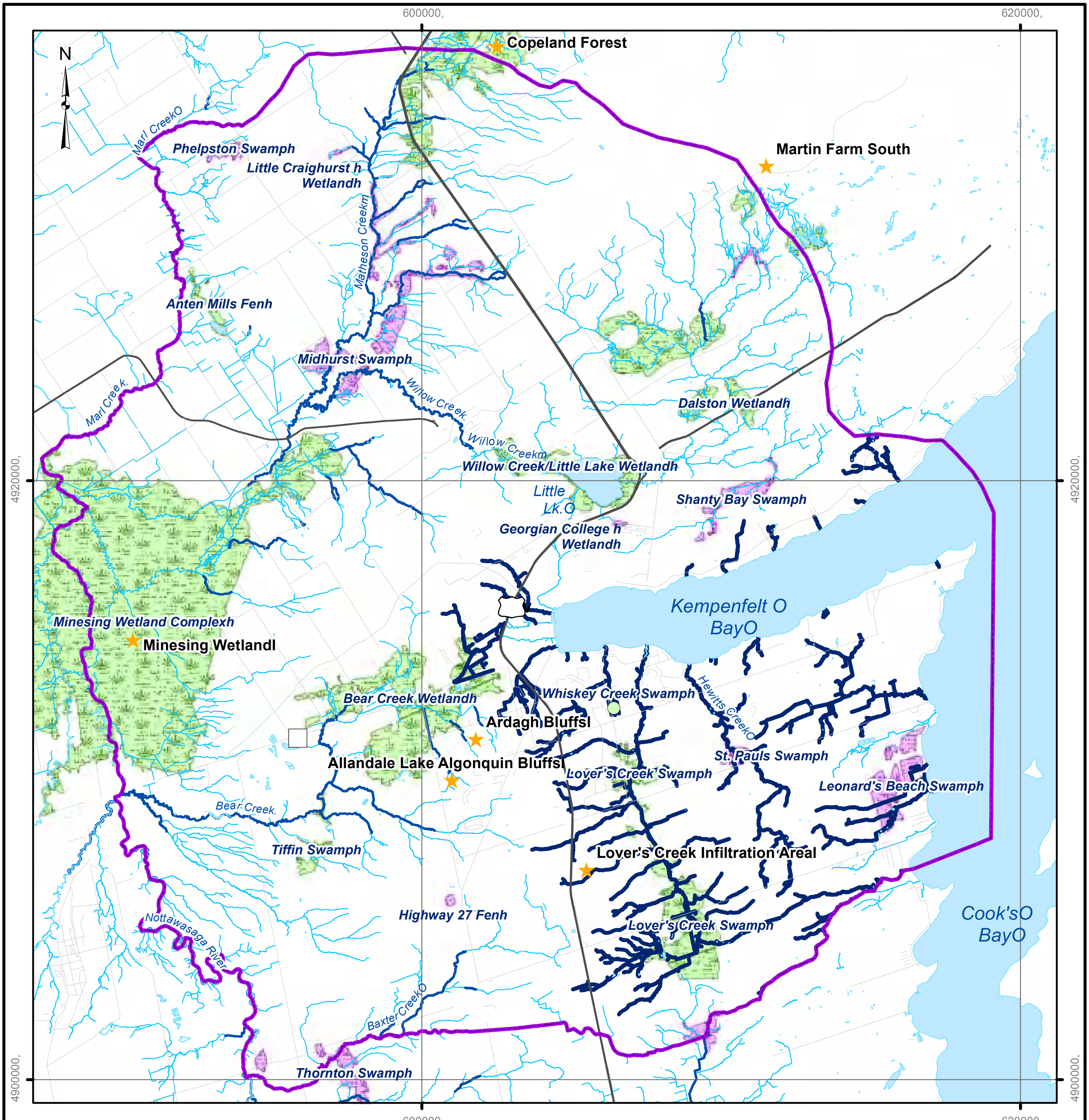
The Innisfil Creek subwatershed (490 km^2) consists of four major creeks – Innisfil Creek, Bailey Creek, Beeton Creek and Penville Creek - that drain the headwaters of the Nottawasaga River watershed. Only 2% of this subwatershed, namely a small portion of the headwaters of Innisfil Creek, is within 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

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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

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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.

Minesing Wetlands

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.

Lover’s Creek Swamp

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).

Bear Creek Wetland

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)

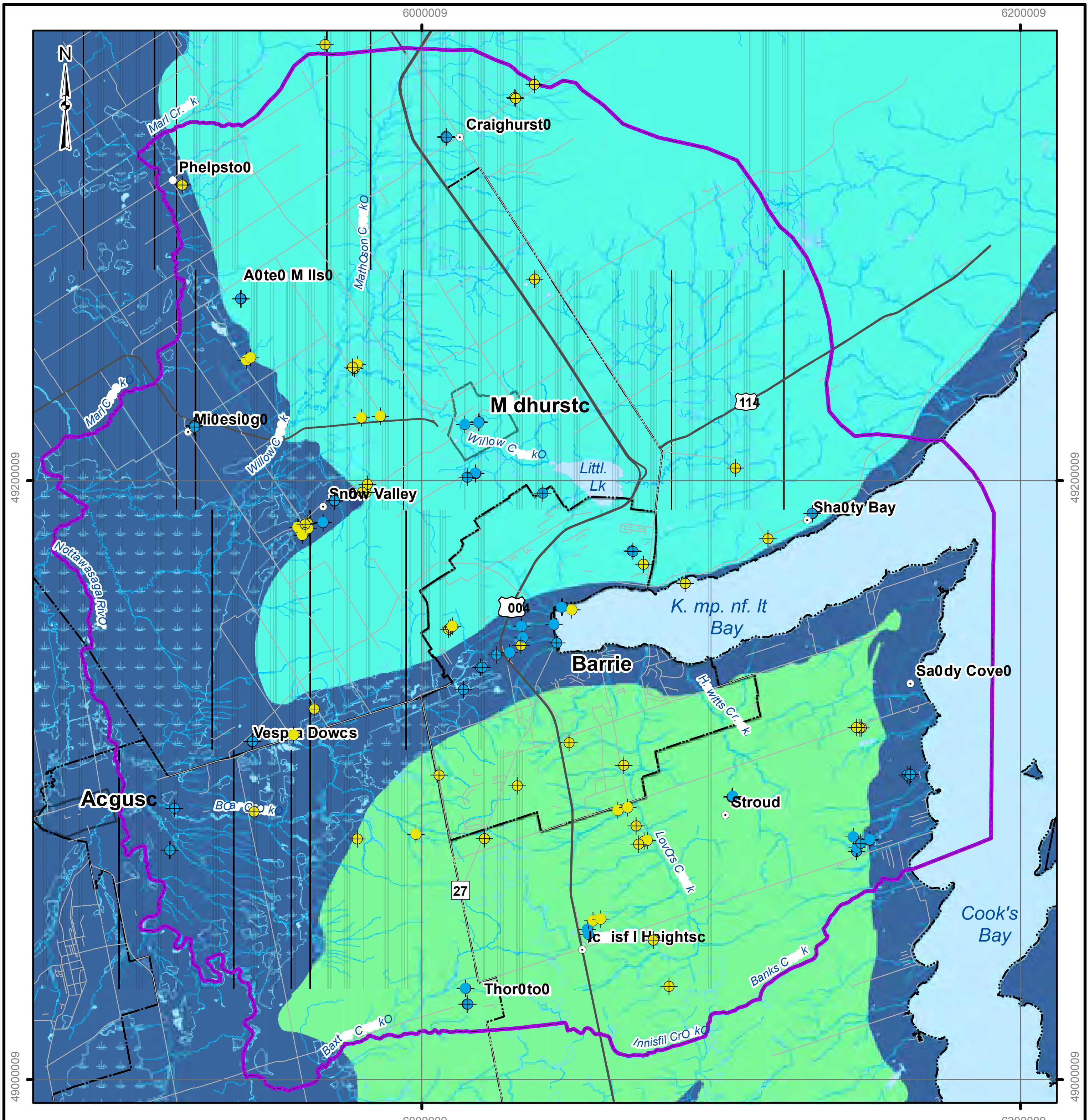
Areas of Natural and Scientific Interest (ANSI) are defined by the OMNR (2010) as "areas of land and water containing natural landscapes or features which have been identified as having values related to protection, natural heritage appreciation, scientific study or education"(Hanna 1984). ANSIs found 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).

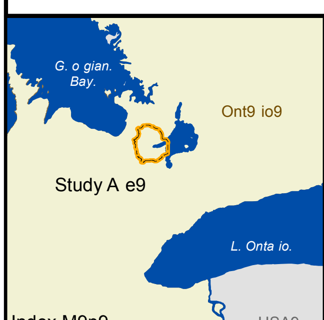
There are various ANSIs that have been identified in the Study Area. Some of the key ANSIs in the area include *Minesing Wetlands, Allandale Lake Algonquin Bluffs, Martin Farm South, Fergusonvale North, Copeland Forest, Ardagh Bluffs. The Ardagh Bluffs* is partially situated on the Allandale Lake Algonquin 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/Vill9ges9
- Priv9te Pe mits9
- Municip9l W9te Supply9
- Highw9ys9
- Ro9ds9
- River / St e9m9
- Open W te
- Wetl9nds
- B9 ie Tier 3 Bound9 y9
- Urb9n Cent es9
- Township Bound9 y9

Physiographic Regio

- 31, Peterbo ough9 Drumlin Field9
- 35, Simcoe Lowl9nds9
- 36, Simcoe Upl9nds9

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Map 2.6

Physiography

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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).

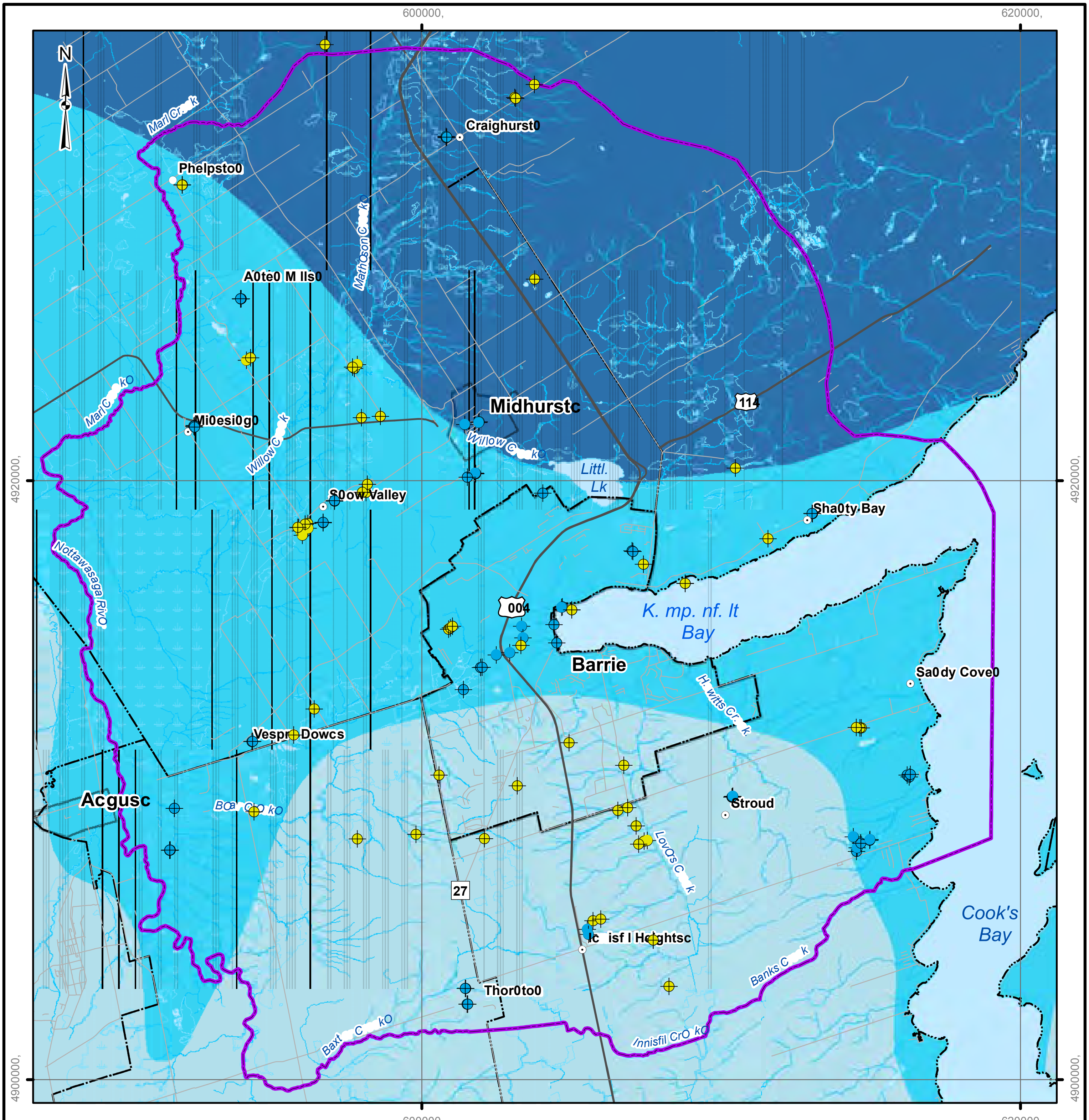
The Peterborough Drumlin Field encompasses the upland areas of Innisfil Heights south of Kempenfelt Bay in the Study Area (Map 2.6), and is characterized by drumlins and drumlinoid hills that rise from the surrounding Newmarket Till plain. Drumlin axes are aligned southwest-northeast (Chapman and Putnam 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



LEGEND4

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

Bedrock Geology4

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

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ap 2.7

Bedrock , Geology

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Bedrock eology - Armstrong, D.K. and Dodge, J.E.P. 2007. Paleozoic geology of southern Ontario; Ontario eological Survey, Miscellaneous Release--Data 219. ISBN 978-1-4249-4526-9,
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Projection: UTM Zone 17N, NAD 83; Map Version: 1; Map Date: 07-Jun-2012; Created By: ccurry,

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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

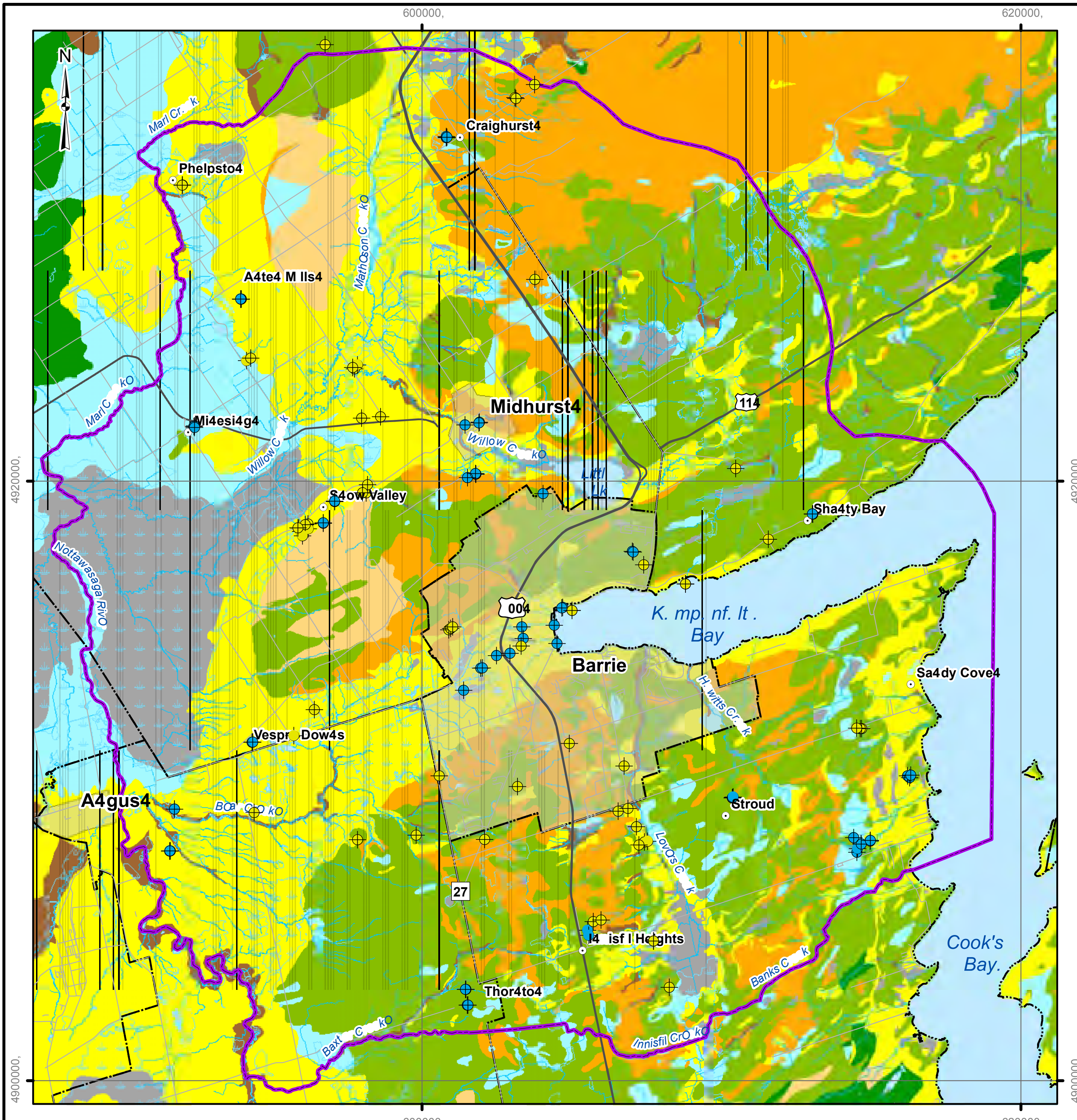
Overburden sediment in the Study Area detail a record of repeated ice advance and retreat of the Simcoe Lobe, which originated from the neighbouring Lake Simcoe basin (Chapman and Putnam, 1984; Barnett 1992). At surface, sediment is characterized by laterally discontinuous till sheets, stratified sand 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.



LEGEND4

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

Quater4ary Geology4

- 1,2:,Precambrian,bedrock,
- 3,4:,Paleozoic,bedrock,
- 5b:,Stone-poor, carbonate, -derived,silty,to,sandy,till,
- 5d:,Glaciolacustrine-derived silty,to,cla e till,
- 6:,Ice-contact,stratified deposits,
- 7:,Glaciofluvial,deposits
- 8:,Fine-textured glaciolacustrine,deposits,
- 9:,Coarse-textured, glaciolacustrine,deposits,
- 12:,Older,alluvial,deposits
- 13:,Fine-textured lacustrine,deposits,
- 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,

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Ontario,Geological,Survey,2003.,Surficial,geology,of,Southern,Ontario;,Ontario,Geological,Surve Miscellaneous,Release-Data,128,
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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)		

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 Stratigraphic Sequences

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).

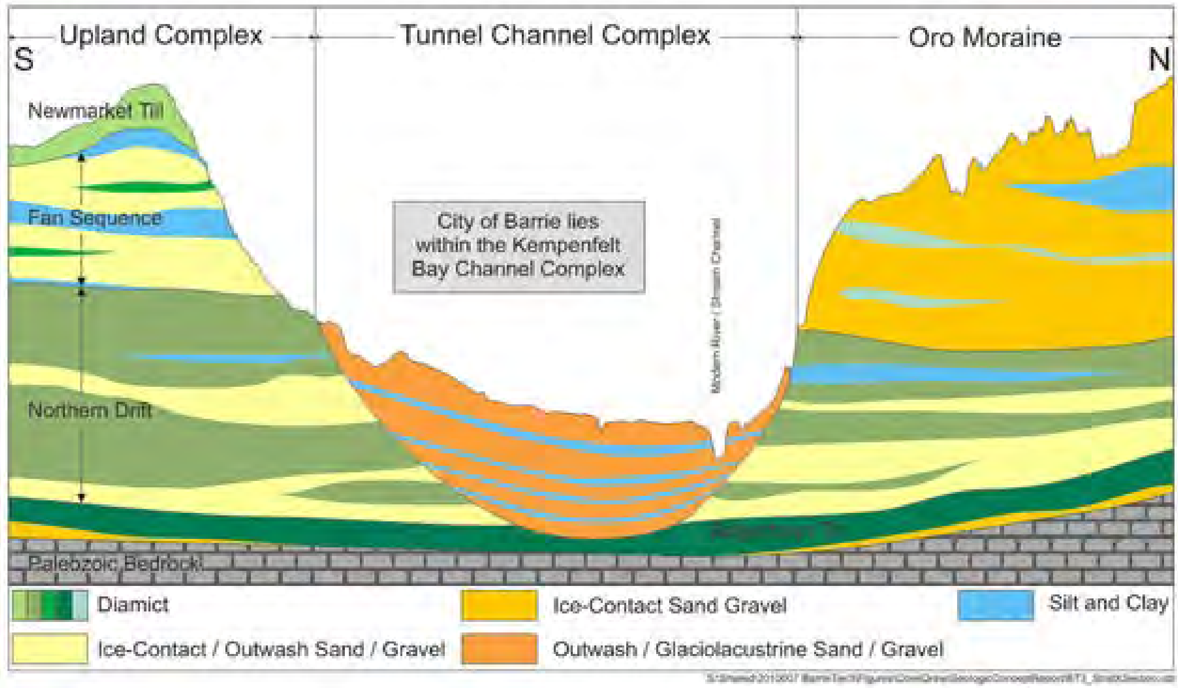


FIGURE 2.4 Generalized conceptual stratigraphy of upland complexes, lowland tunnel channel complexes, and the Oro Moraine.

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.

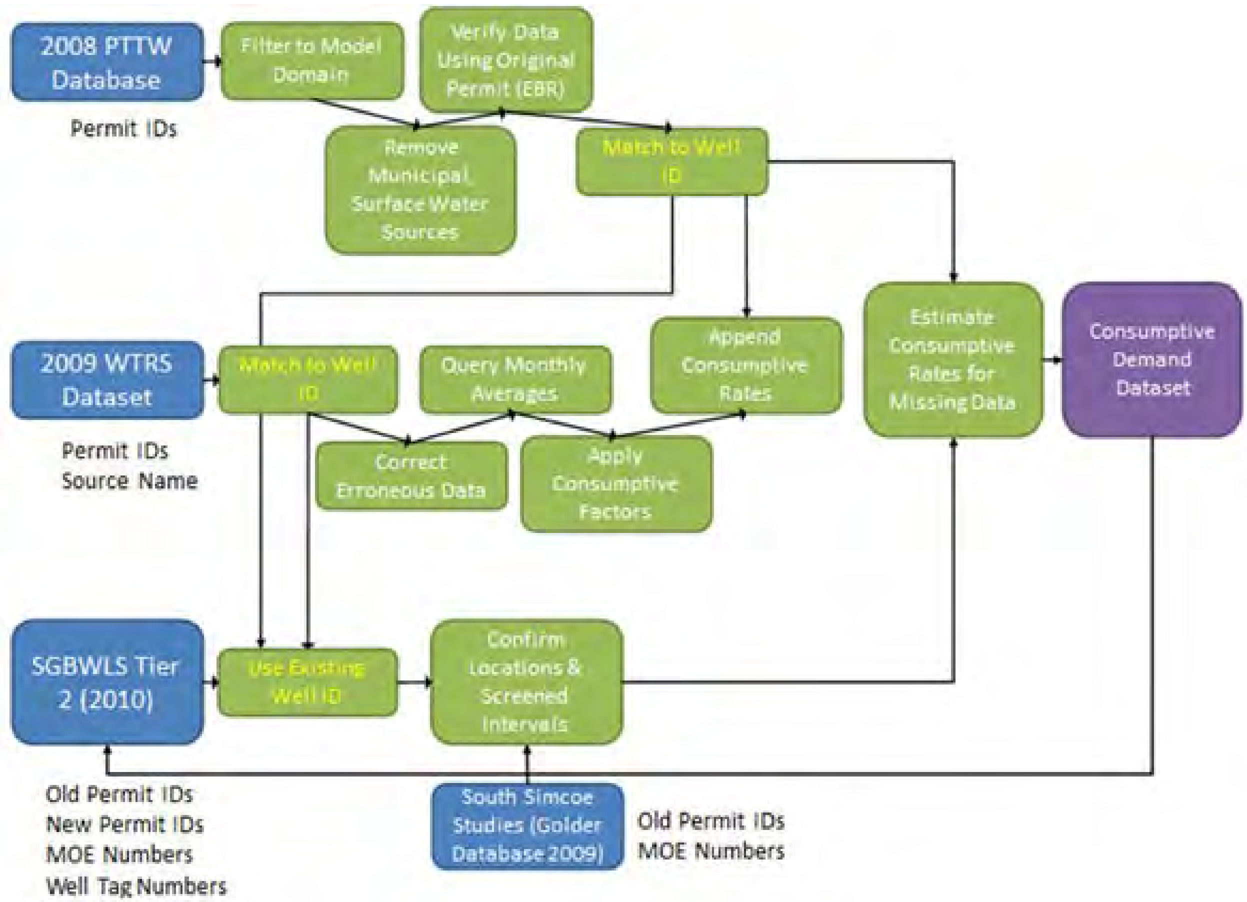


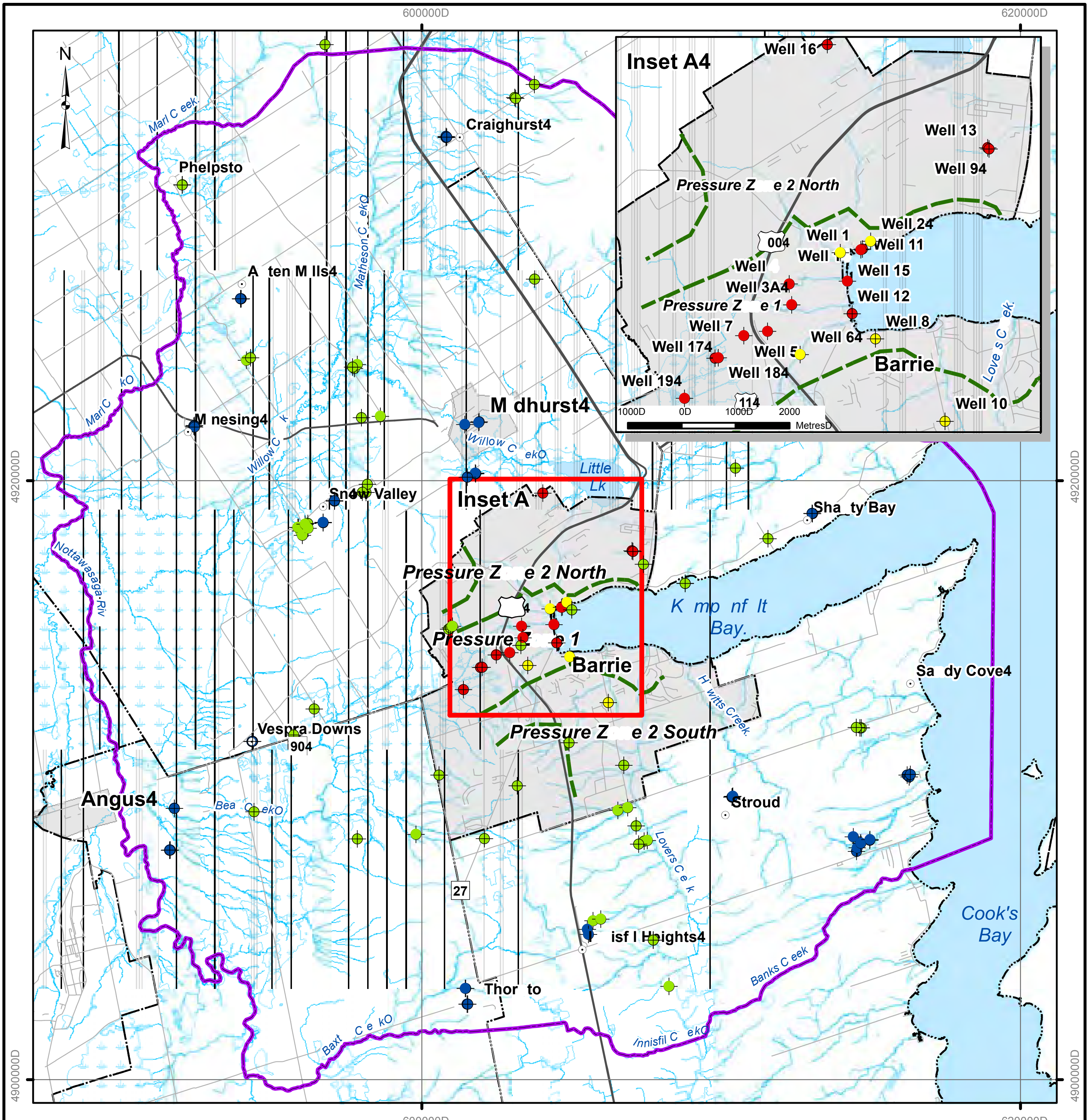
FIGURE 3.1 Establishing Consumptive Demand Dataset Workflow

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 Well Field Description

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



LEGEND4

- Barrie Municipa WellsD
- Other Municipa Wells D
- Private PTTWsD
- Muncipa Supply Wells No Longer in OperationD
- Towns/Vil agesD
- Pressure Zone Extents (Approximate)D
- HighwaysD
- RoadsD
- River / StreamD
- Open WaterD
- WetlandsD
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary

Barrie Tier 3 Conceptual Understanding Report

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IWC International Water Consultants Ltd.

Map 3.14

Municipal and Private Pumping Wells D

REFERENCESD
Base ata - NVCA, 2009D
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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

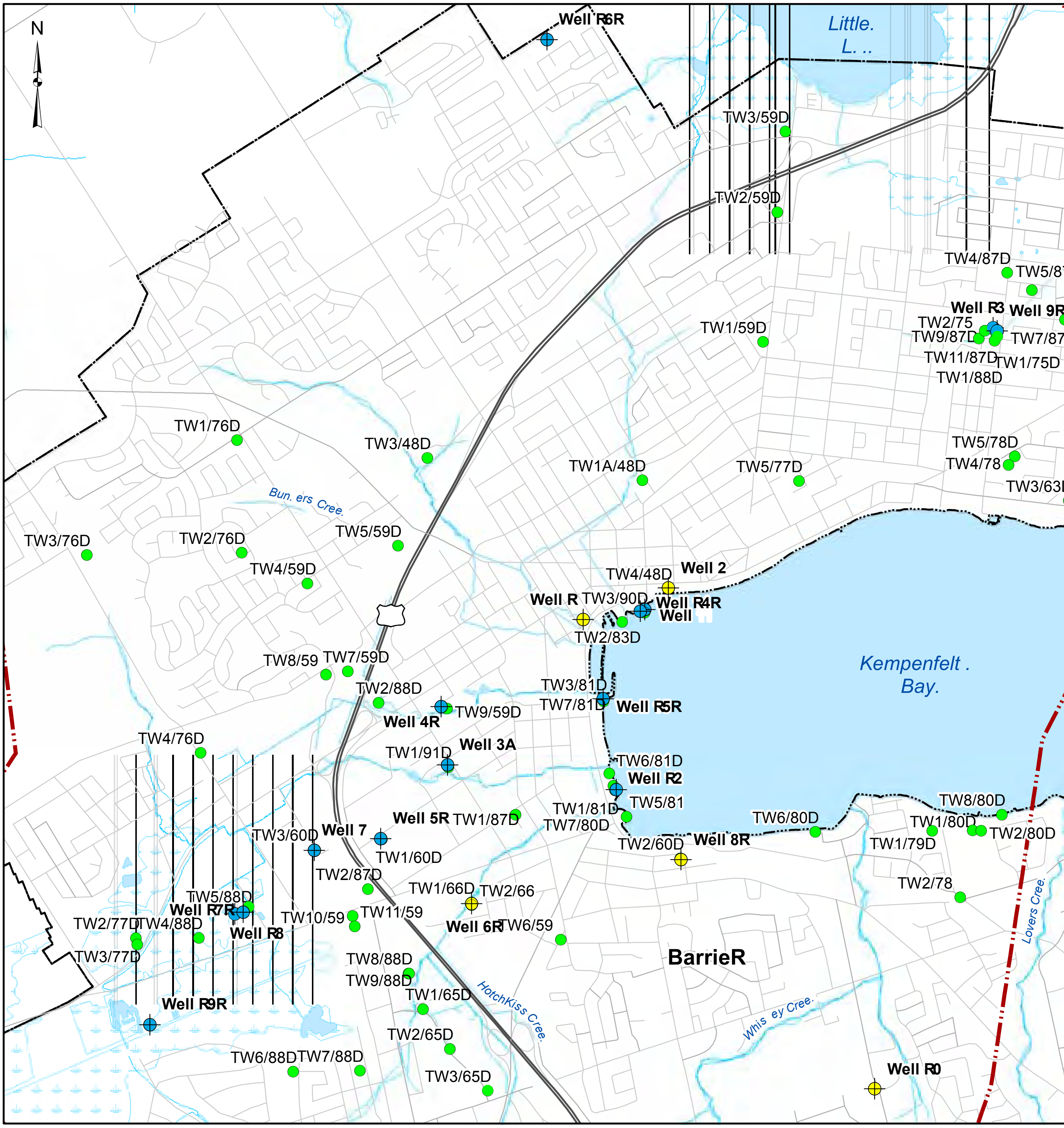
*Note: Average pumping rates for 2010 are based on data from January through September.

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.



LEGENDR

- Muncipal Supply Wells No Longer in OperationD
- Municipal Water SupplyD
- City of Barrie Monitoring NetworkD
- Towns/VillagesD
- HighwaysD
- RoadsD
- River / StreaD
- Open WaterD
- Wetlands
- Barrie Tier 3 BoundaryD
- Urban CentresD
- Township BoundaryD
- Focus AreasD

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

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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

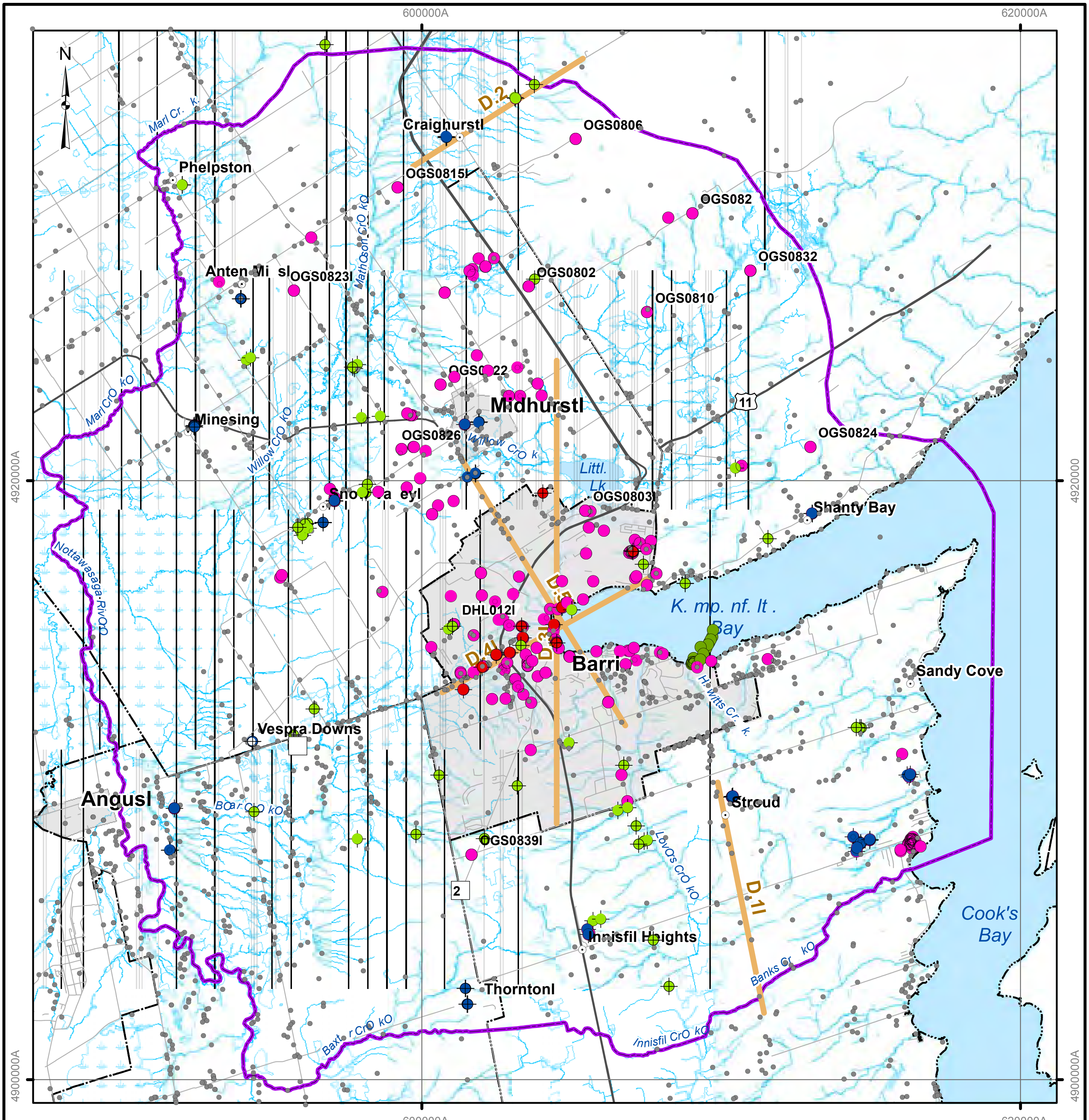
The hydrogeological setting described above provides the basis for the three dimensional hydrogeological model. The thickness and distribution of the aquifers and confining layers are based primarily on well records from mud rotary drilled wells, whose materials descriptions are largely based on cuttings 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.



LEGENDl

- Investigative (High Quality) Borehole A
- Kempenfelt Bay BoreholesA
- PiAksA
- Barrie MuniAipal WellsA
- Other MuniAipal Wells A
- Private Wells A
- Towns/VillagesA
- Profile LoAationsA
- HighwaysA
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban CentresA
- Township BoundaryA

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REFERENCESA

Base Data - NVCA, 2009A
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Map Version: 1; Map Date: 07-Jun-2012; Created By: A urryA

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KilometresA

Map 4.1l

StratigraphiA Interpretation A LoAationsA

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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

Well No. 3A	77.7	24	2,875	(983)	125 (43)	3 x 10^{-4}	43 - 66	57.6 - 66.7
Well No. 4	76.6	24	1,250	-	78	4 x 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 x 10^{4}	63 - 102	88.4 - 106.7
Well No. 6*	83.4	24	2,530	(968)	79 (30)	2.5 x 10^{-2}	32 - 71.6	53.6 - 71.6
Well No. 7	91.0	24	3,380	(1,385)	125 (51)	7 x 10^{-3}	73 - 100.3	85.3 - 100.6
Well No. 8*	60.0	24	238 - 325		8 - 11	5 x 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 x 10^{-4}	32 - 65.5	47.2 - 61.3
Well No. 12	106.0	30	1,043	(834)	26 (21)	1 x 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 x 10^{-4}	42 - 66	
Well No. 16	91.0	72	1,490		67	5 x 10^{-4}	52 - 74	64 - 73.5
Well No. 17	136.5	72	2,385 – 2,980		51 - 65	5 x 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

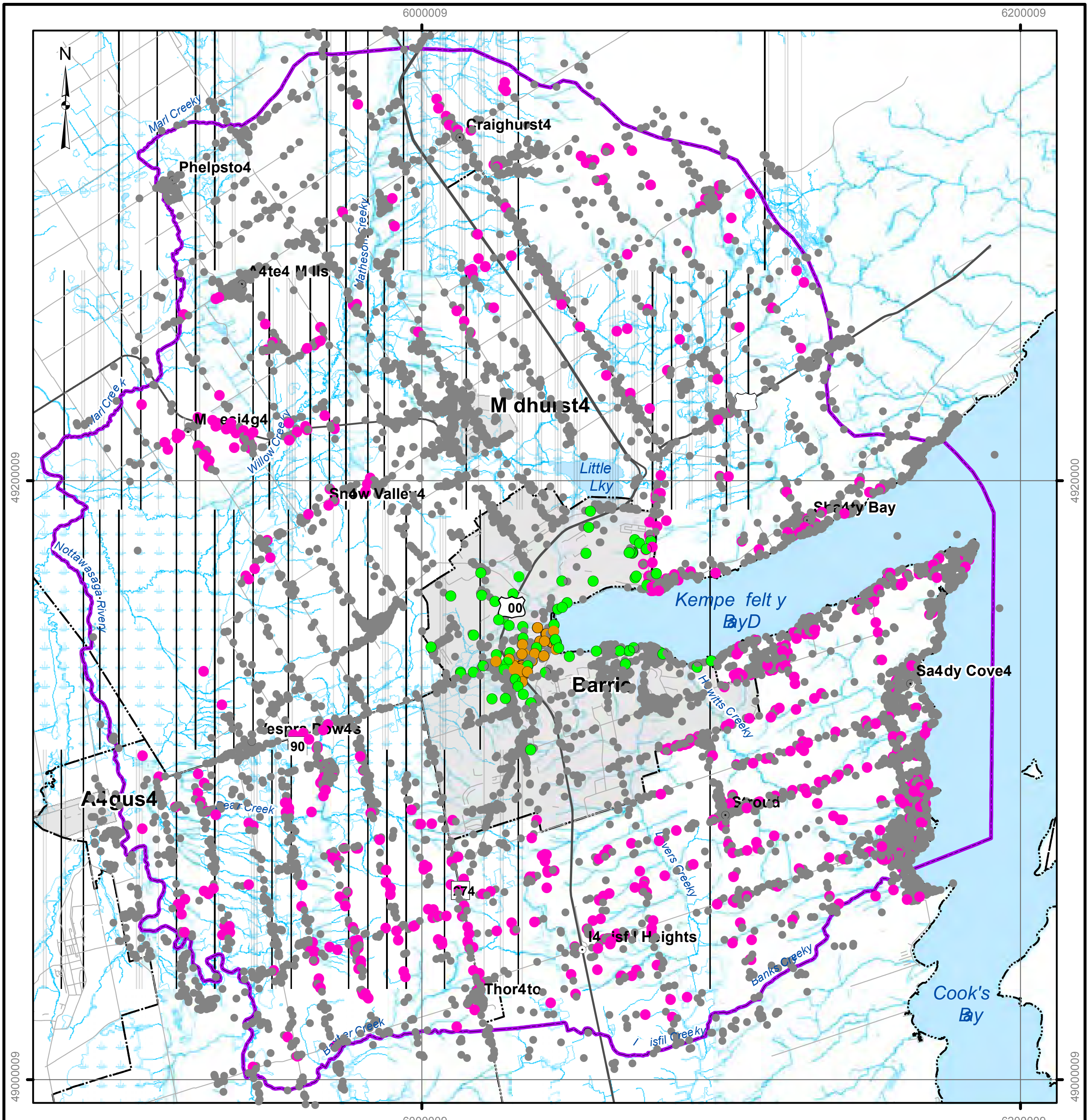
In addition to the municipal monitoring network, other high quality observation wells were identified. These high quality observations wells were extracted from a conducted by Golder (2009b) to more-accurately map flow directions in the immediate vicinity of municipal production wells. These wells, which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

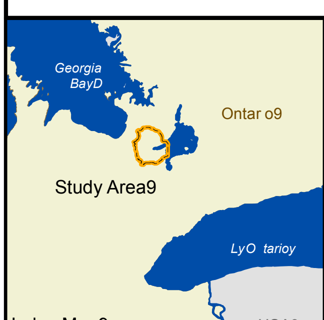
4.5 Water Level Mapping

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





Index Map9

LEGEND4

- C ty of Barr e Mult level Wells 9
- C ty of Barr e Mon tor ng Ne work
- H gh Qual ty Da ase
- S andard Da ase
- Towns/V llages9
- H ghways9
- Roads9
- R ver / S ream9
- Open Wa er9
- Wetlands
- Barr e T er 3 Boundary
- Urban Centres9
- Townsh p Boundary9

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Map 4.24

Observa on Wells9

REFERENCES9
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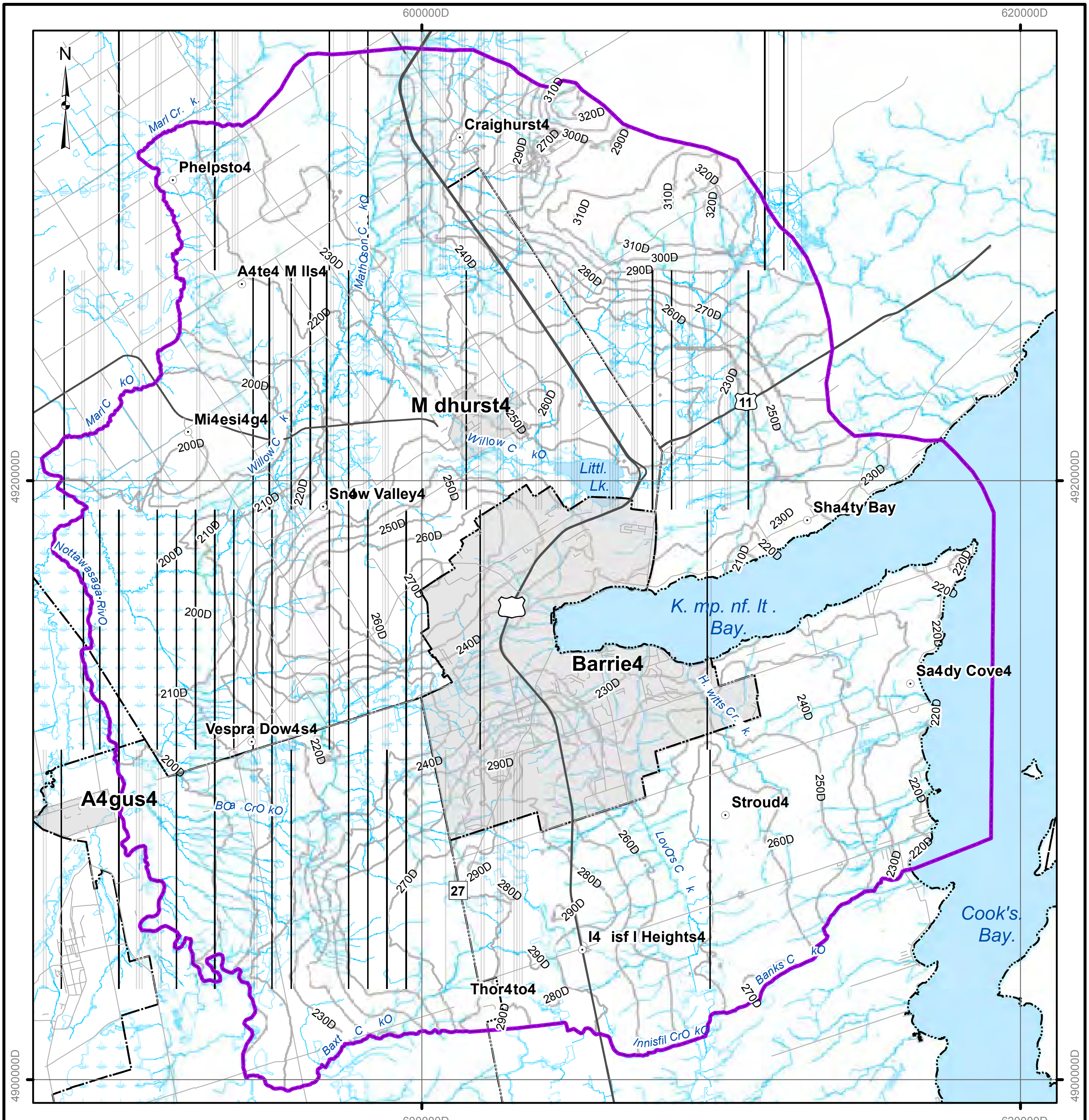

LEGEND4

- Towns/VillagesD
- Shallow Water Contour Levels Interval 10m (masl)D
- HighwaysD
- RoadsD
- River / StreamD
- Open WaterD
- WetlandsD
- Barrie Tier 3 BoundaryD
- Urban CentresD
- Township BoundaryD

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Map 4.34

Shallow EDuipotentials (A1)D

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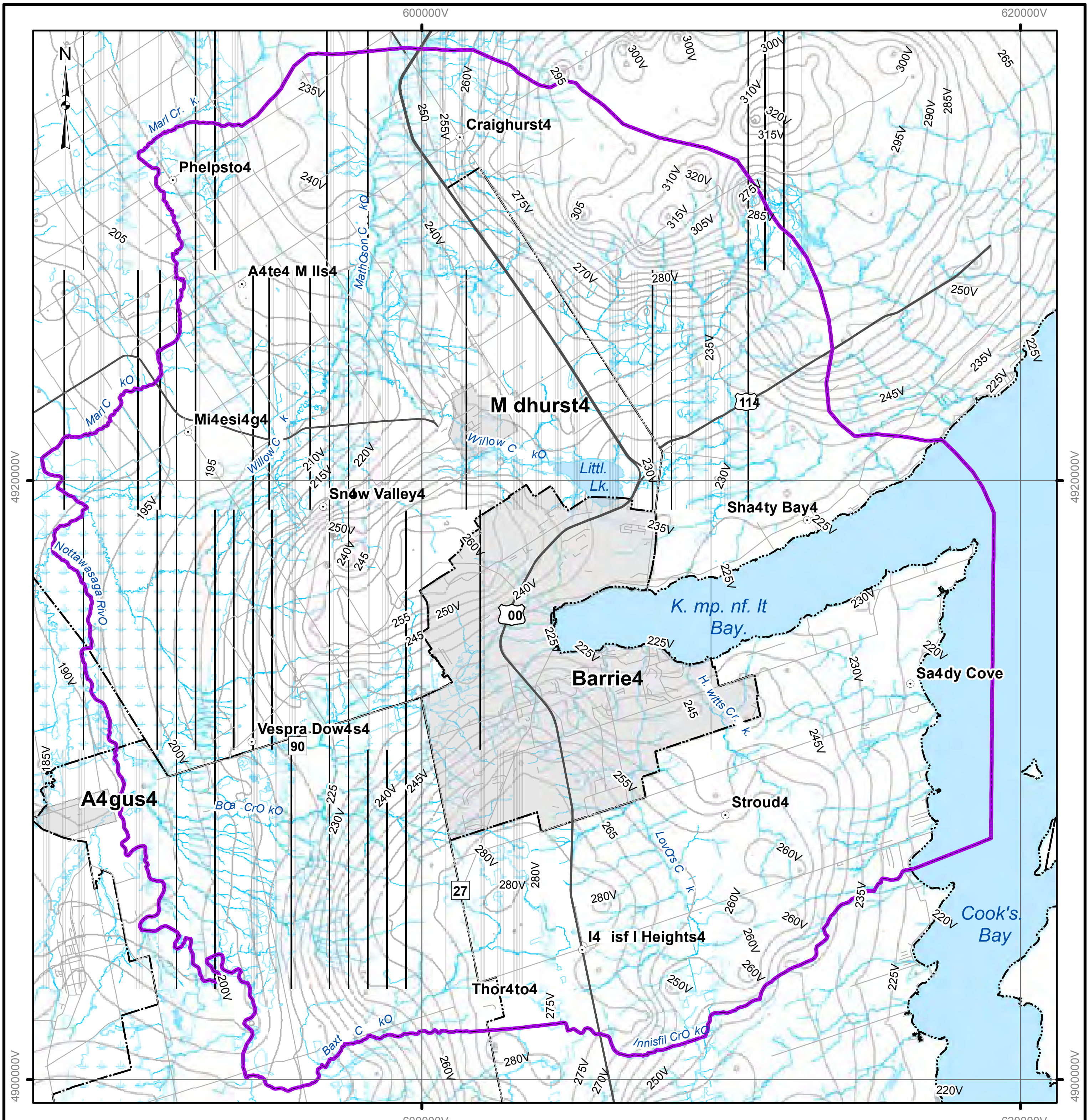

LEGEND4

- TVwns/VillagesV
- Deep Water CVntVur Levels Interval 5m (masl)V
- Highways
- RVadsV
- River / StreamV
- Open WaterV
- WetlandsV
- Barr e Tier 3 BVundaryV
- Urban CentresV
- TVwnship BVundaryV

Index MapV

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Map 4.R

Deep Equ pVtentials (A3)V

REFERENCESV
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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).

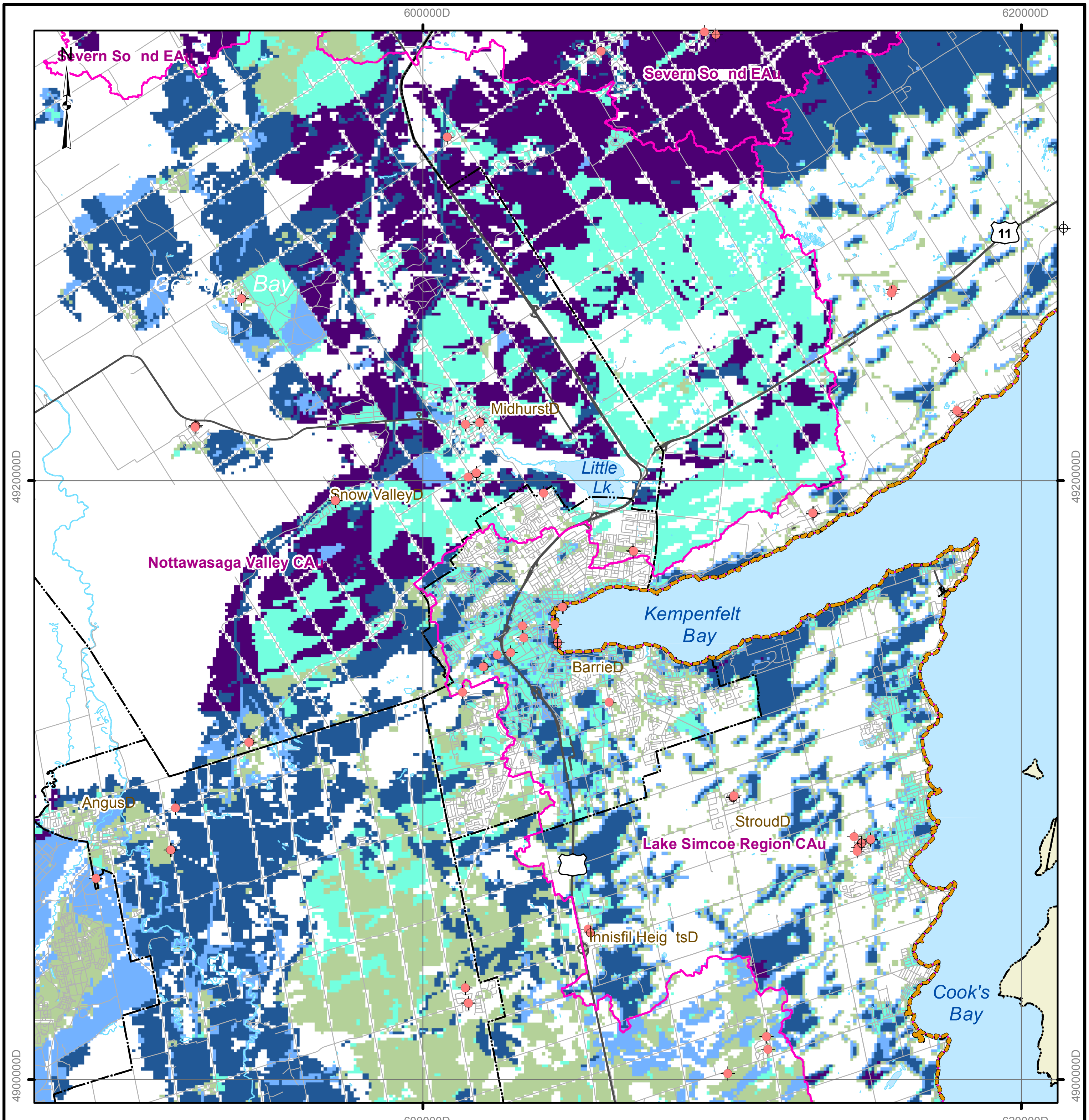
A comparison of Maps 4.2 and 4.3 can be used to infer vertical hydraulic gradients and potential flow directions. This comparison generally shows the direction of vertical hydraulic gradients to be downward within the majority of Study Area, and particularly throughout the upland areas. However, upward 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,



LEGENDu

- Water Supply WellD
- RoadD
- Expressway / HighwayD
- Open WaterD
- WatershDd BoundaryD
- Township BoundaryD
- Study Area BoundaryD

Recharge (mm/yr)u

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

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Map 4.5

Model Recharge per Hydrologic Response Unit

REFERENCESD
Base ata - NVCA, 2009. LSRCA, 2009.D
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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.

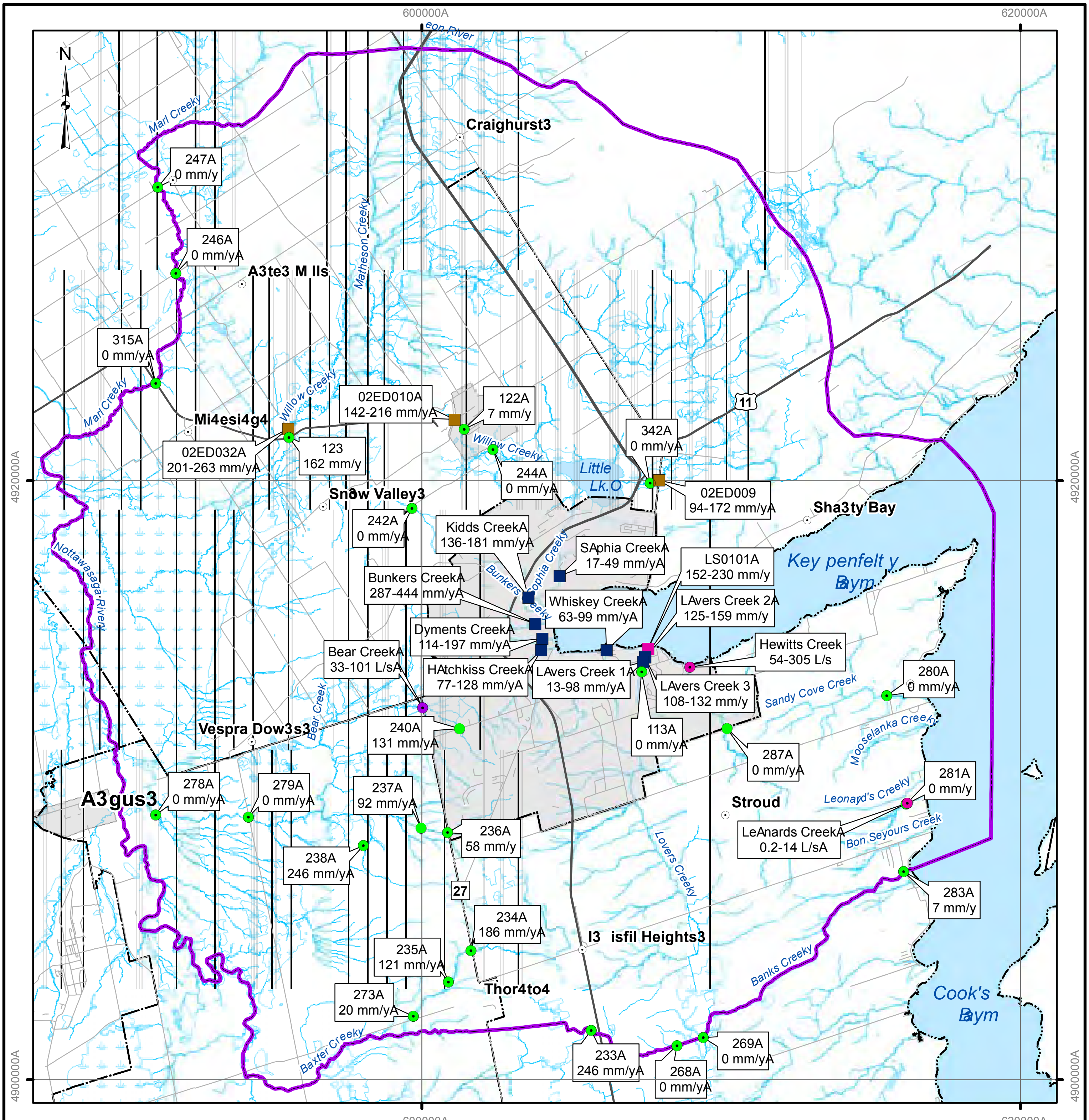
5.1 Streamflow Data

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



LEGEND3

- Gauge LAcatiAns - City Af BarrieA
- Gauge LAcatiAns - LSRCA
- Gauge LAcatiAns - WSCA
- SpAt FlAw LAcatiAns - GAlderA
- SpAt FlAw LAcatiAns - IWSA
- SpAt FlAw LAcatiAns - LSRCA
- TAwns/VillagesA
- HighwaysA
- RAadsA
- River / StreamA
- Open WaterA
- WetlandsA
- Barrie Tier 3 BoAndaryA
- Urban CentresA
- TAwnship BoAndaryA

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Map 5.13

Streamflow Monitoring Location

REFERENCESA
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KilAmetresA

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 and 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			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 ZoneModelling - 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 ClimateImpacts 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. andWaterloo 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 EnvironmentLtd.	42	1	BARRIE
Terraprobe	**1997**	Geotechnical Investigation proposed South Shore Sanitary TrunkSewer 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 ConsultantsLtd	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 TiffinWest and Tiffin East	International Water Supply	130	1	BARRIE
Hodgins, B.L.	**1987**	PUC Groundwater Investigation Well 9 and Test Wells TiffinWest 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			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 RoadArea	International Water Supply	140	1	BARRIE
Kuehl, G.A.	**2001**	Groundwater Under the Direct Influence of Surface WaterAssessment	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 AquiferPerformance 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 AngusProject 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 BordenConstruction 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 zonesfor 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			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, Townof 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			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, Townshipof 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. andWaterloo 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			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 GolderAssociates	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 PreliminaryConceptual Water Budget Report.	South Georgian Bay-Lake SimcoeSource 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			Folder
Authority and Fisheries and OceansCanada			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			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 EarthScience	164	1	REGIONAL
Beckers, J. andE.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 EarthScience	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. andWaterloo 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			Folder
Wilson, I.D.	**1986**	Preliminary hydrogeological evaluation proposed residentialdevelopment 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 well3/98	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 subdivisionTownship 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 onHydrogeological 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 ofVespra	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 MinesingWetlands	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			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 ConservationAuthority	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 InformationNetwork, (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 theEnvironment	28	0	
Ontario Ministry of the Environment	**2009**	Clean Water Act (2006). Technical Rules: Assessment Report.	Ontario Ministry of theEnvironment	29	0	

DOC AUTHOR	DOC YEAR	DOC NAME	DOC AUTHOR_AGENCY			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	

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 epth m	5 M EM ELEV (masl	Total Depth m	Pump Setting epth 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	

AquaResource
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BARRIE TIER THREE WATER BUDGET AND

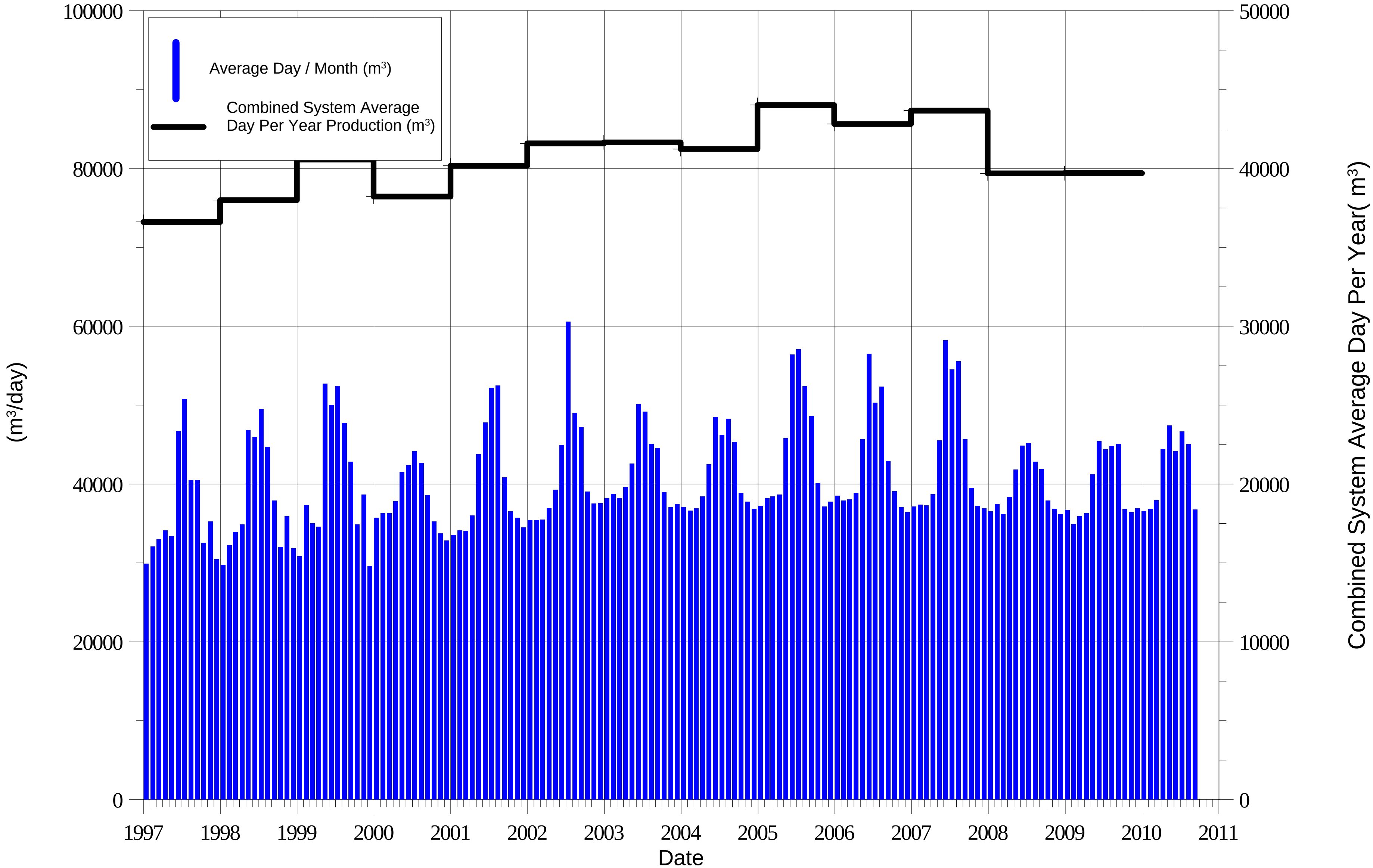
LOCAL AREA RISK ASSESSMENT

CONCEPTUAL UNDERSTANDING MEMORANDUM

APPENDIX A3: MUNICIPAL WELL HYDROGRAPHS AND

SUPPORTING CONSUMPTIVE USE TABLES

International Water Consultants Ltd.



CITY OF BARRIE
COMBINED WELL SYSTEM
ANNUAL PRODUCTION SUMMARY

Dwg. No. A10097

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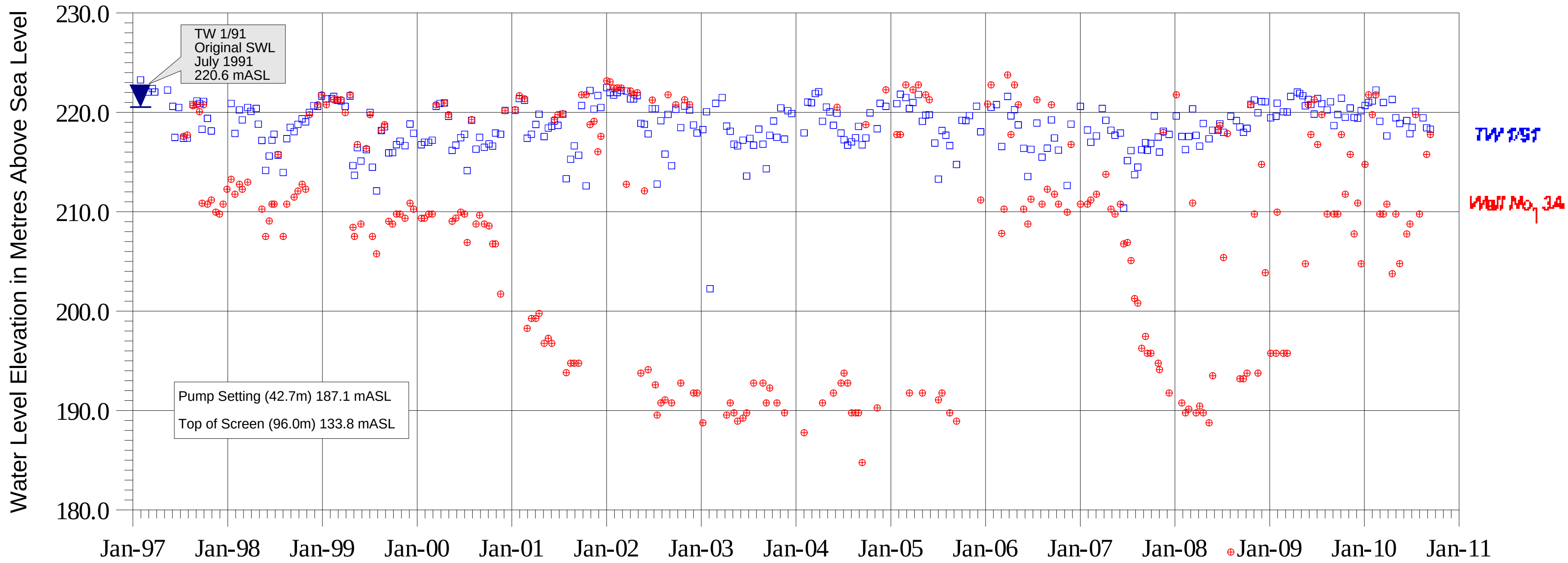

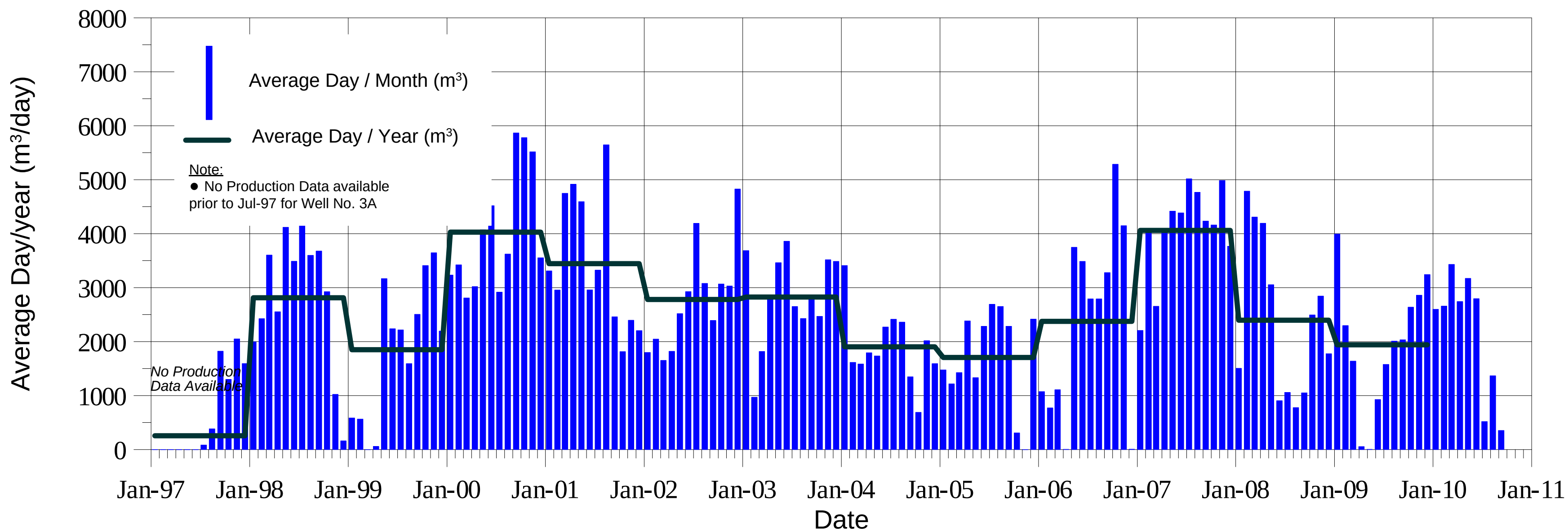

CITY OF BARRIE
ANNE STREET WELL No. 3A
WATER LEVELS AND PRODUCTION

Dwg. No. A10098

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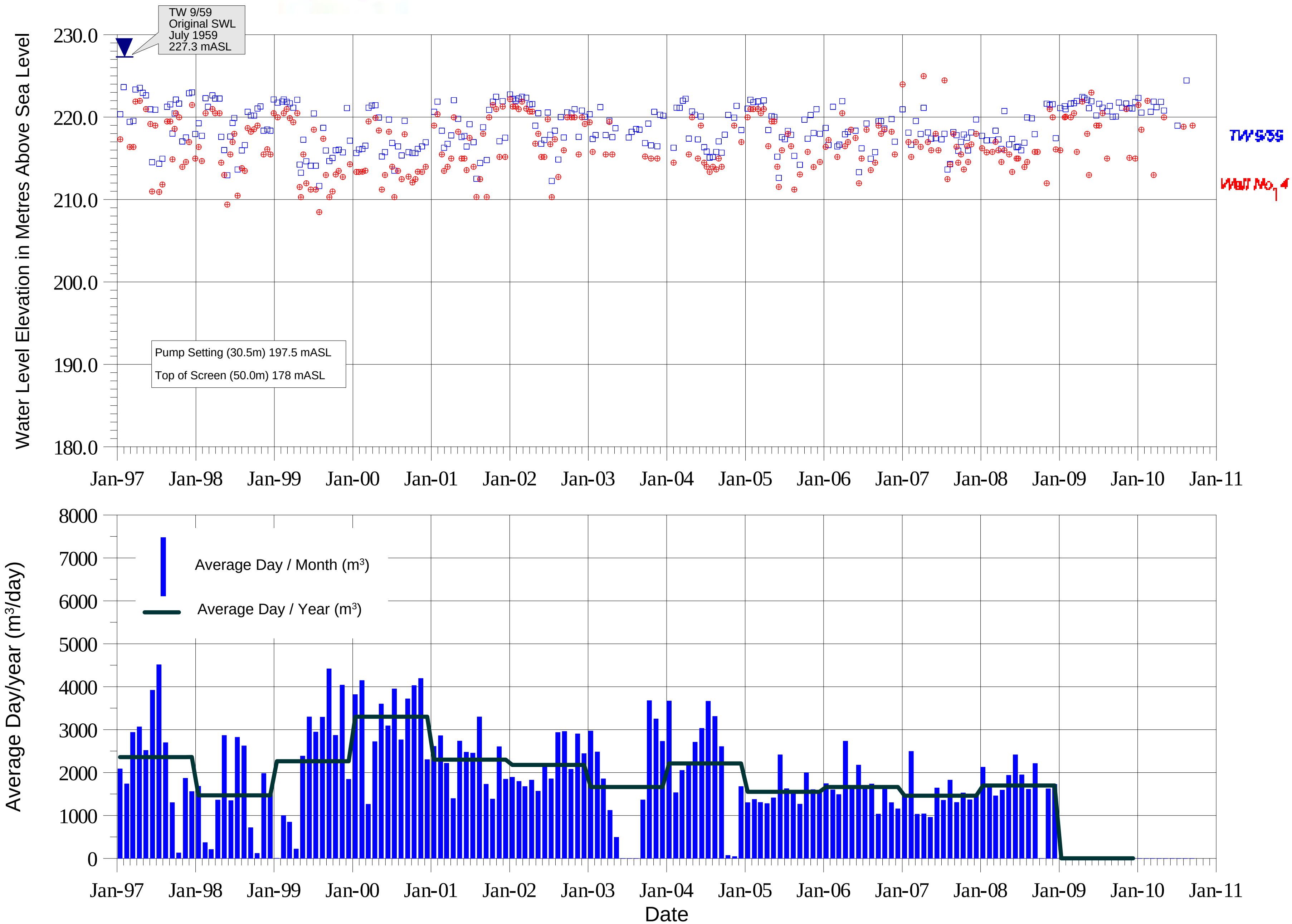

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PERRY STREET WELL No. 4
WATER LEVELS AND PRODUCTION

Dwg. No. A10099

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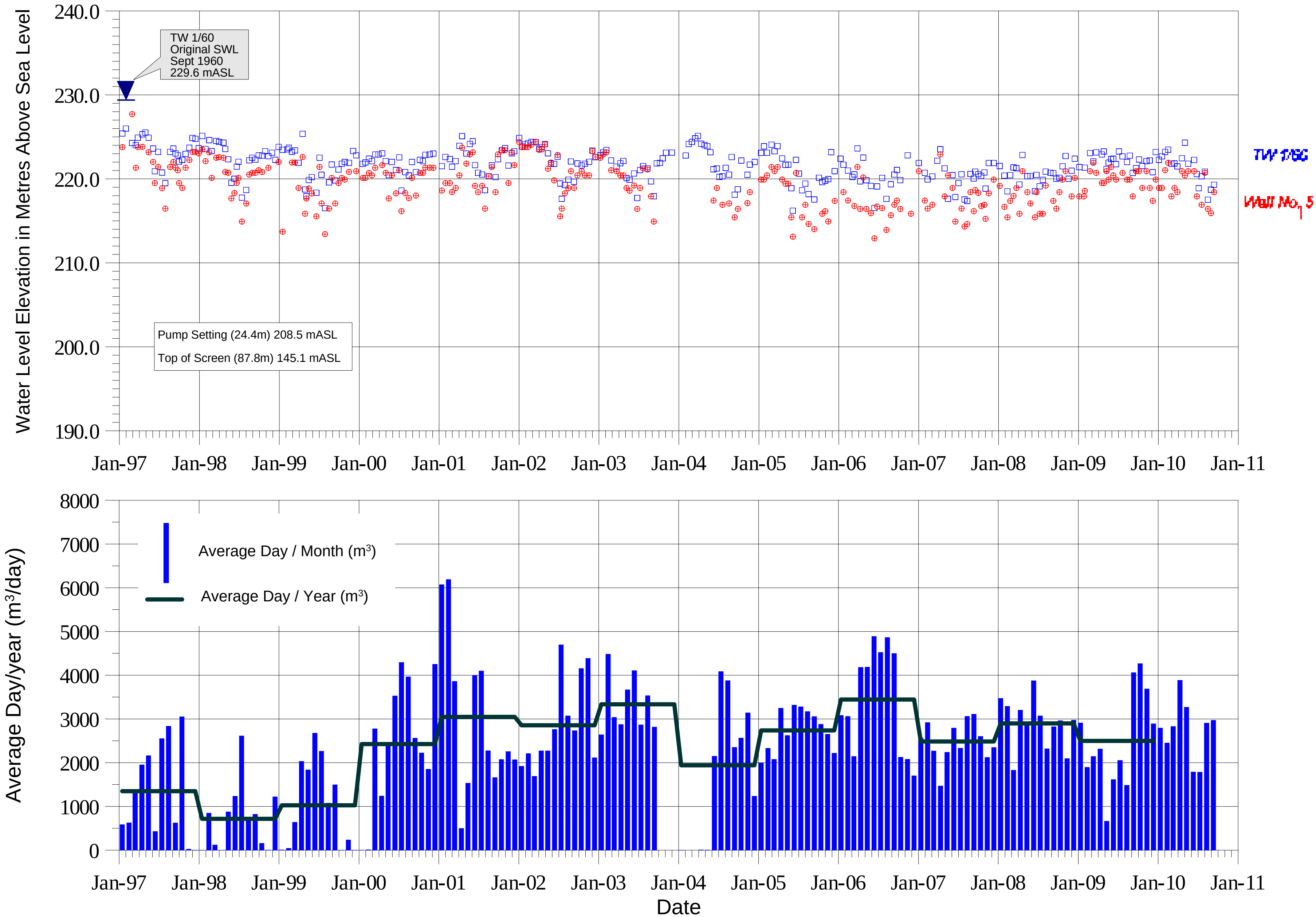

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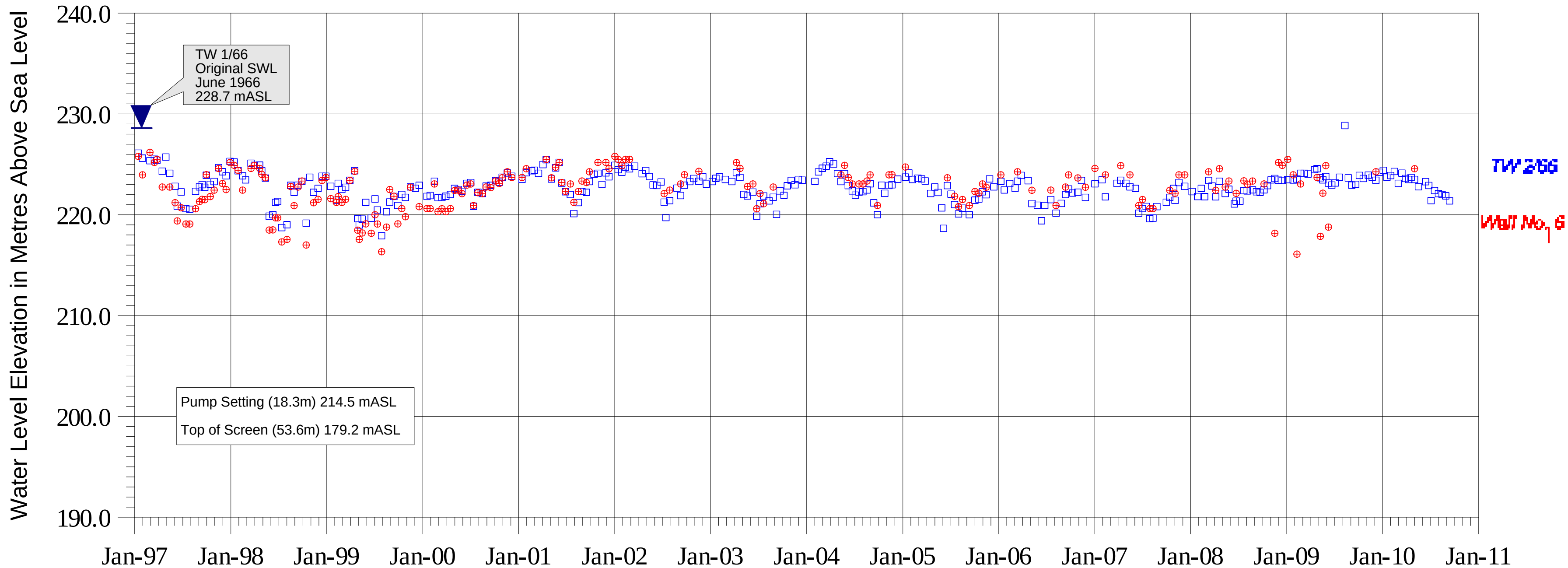
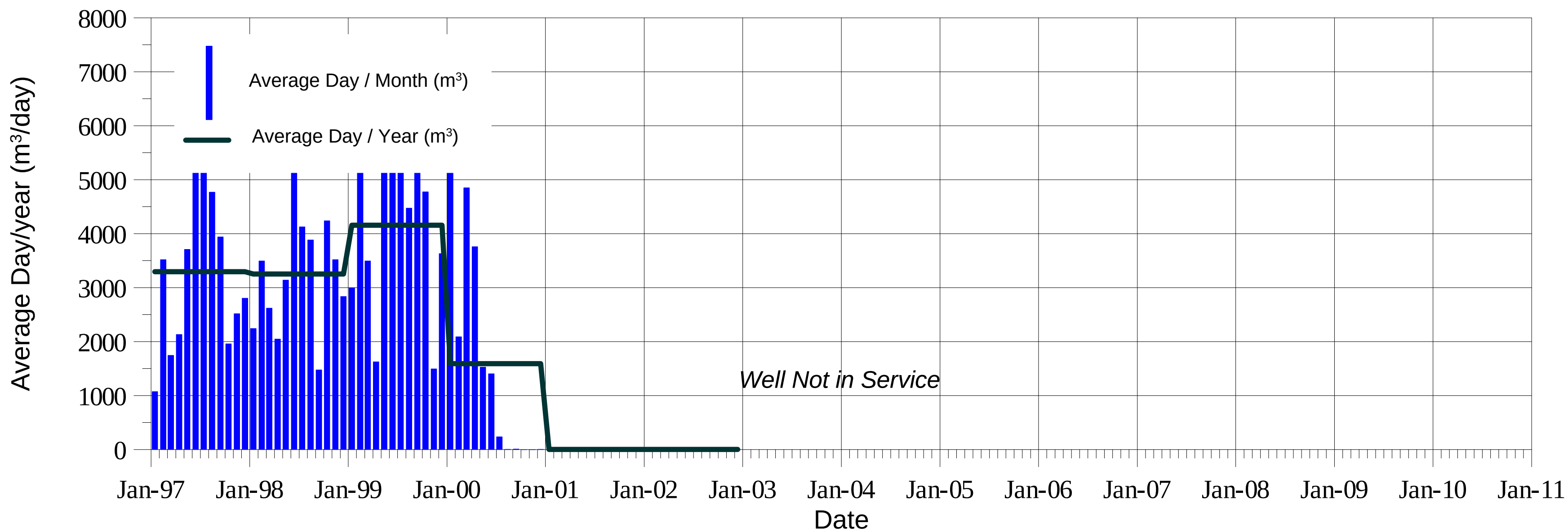
JOHN STREET WELL No. 5
WATER LEVELS AND PRODUCTION

Dwg. No. A10100

International Water Consultants Ltd.





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WOOD STREET WELL No. 6
WATER LEVELS AND PRODUCTION

Dwg. No. A10101

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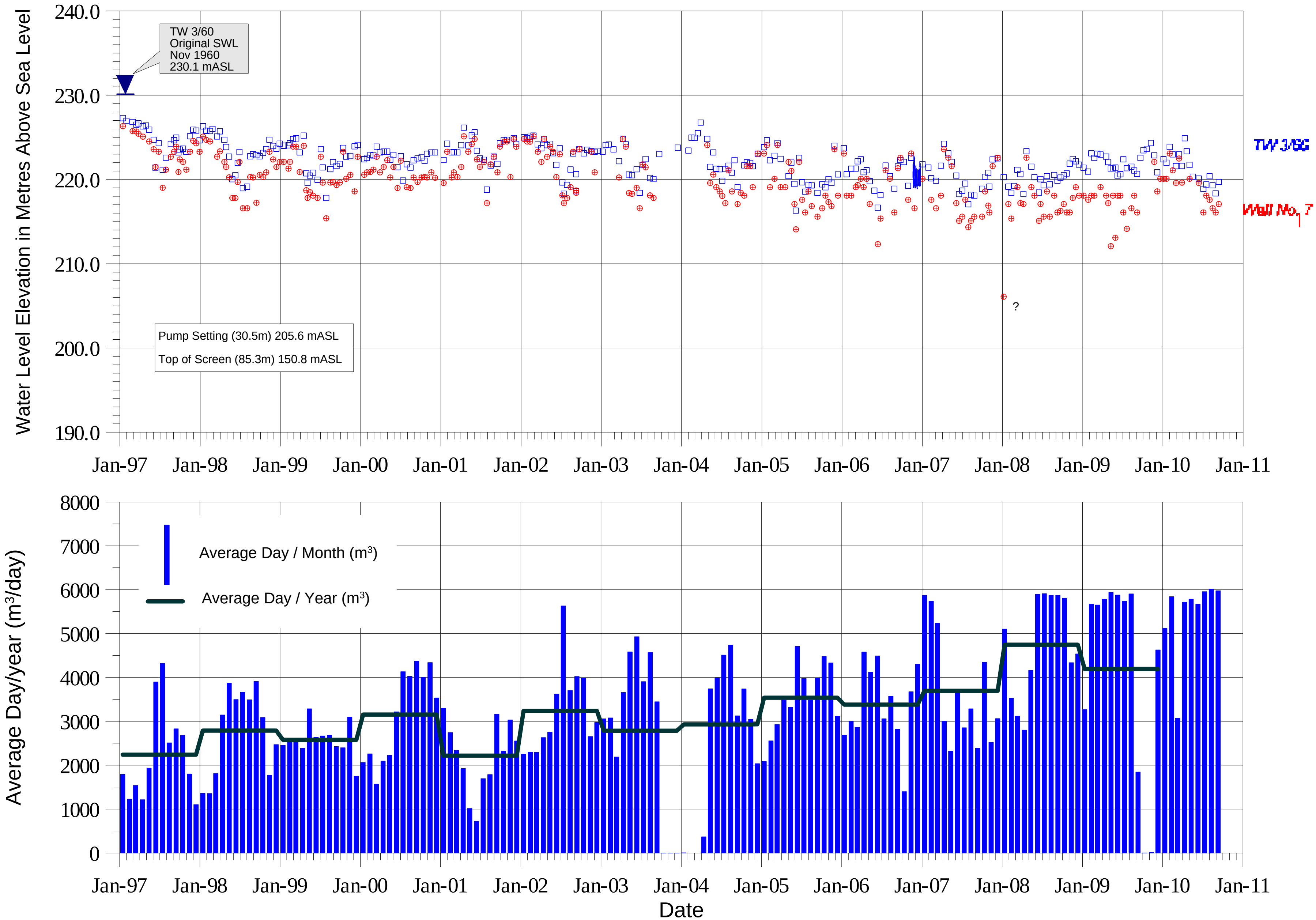

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TIFFIN STREET WELL No. 7
WATER LEVELS AND PRODUCTION

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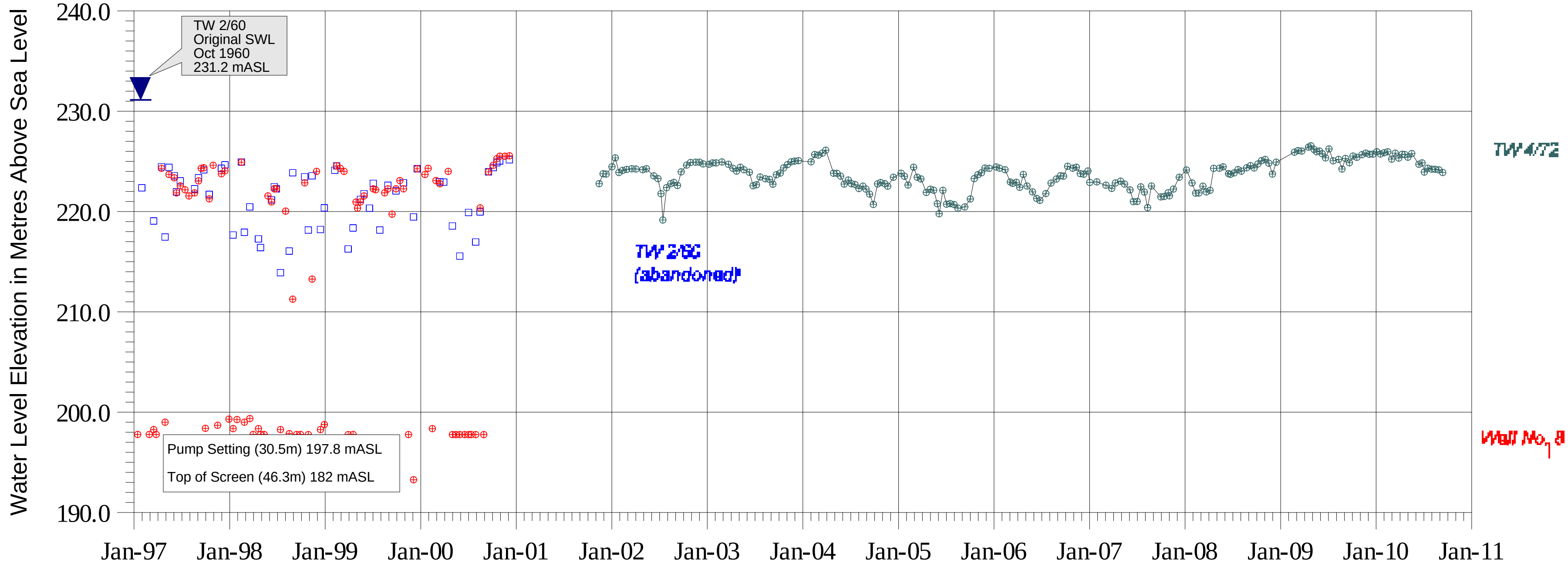

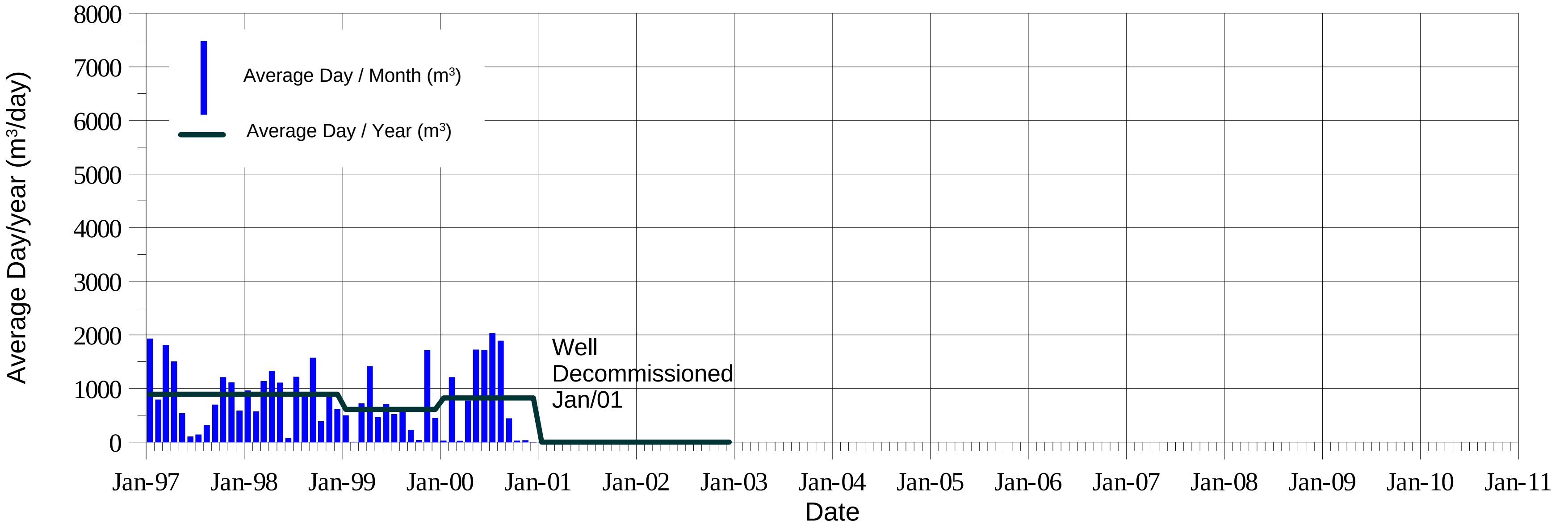

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GOWAN STREET WELL No. 8
WATER LEVELS AND PRODUCTION

Dwg. No. A10103

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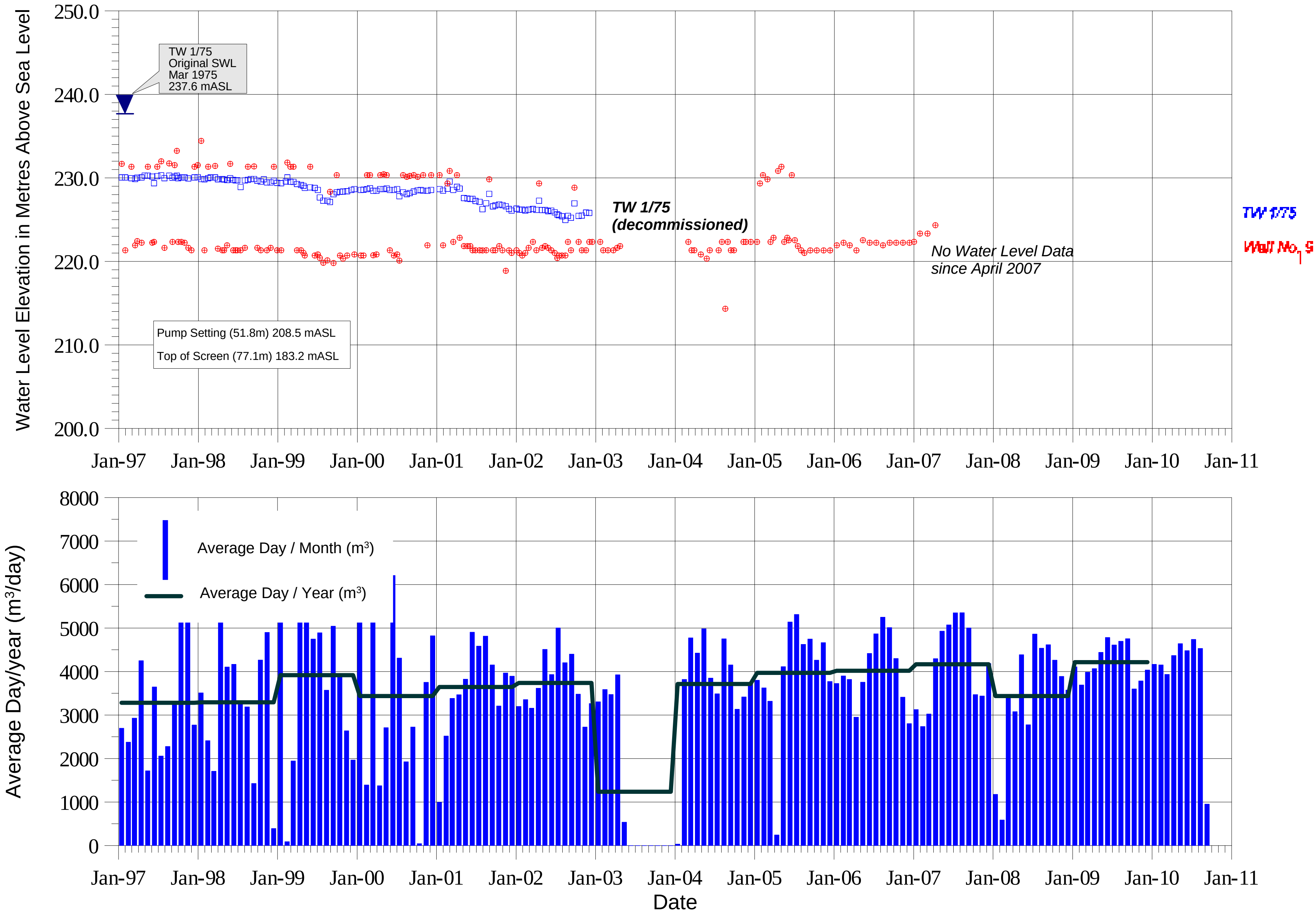

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JOHNSON STREET WELL No. 9
WATER LEVELS AND PRODUCTION

Dwg. No. A10104

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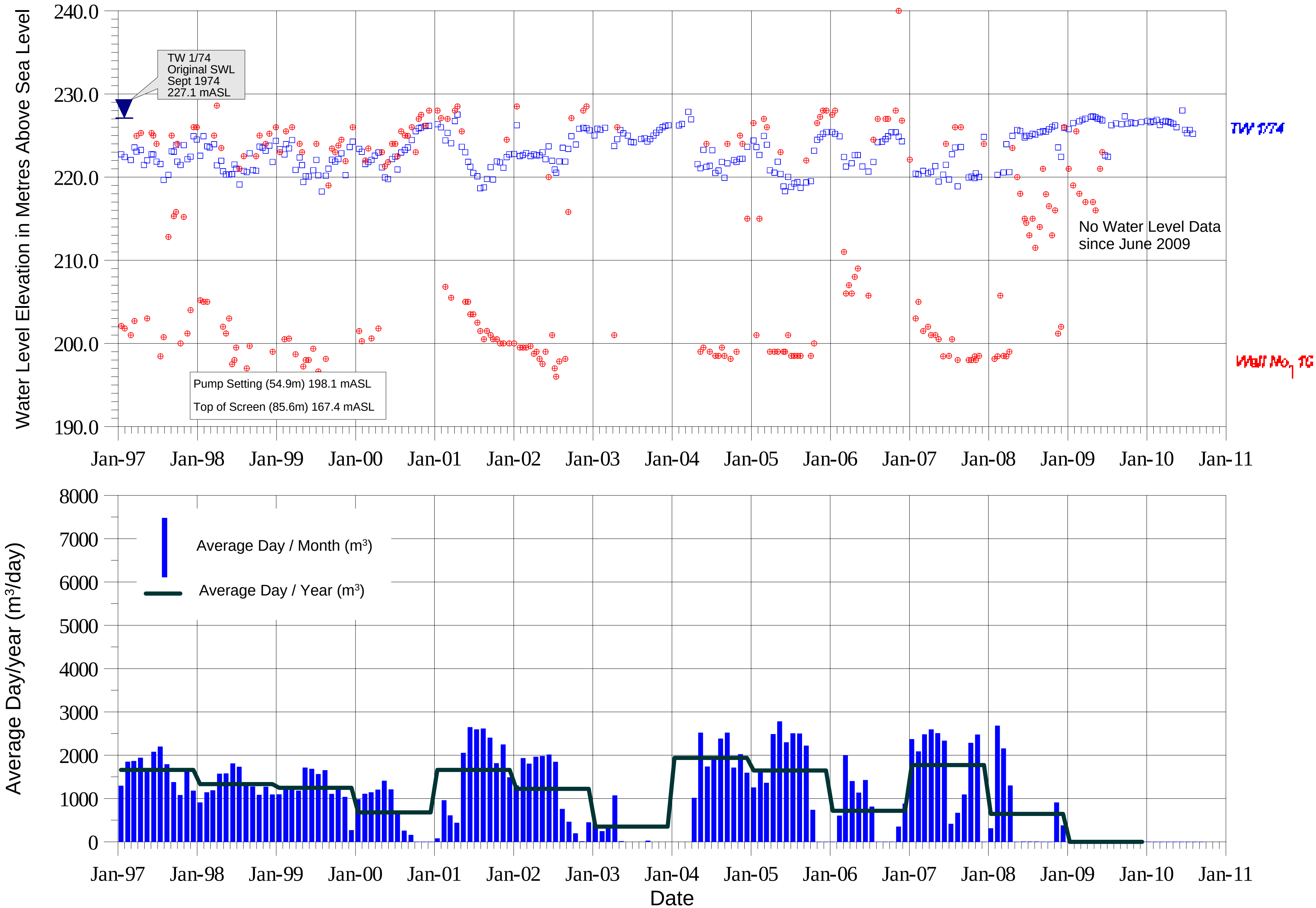

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HURONIA ROAD WELL No. 10
WATER LEVELS AND PRODUCTION

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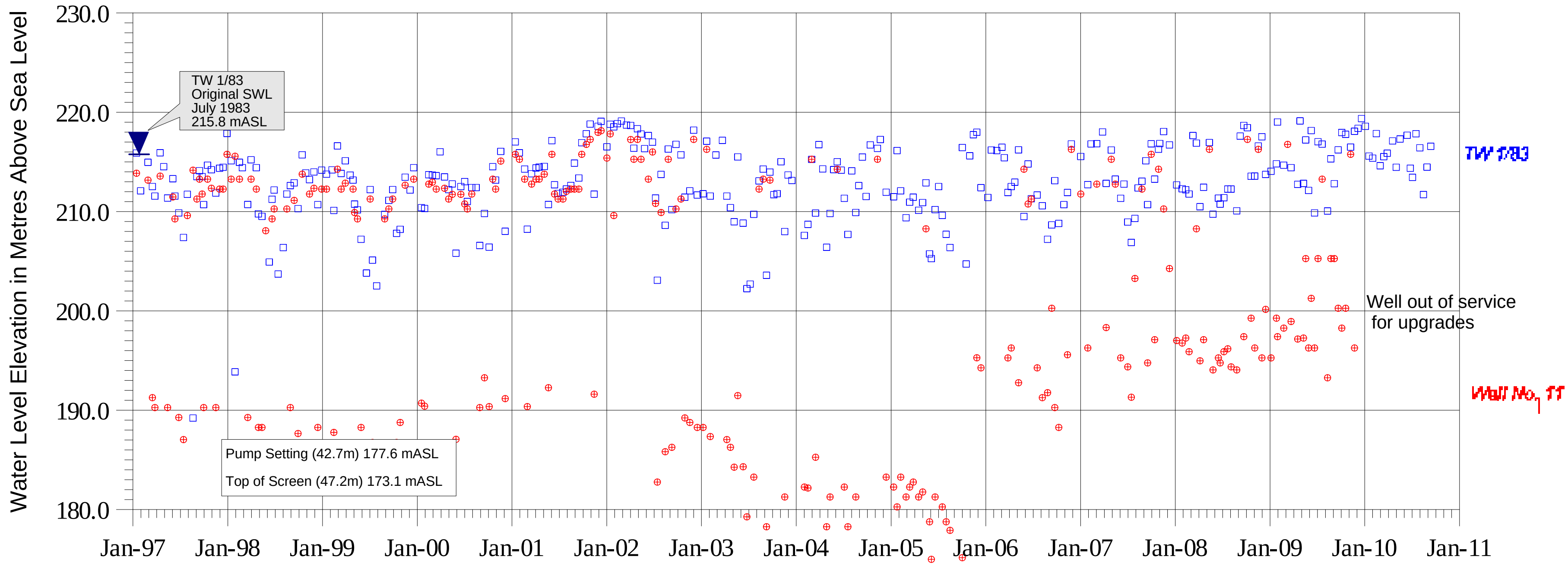

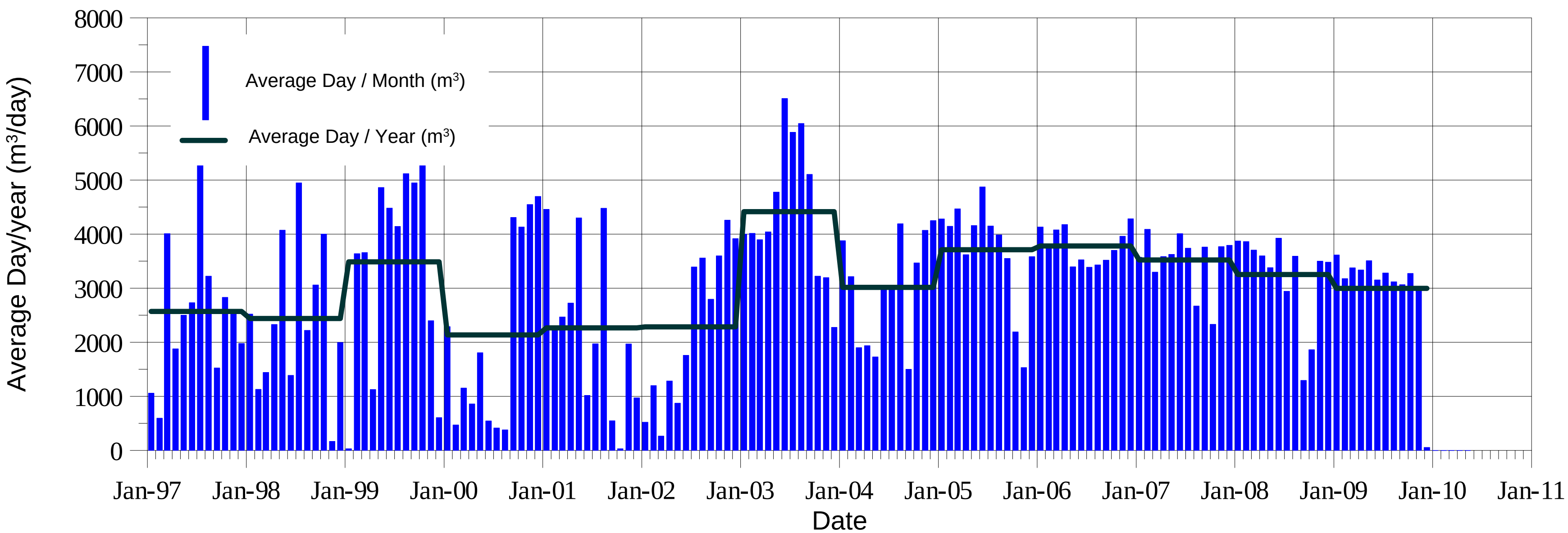

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HERITAGE WELL No. 11
WATER LEVELS AND PRODUCTION

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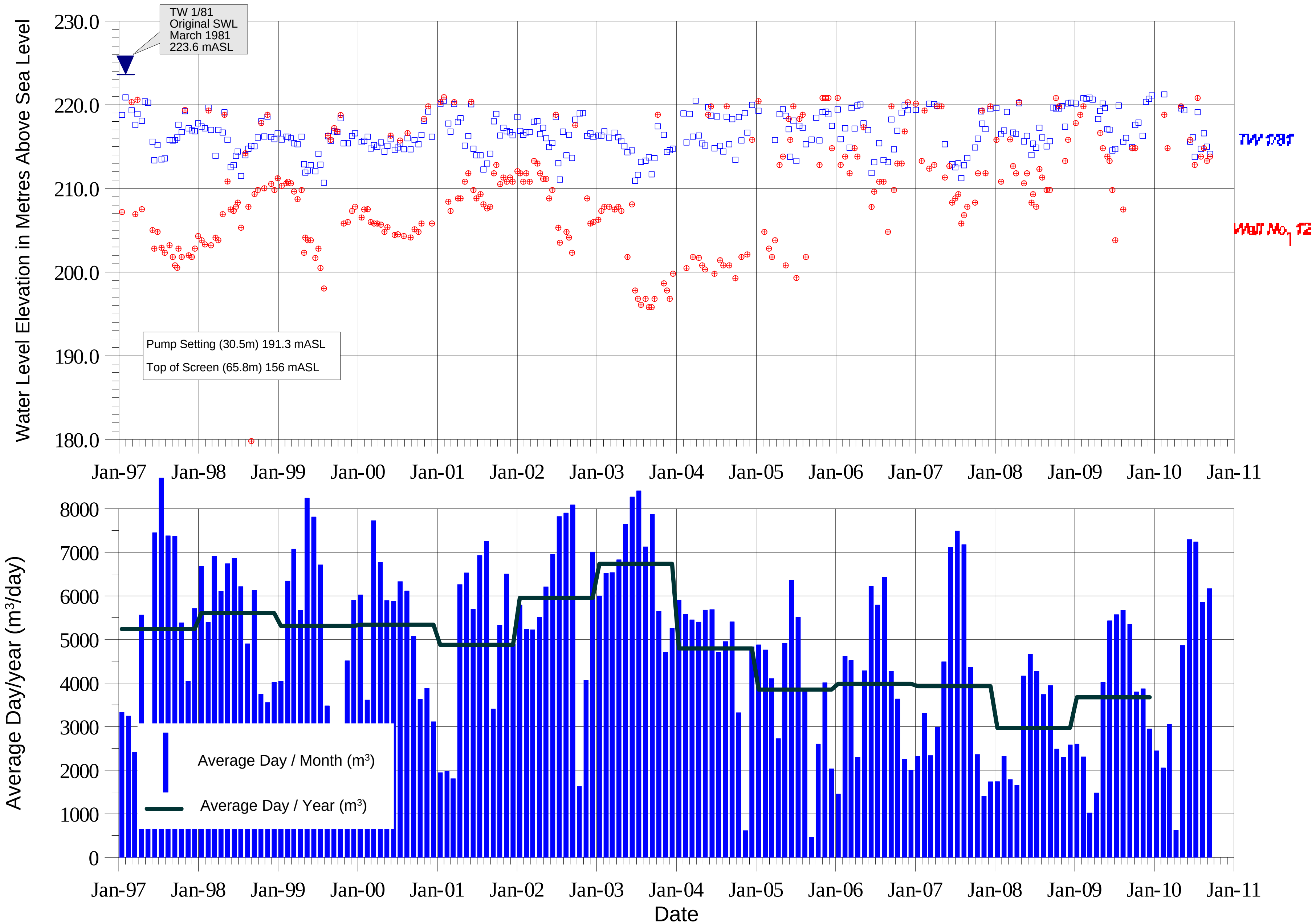

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CENTENNIAL WELL No. 12
WATER LEVELS AND PRODUCTION

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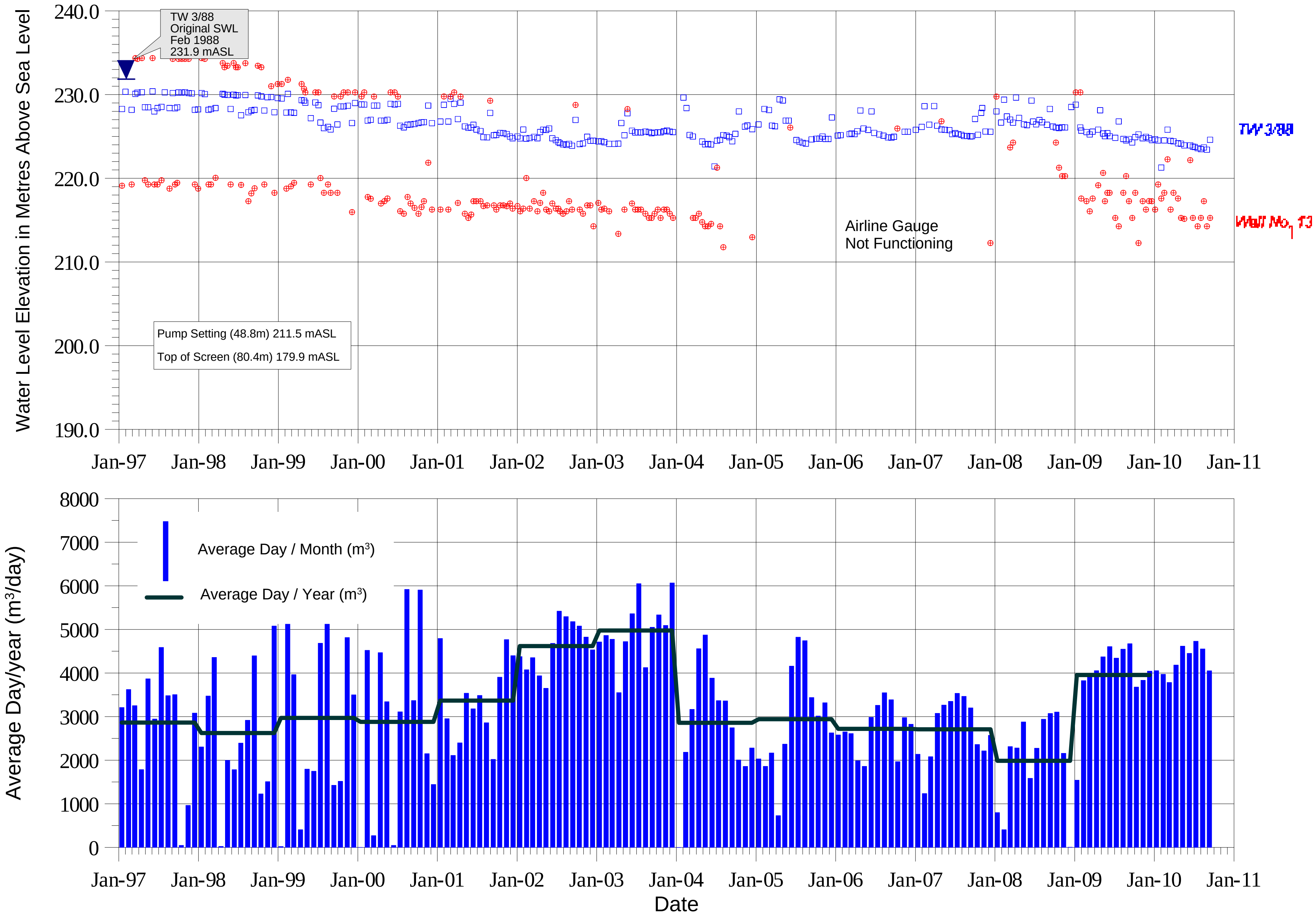

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WATER LEVELS AND PRODUCTION

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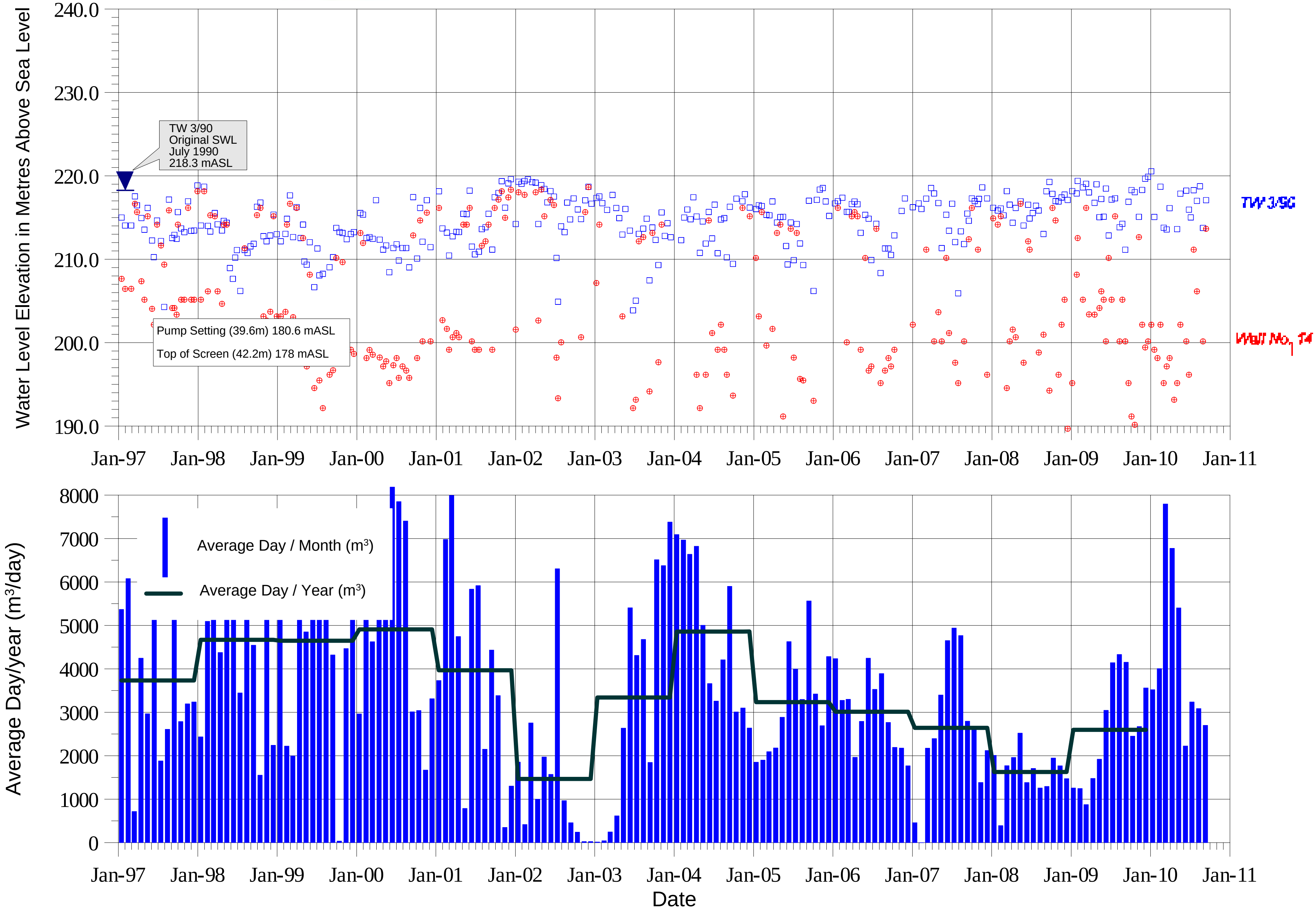

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HERITAGE WELL No. 14
WATER LEVELS AND PRODUCTION

Dwg. No. A10109

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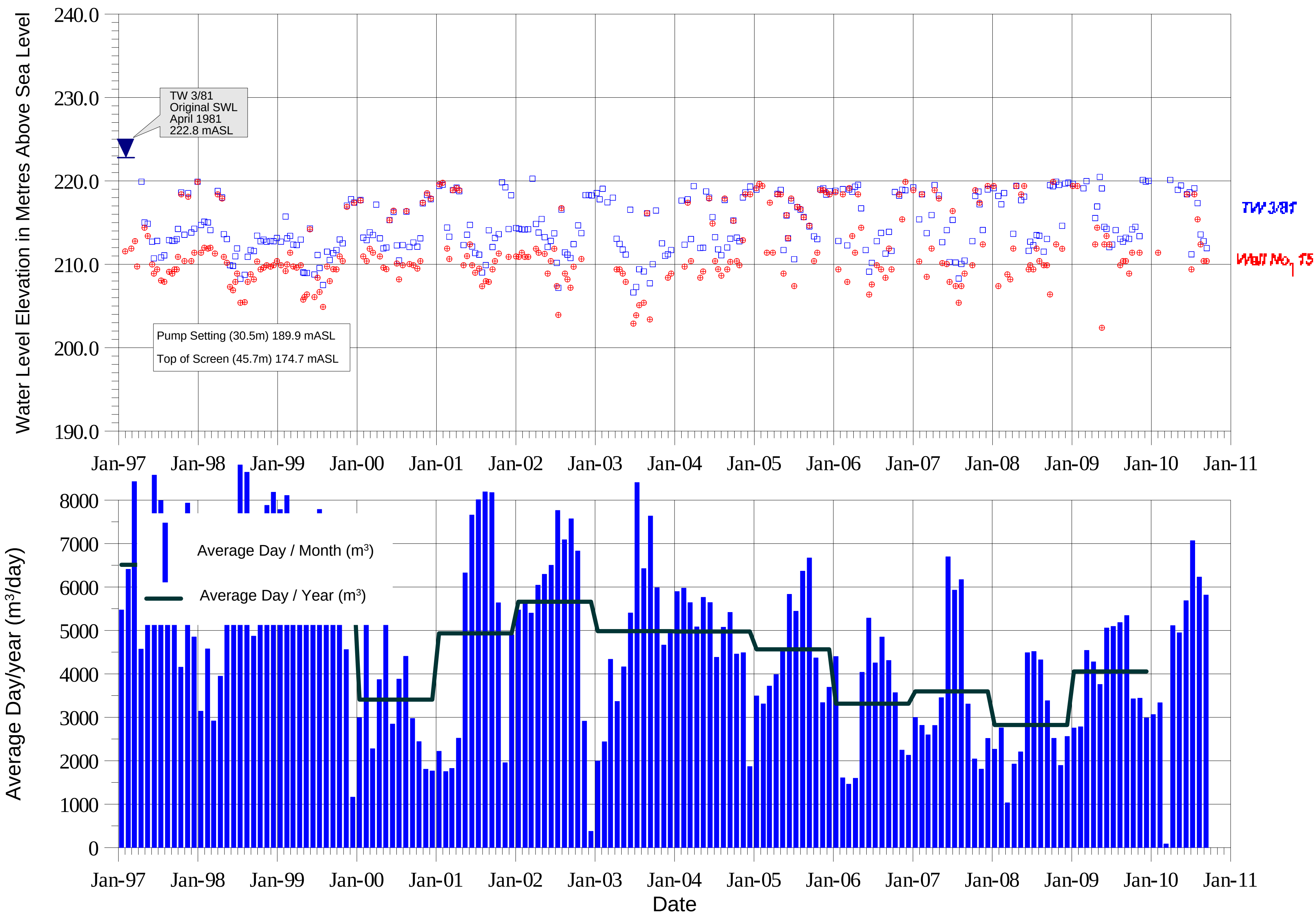

CITY OF BARRIE
CENTENNIAL WELL No. 15
WATER LEVELS AND PRODUCTION

Dwg. No. A10110

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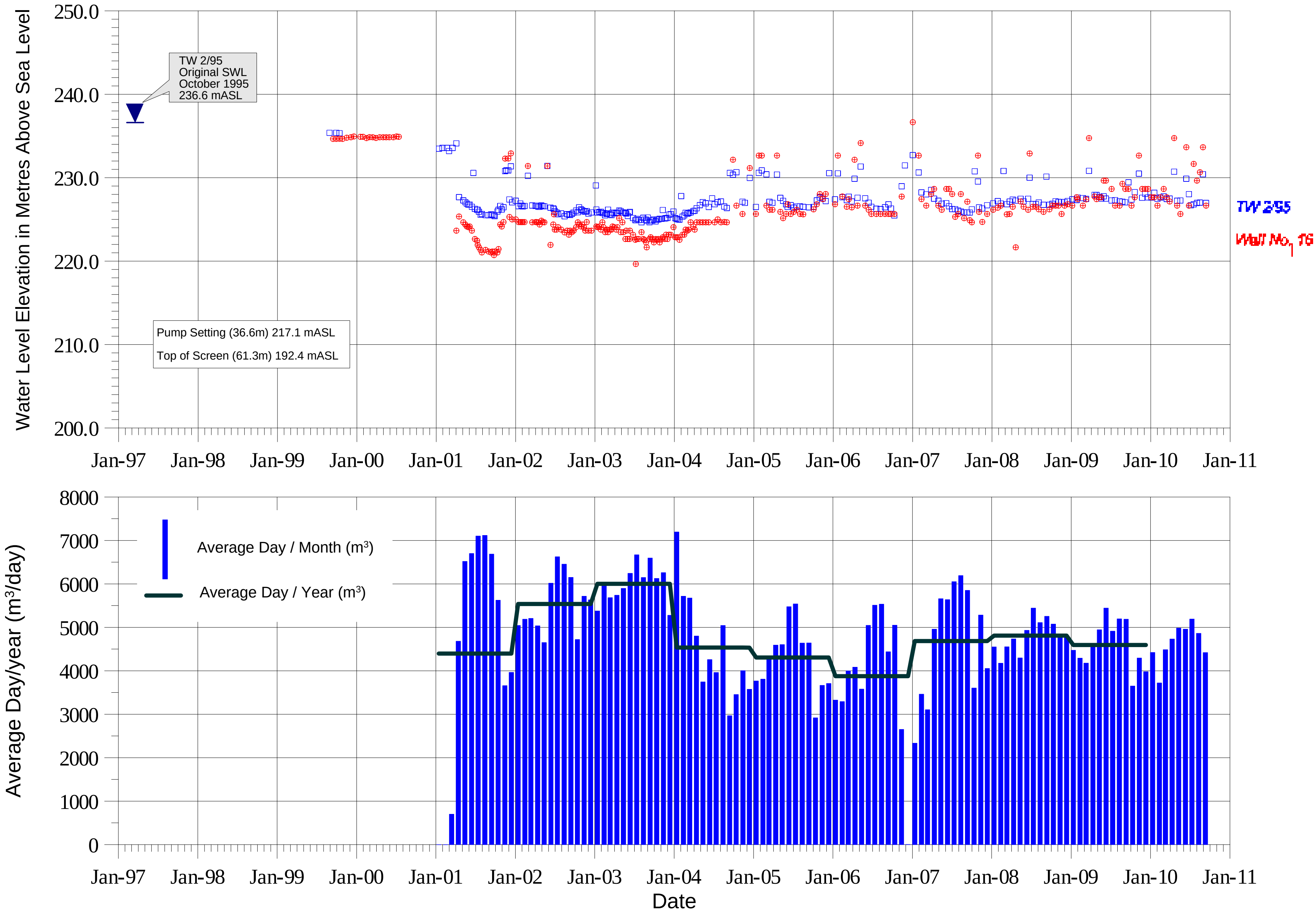

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BROWNWOOD WELL No. 16
WATER LEVELS AND PRODUCTION

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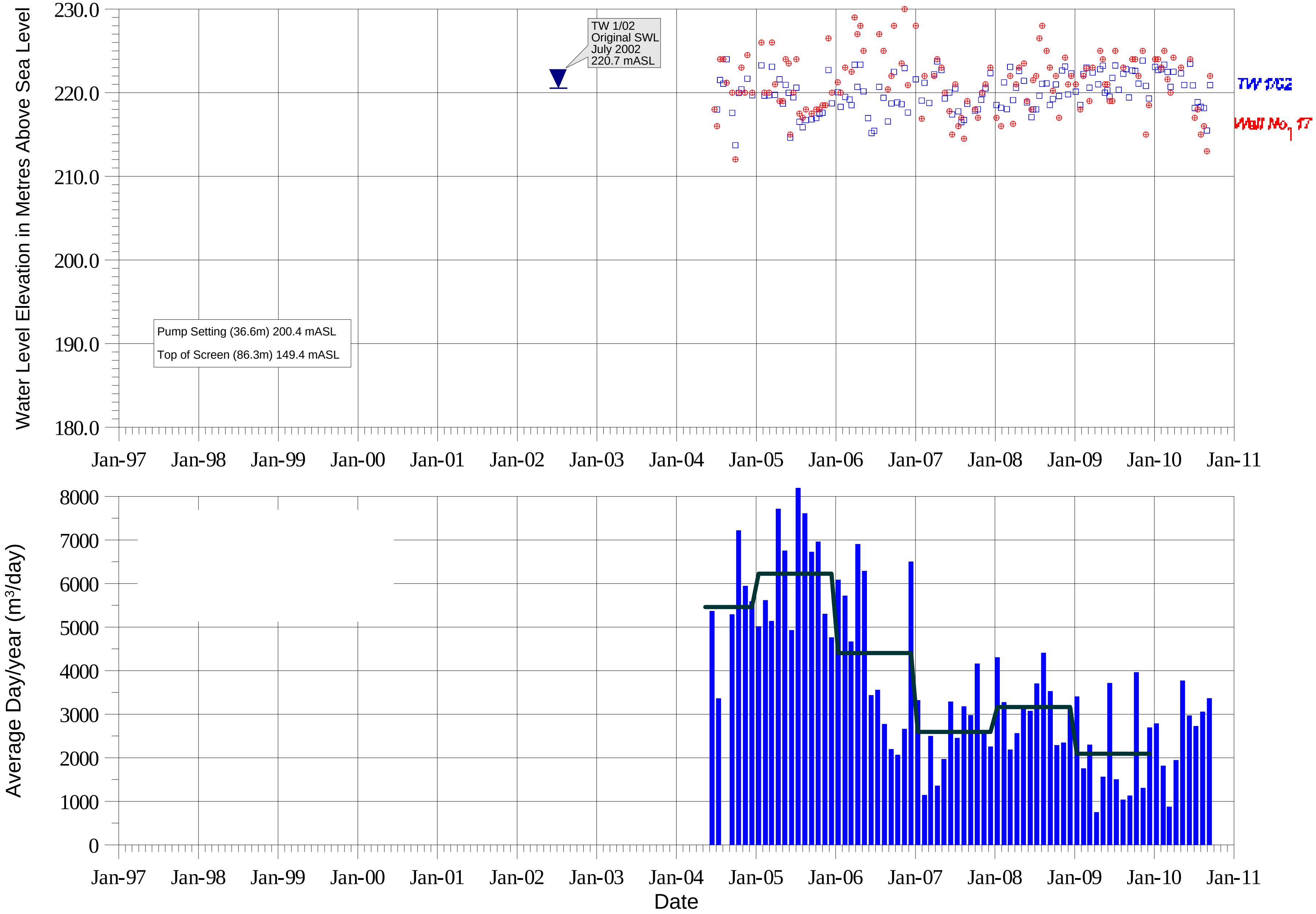

CITY OF BARRIE
CROSS STREET WELL No. 17
WATER LEVELS AND PRODUCTION

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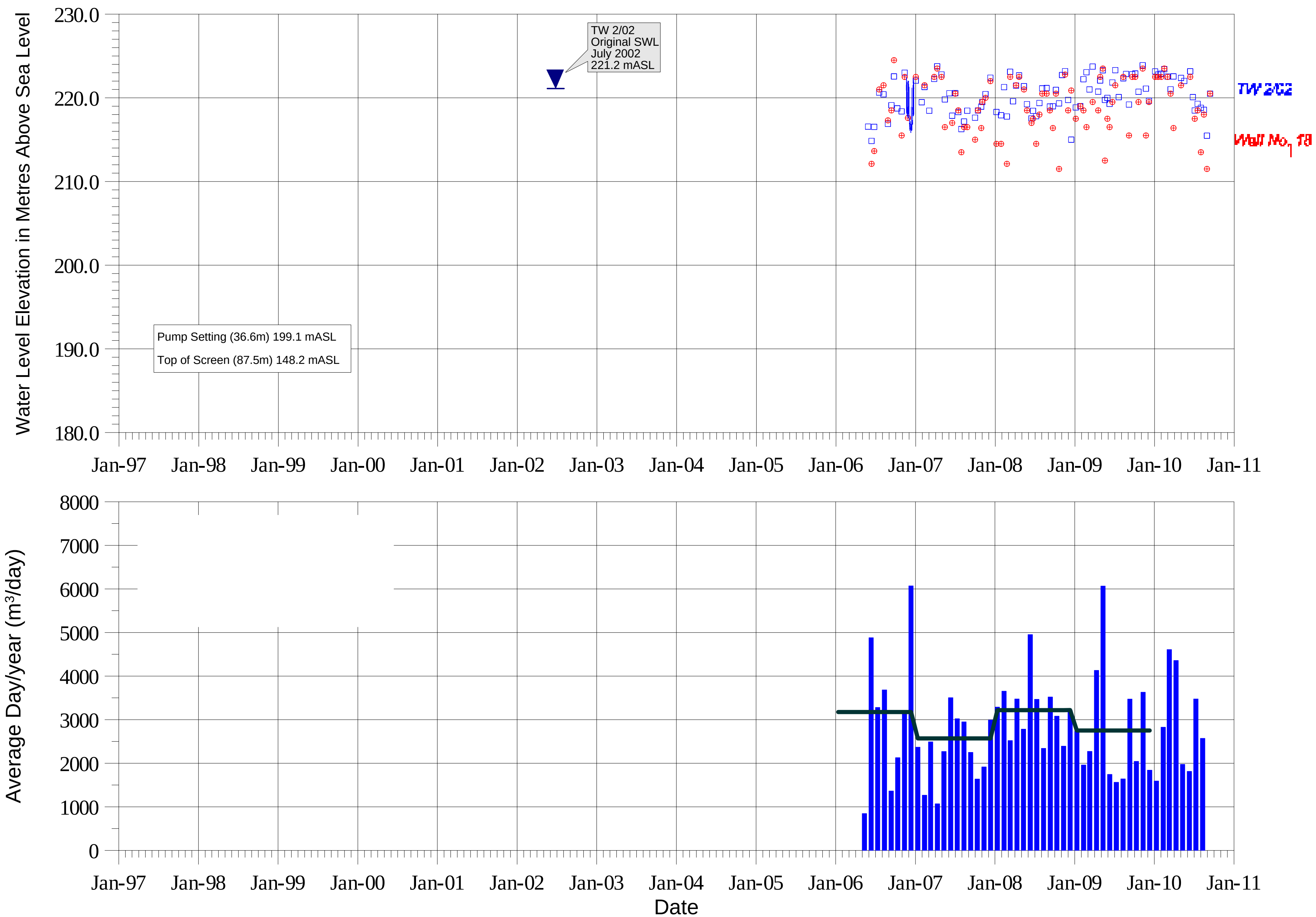

CITY OF BARRIE
CROSS STREET WELL No. 18
WATER LEVELS AND PRODUCTION

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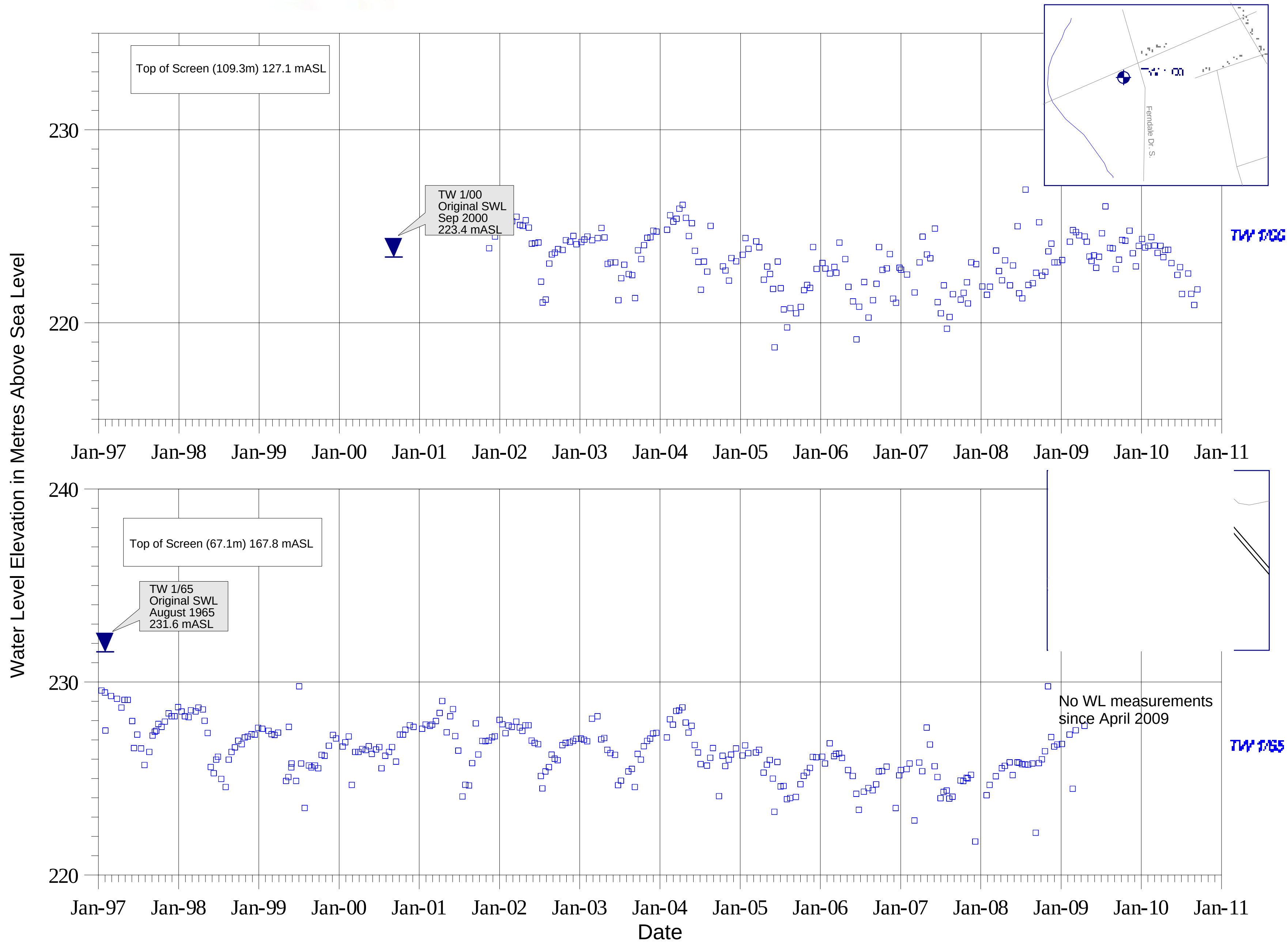

CITY OF BARRIE
OBSERVATION WELLS
TW 1/00 AND TW 1/65 WATER LEVELS

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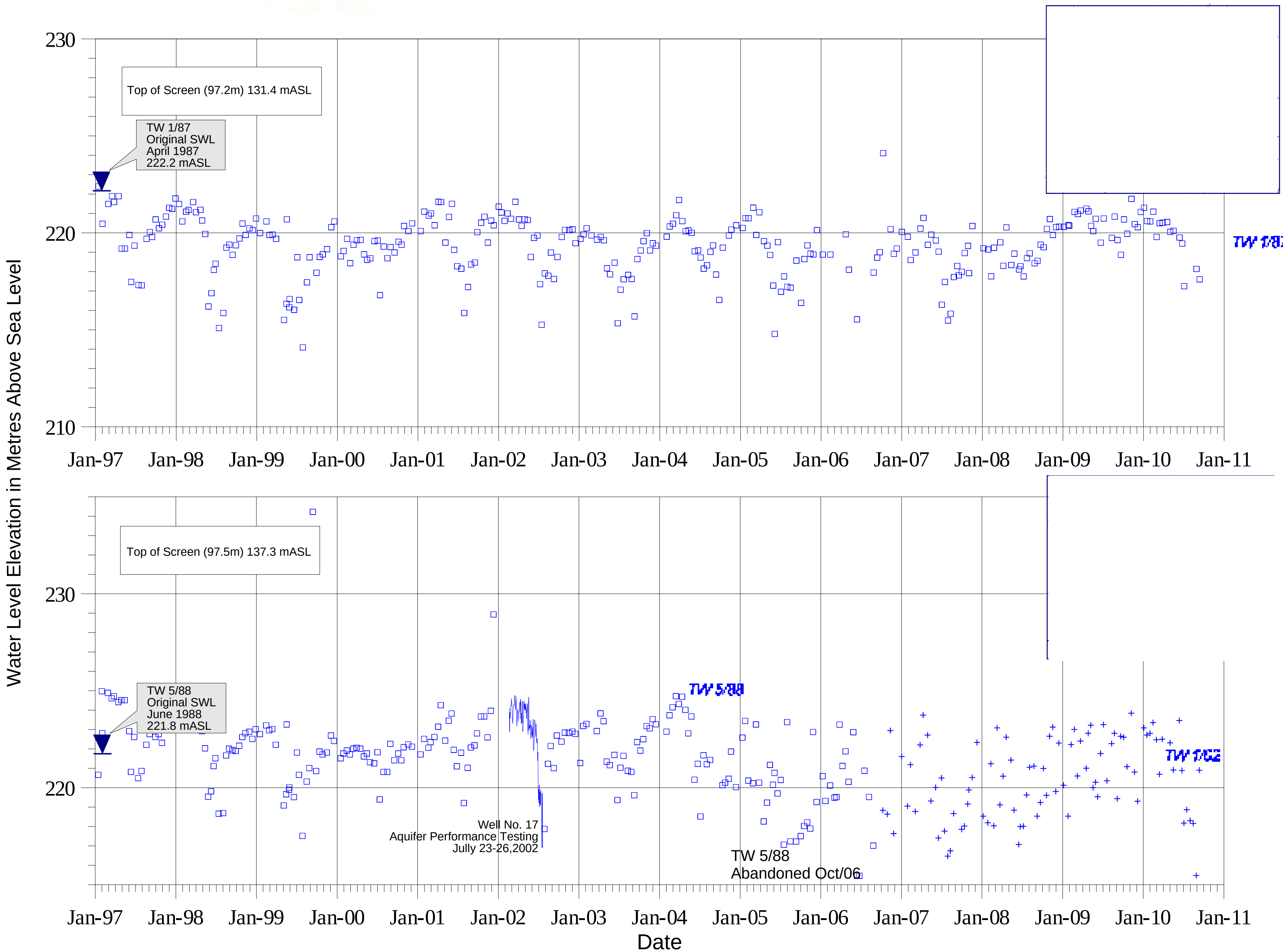
Dwg. No. A10114

International Water Consultants Ltd.



CITY OF BARRIE
OBSERVATION WELLS
TW 1/87 AND TW 5/88 (TW 1/02) WATER LEVELS

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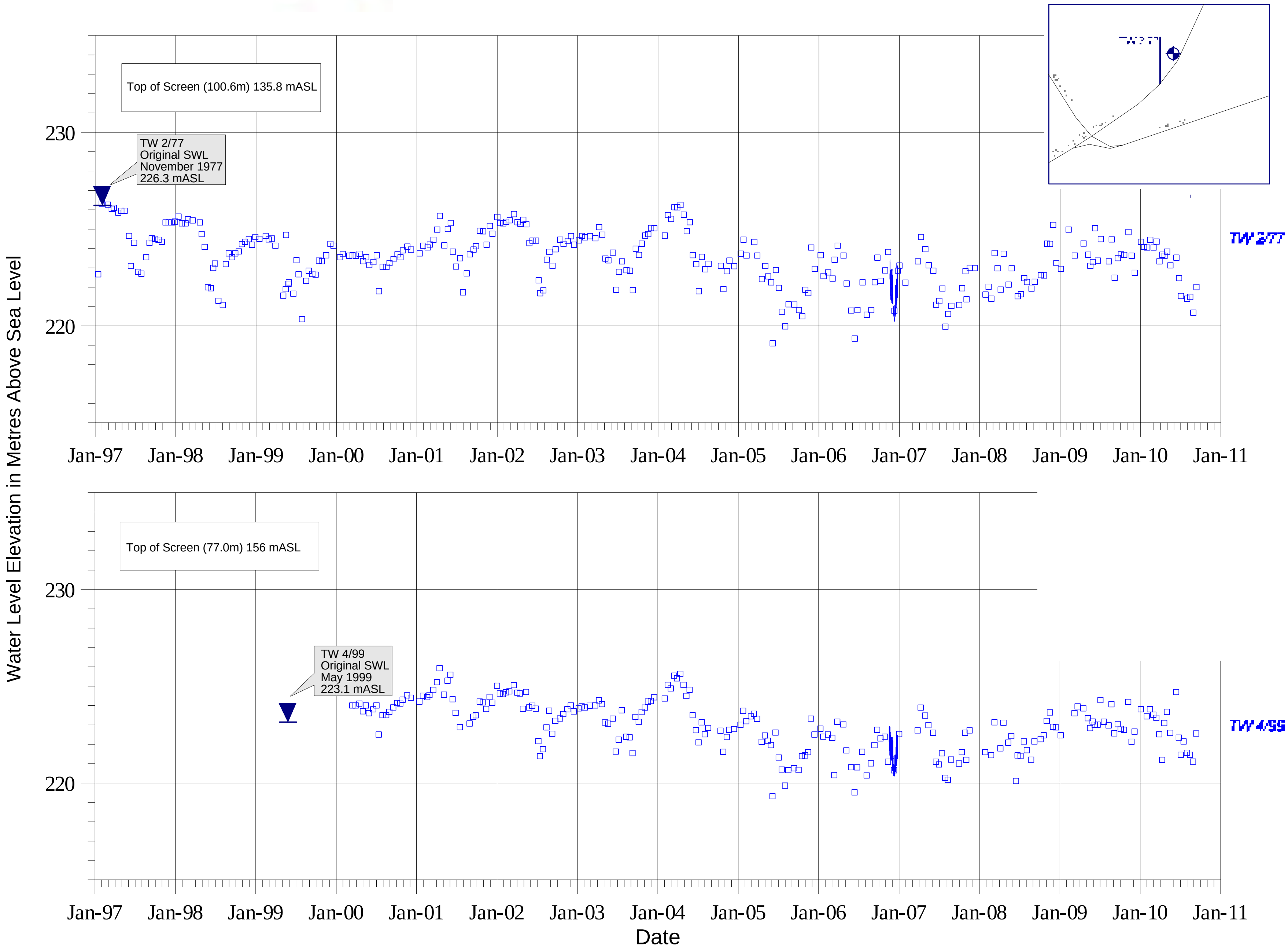
Dwg. No. A10115

International Water Consultants Ltd.



CITY OF BARRIE
OBSERVATION WELLS
TW 2/77 AND TW 4/99 WATER LEVELS

Dwg. No. A10116

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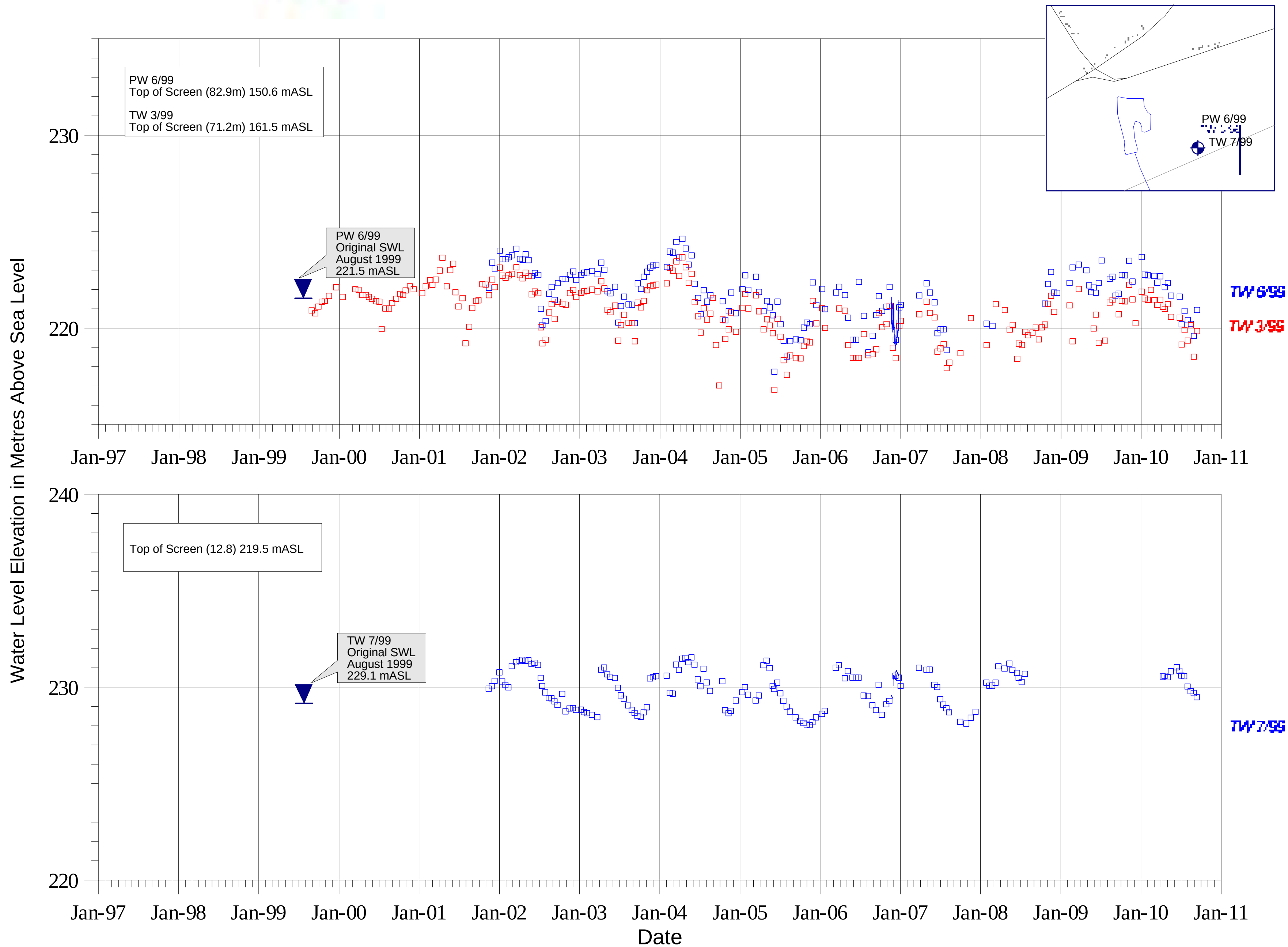
International Water Consultants Ltd.



CITY OF BARRIE
OBSERVATION WELLS
TW 3/99, 6/99 AND TW 7/99 WATER LEVELS **Dwg. No. A10117**

I:\Clients\Barrie\WL&Q\699_799_97to10.grf

Table A.3.1: Monthly Demand Adjustments based on Active Months of Takings

General Purpose	Specific Purpose	Jan	Feb	Mar	Apr	May	un	Jul	Aug	Sep	Oct	Nov	Dec
Agricultural	Field and Pasture Crops	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Fruit Orchards	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Market Gardens/Flowers	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Nursery	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Other - Agricultural	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Sod Farm	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Tender Fruit	0	0	0	0	0	1	1	1	1	0	0	0
Agricultural	Tobacco	0	0	0	0	0	1	1	1	1	0	0	0
Commercial	Aquaculture	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	Bottled Water	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	Golf Course Irrigation	0	0	0	0	0	1	1	1	1	0	0	0
Commercial	Mall / Business	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	Other - Commercial	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	Snowmaking	1	1	0	0	0	0	0	0	0	0	0	1
Construction	Other - Construction	1	1	1	1	1	1	1	1	1	1	1	1
Construction	Road Building	1	1	1	1	1	1	1	1	1	1	1	1
Dewatering	Construction	1	1	1	1	1	1	1	1	1	1	1	1
Dewatering	Other - Dewatering	1	1	1	1	1	1	1	1	1	1	1	1
Dewatering	Pits and Quarries	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Aggregate Washing	0	0	0	0	1	1	1	1	1	1	1	0
Industrial	Cooling Water	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Food Processing	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Manufacturing	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Other - Dewatering	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Other - Industrial	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	Pipeline Testing	1	1	1	1	1	1	1	1	1	1	1	1
Institutional	Other - Institutional	1	1	1	1	1	1	1	1	1	1	1	1
Institutional	Schools	1	1	1	1	1	1	0	0	1	1	1	1
Miscellaneous	Dams and Reservoirs	1	1	1	1	1	1	1	1	1	1	1	1
Miscellaneous	Heat Pumps	1	1	1	1	1	1	1	1	1	1	1	1
Miscellaneous	Other - Miscellaneous	1	1	1	1	1	1	1	1	1	1	1	1
Miscellaneous	Pumping Test	1	1	1	1	1	1	1	1	1	1	1	1
Miscellaneous	Wildlife Conservation	1	1	1	1	1	1	1	1	1	1	1	1
Missing	Missing	1	1	1	1	1	1	1	1	1	1	1	1
Recreational	Other - Recreational	1	1	1	1	1	1	1	1	1	1	1	1
Recreational	Wetlands	1	1	1	1	1	1	1	1	1	1	1	1
Remediation	Groundwater	1	1	1	1	1	1	1	1	1	1	1	1
Remediation	Other - Remediation	1	1	1	1	1	1	1	1	1	1	1	1
Water Supply	Campgrounds	0	0	0	0	1	1	1	1	1	0	0	0
Water Supply	Communal	1	1	1	1	1	1	1	1	1	1	1	1
Water Supply	Municipal	1	1	1	1	1	1	1	1	1	1	1	1
Water Supply	Other - Water Supply	1	1	1	1	1	1	1	1	1	1	1	1

(Source: MOE, 2006)

Table A.3.2: Consumptive Use Factors

Category	Specific Purpose	Consumptive Factor	Category	Specific Purpose	Consumptive Factor
Agricultural	Field and Pasture Crops	0.80	Institutional	Hospitals	0.25
Agricultural	Fruit Orchards	0.80	Institutional	Other - Institutional	0.25
Agricultural	Market Gardens / Flowers	0.90	Institutional	Schools	0.25
Agricultural	Nursery	0.90	Miscellaneous	Dams and Reservoirs	0.10
Agricultural	Other - Agricultural	0.80	Miscellaneous	Heat Pumps	0.10
Agricultural	Sod Farm	0.90	Miscellaneous	Other - Miscellaneous	1.00
Agricultural	Tender Fruit	0.80	Miscellaneous	Pumping Test	0.10
Agricultural	Tobacco	0.90	Miscellaneous	Wildlife Conservation	0.10
Commercial	Aquaculture	0.10	Recreational	Aesthetics	0.25
Commercial	Bottled Water	1.00	Industrial	Manufacturing	0.25
Commercial	Golf Course Irrigation	0.70	Industrial	Other - Industrial	0.25
Commercial	Mall / Business	0.25	Industrial	Pipeline Testing	0.25
Commercial	Other - Commercial	1.00	Industrial	Power Production	0.10
Commercial	Snowmaking	0.50	Recreational	Fish Ponds	0.25
Construction	Other - Construction	0.75	Recreational	Other - Recreational	0.10
Construction	Road Building	0.75	Recreational	Wetlands	0.10
Dewatering	Construction	0.25	Remediation	Groundwater	0.50
Dewatering	Other - Dewatering	0.25	Remediation	Other – Remediation	0.25
Dewatering	Pits and Quarries	0.25	Water Supply	Campgrounds	0.20
Industrial	Aggregate Washing*	0.10	Water Supply	Communal	0.20
Industrial	Brewing and Soft Drinks	1.00	Water Supply	Municipal	0.20
Industrial	Cooling Water	0.25	Water Supply	Other - Water Supply	0.20
Industrial	Food Processing	1.00			

Sources: MOE, 2006; *OSSGA, 2006)

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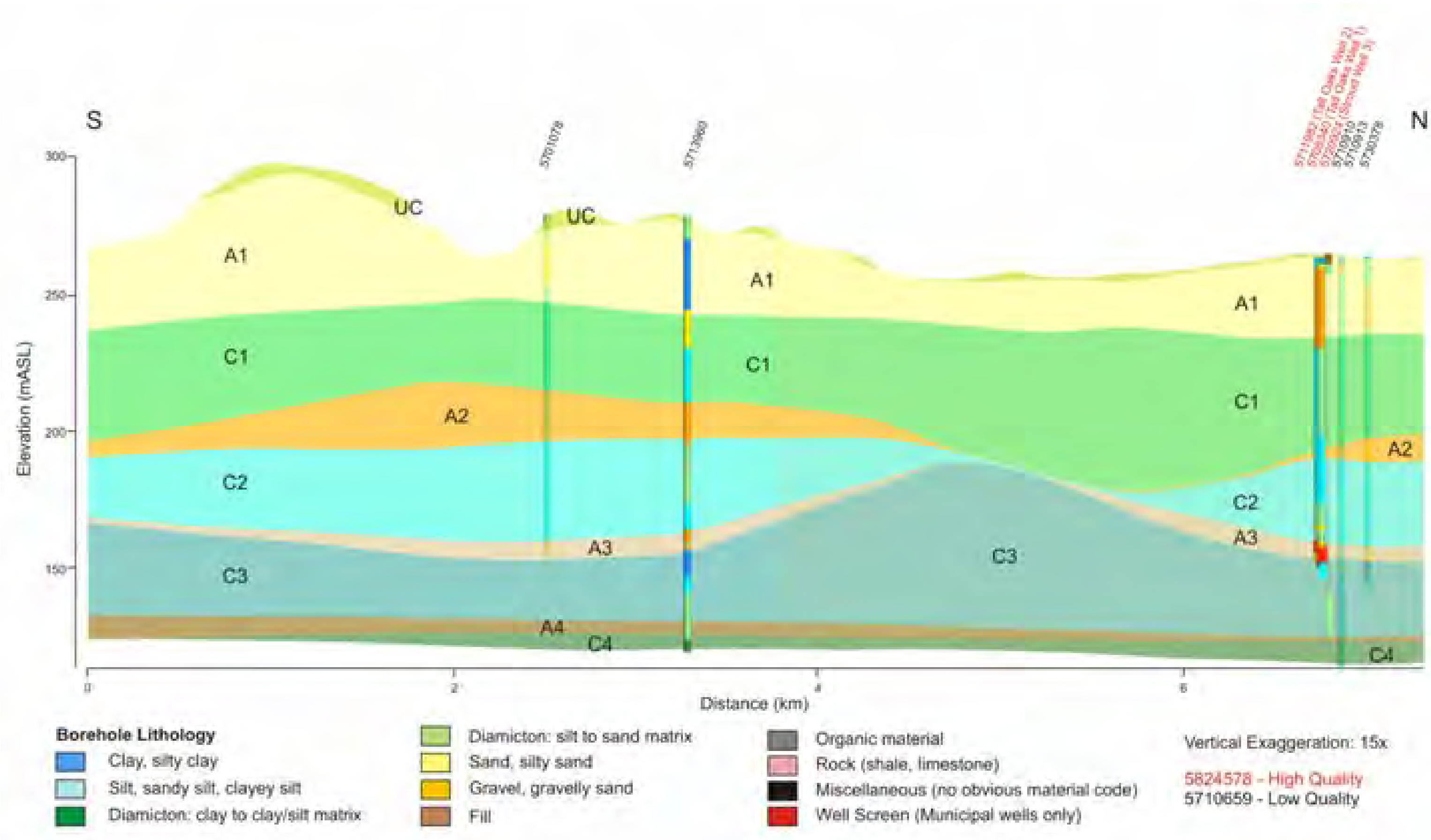
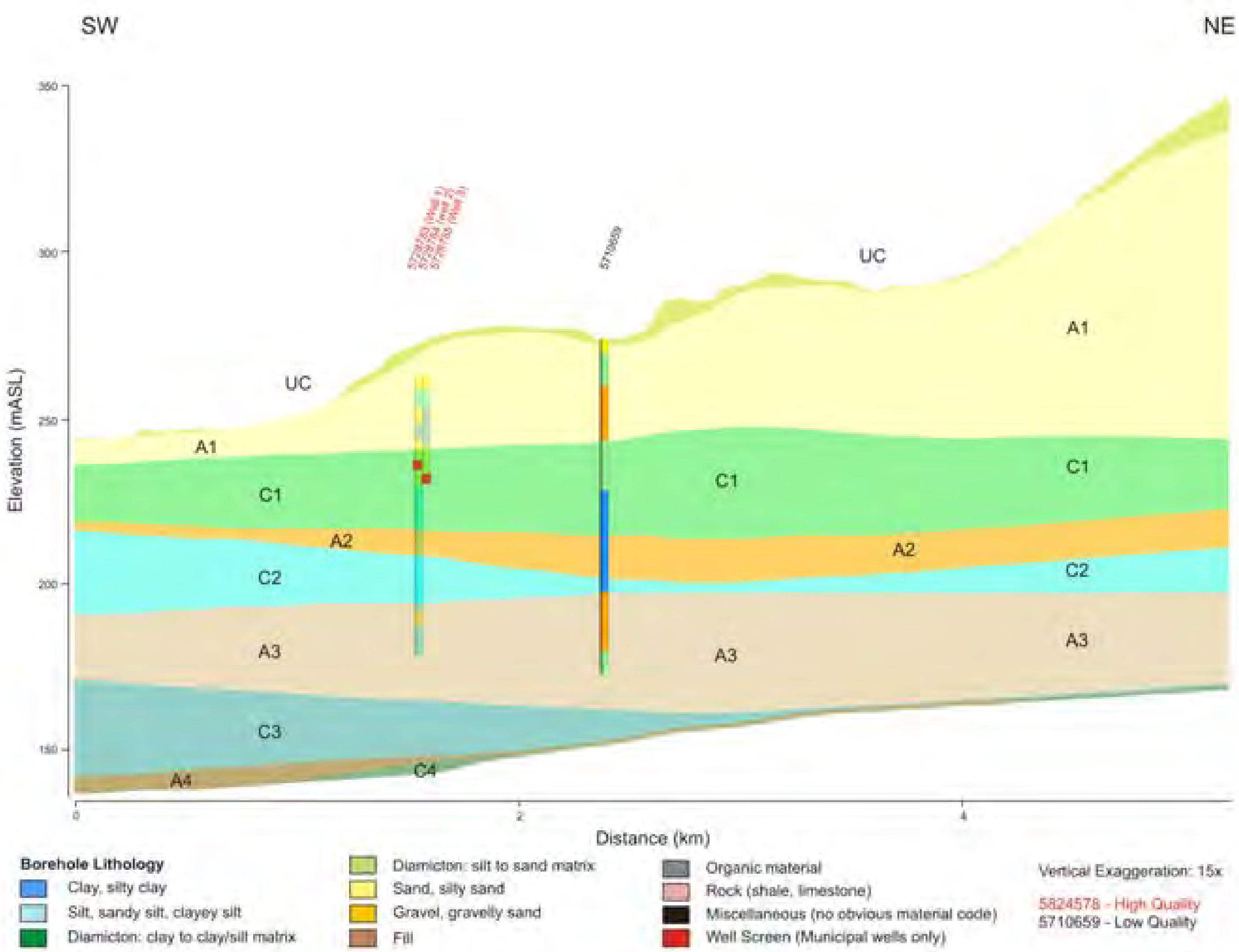
BARRIE TIER THREE WATER BUDGET AND
LOCAL AREA RISK ASSESSMENT
CONCEPTUAL UNDERSTANDING MEMORANDUM

APPENDIX A4: SELECTED CROSS SECTIONS



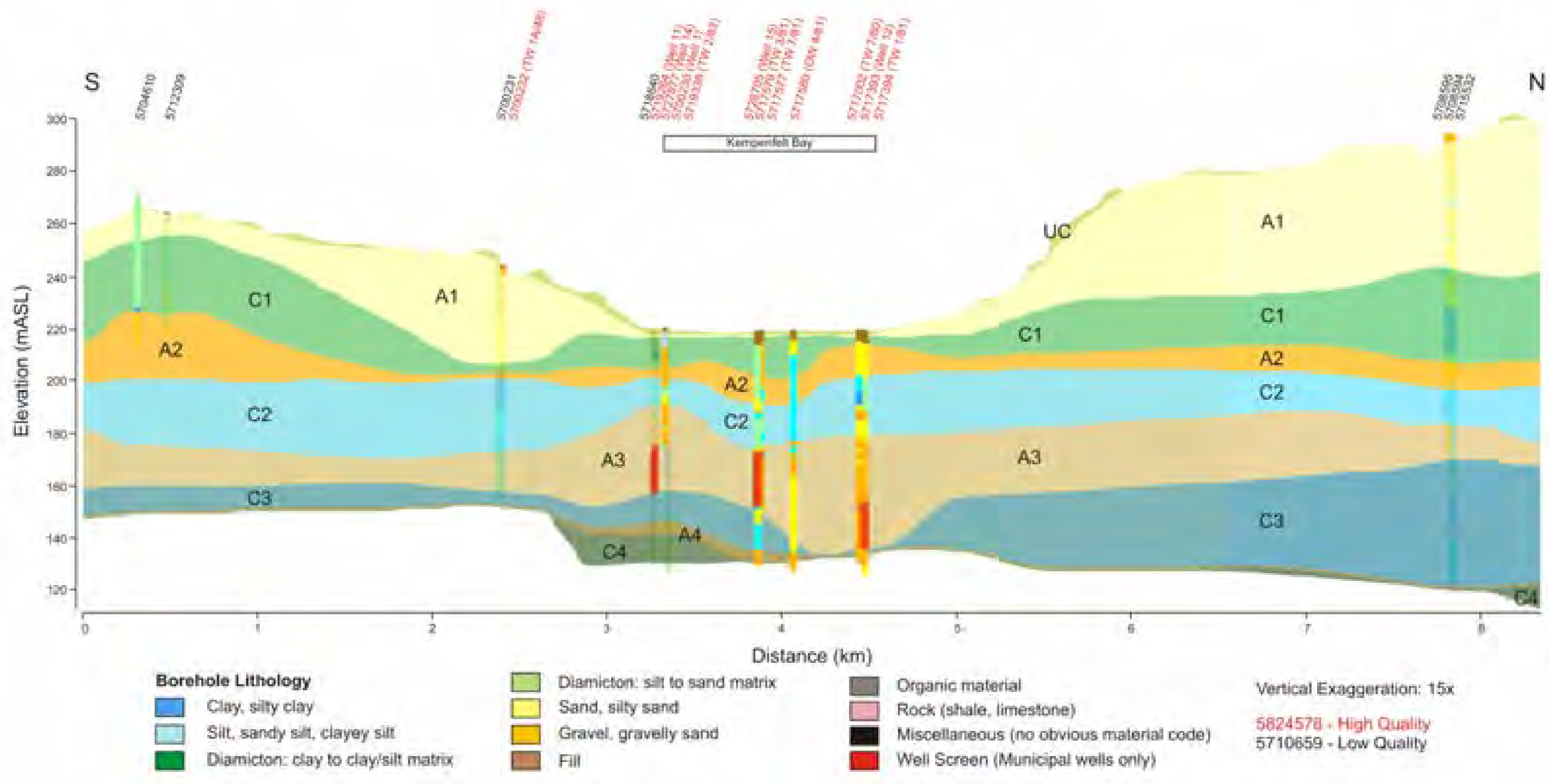
Cross Section A4.1

June 2012



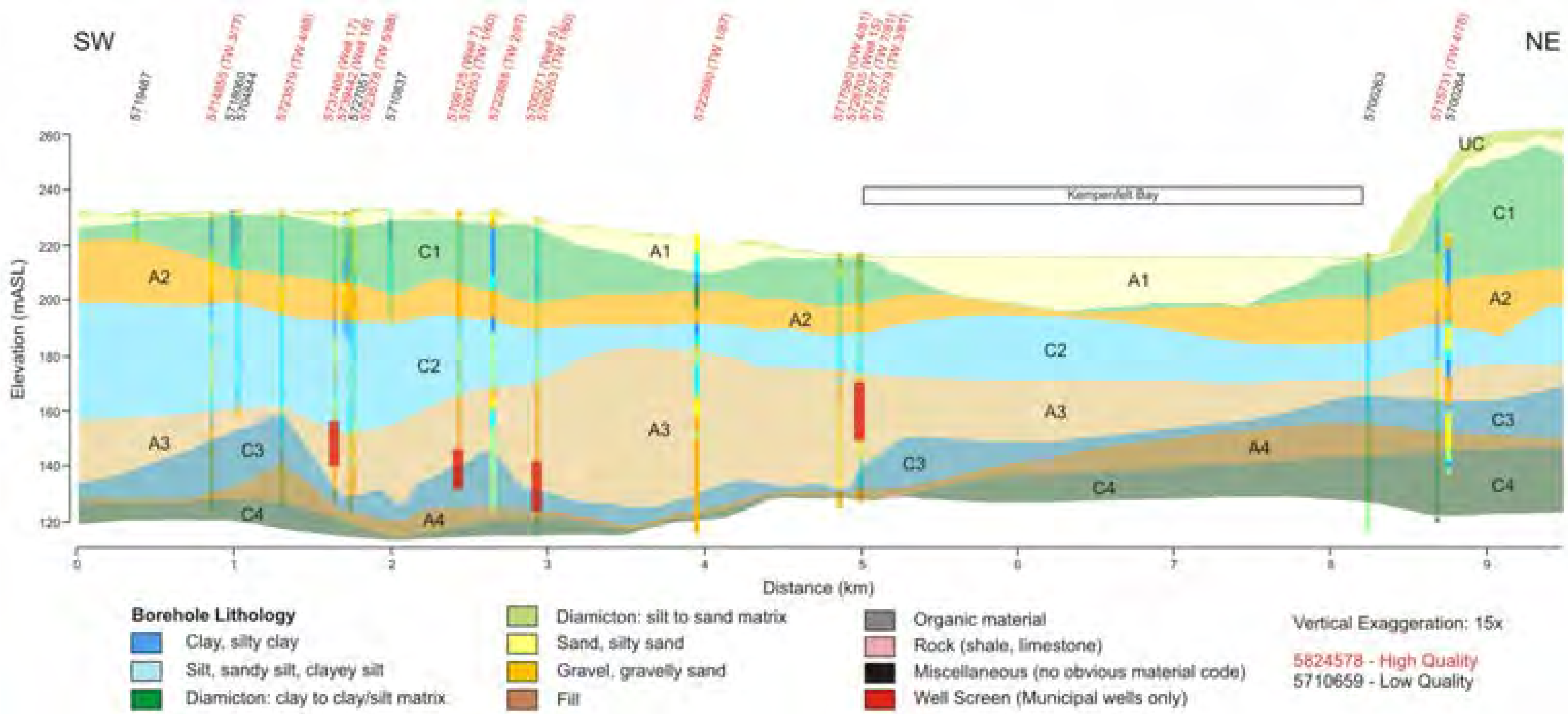
Cross Section A4.2

June 2012



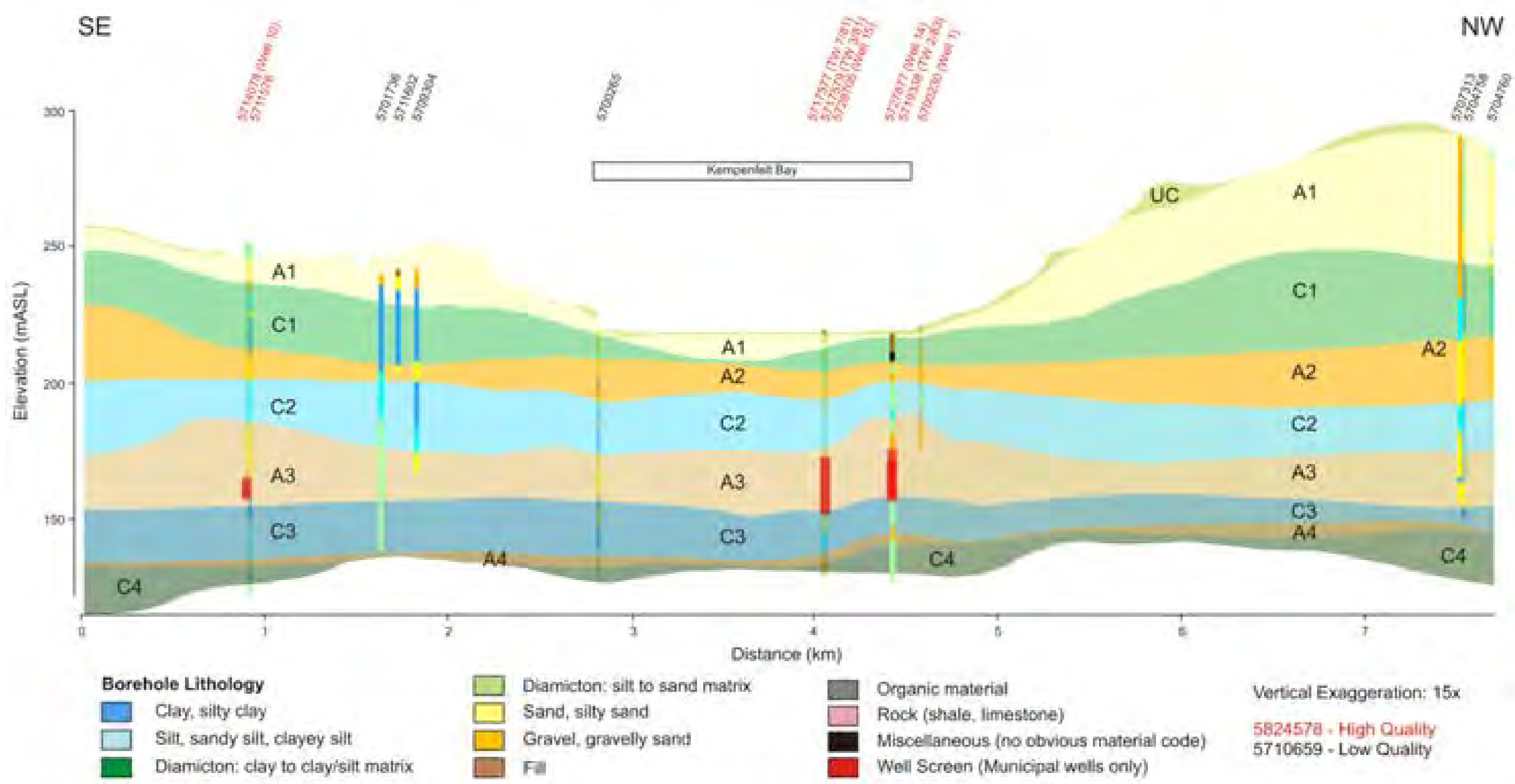
Cross Section A4.3

June 2012



Cross Section A4.4

June 2012



Cross Section A4.5

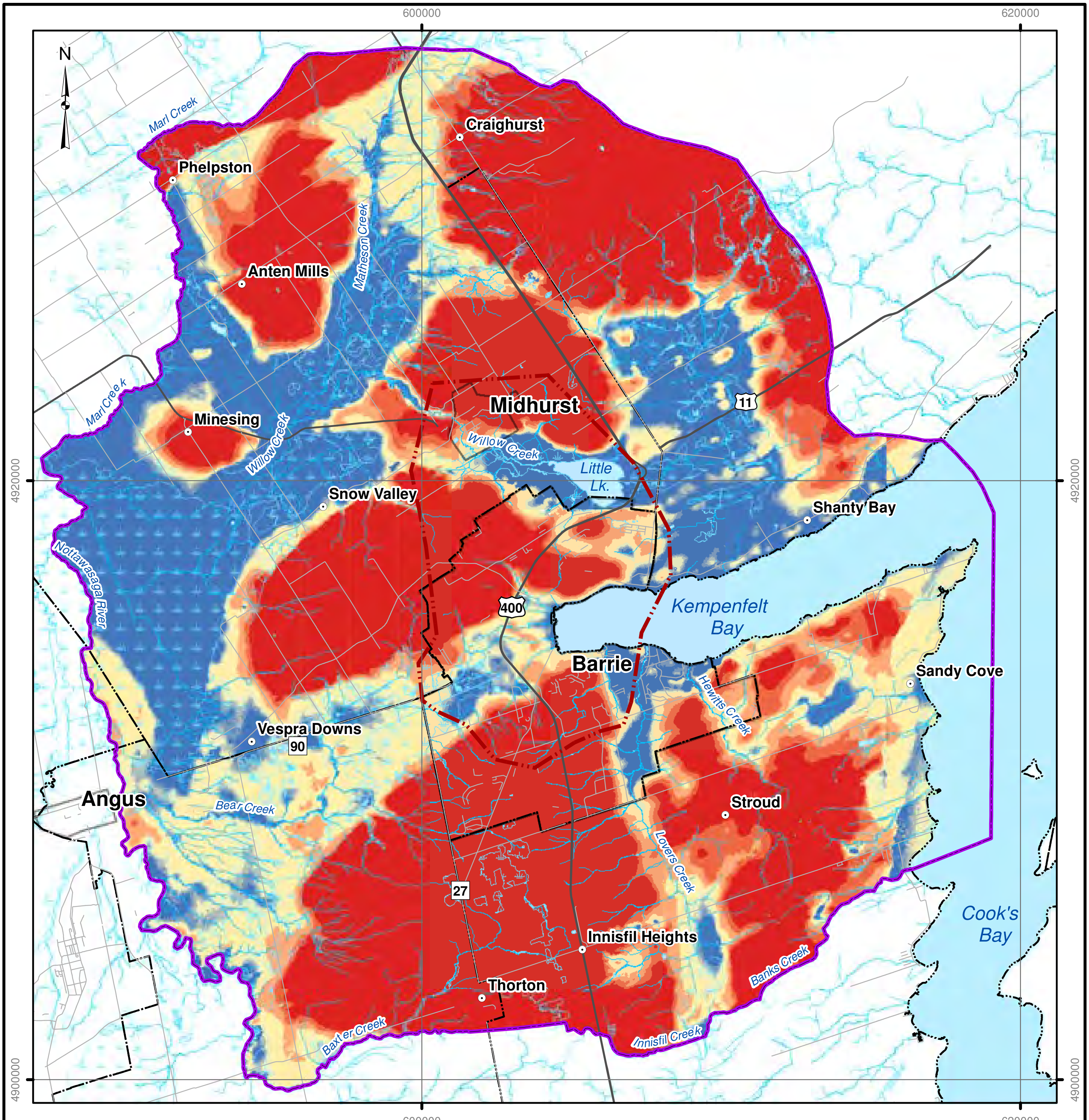
June 2012

BARRIE TIER THREE WATER BUDGET AND

LOCAL AREA RISK ASSESSMENT

CONCEPTUAL UNDERSTANDING MEMORANDUM

APPENDIX A5: AQUIFER AND AQUITARD ISOPACHS



LEGEND

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

Thickness (m)

- 0.0 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 15.0
- 15.0 - 20.0
- > 20

Barrie Tier 3 Conceptual Understanding Report

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Golder Associates

IWC International Water Consultants Ltd.

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: 09-Dec-2010; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

Map A5.1

A1 Thickness

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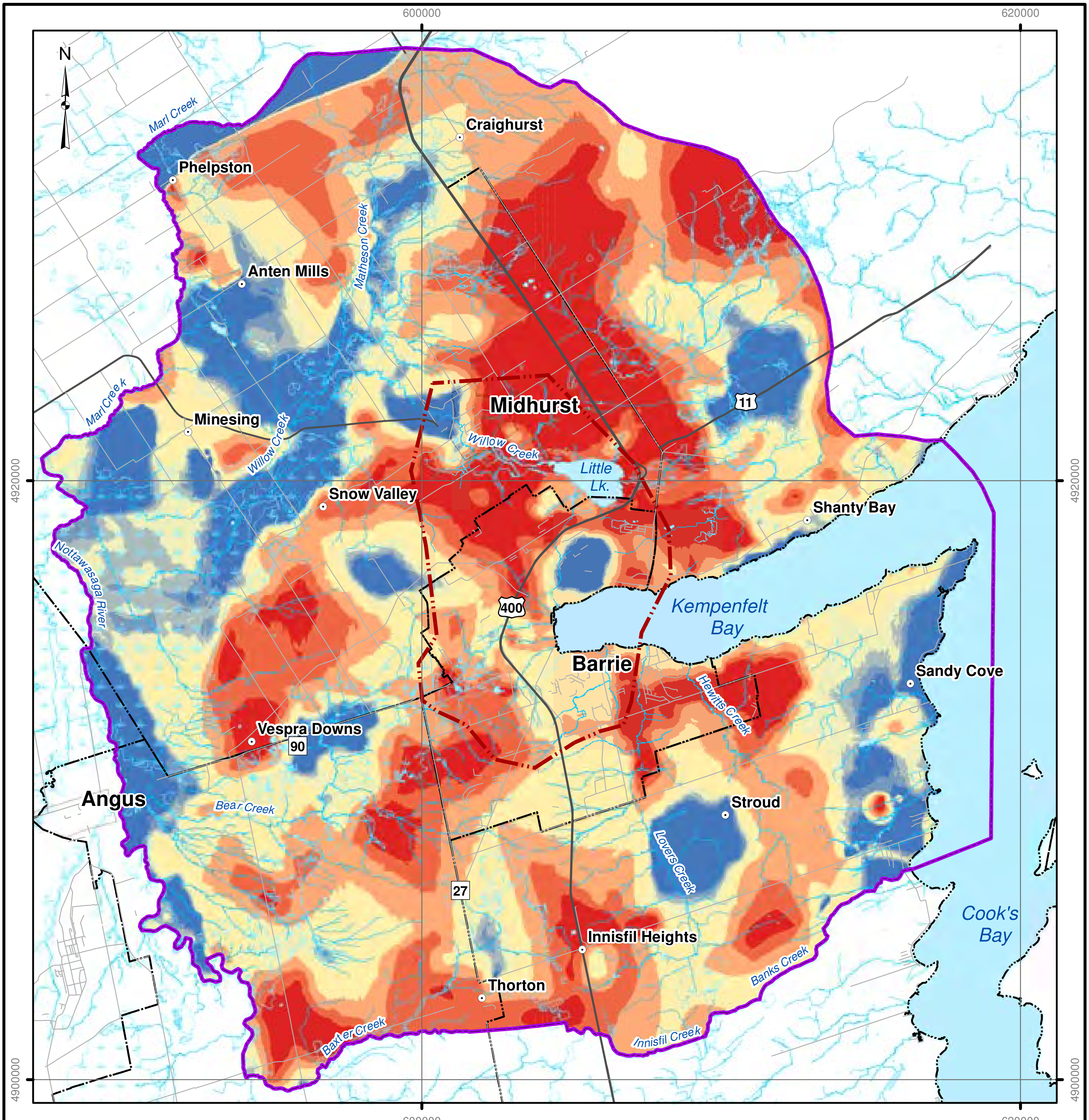
Project: 2010007 BarrieTier3



LEGEND

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

Thickness (m)

- 0.0 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 15.0
- 15.0 - 20.0
- > 20

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REFERENCES
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Map Version: 1; Map Date: 09-Dec-2010; Created By: ccurry

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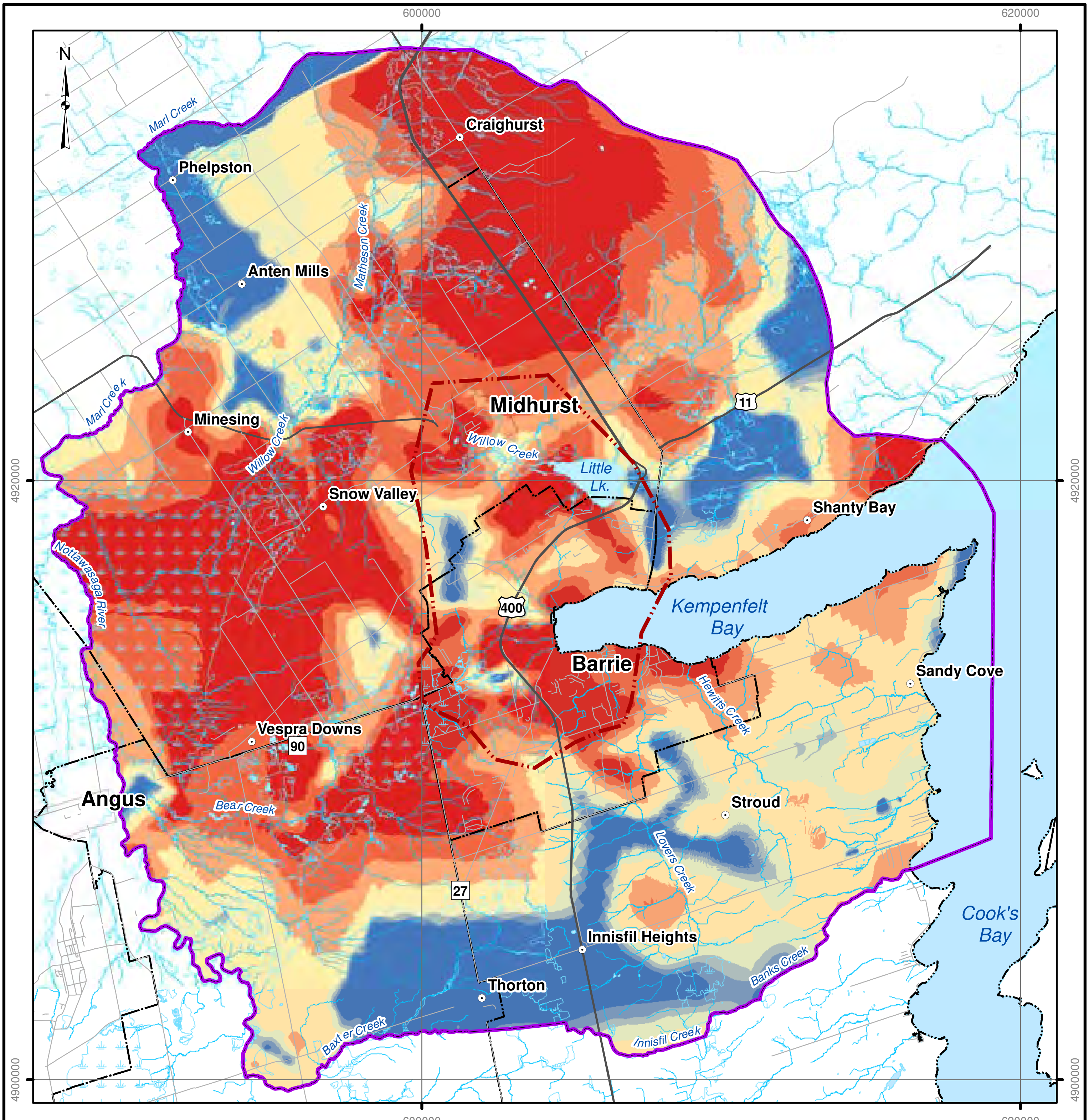
2 0 2 4
Kilometres

Map A5.2

A2 Thickness



LEGEND

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

Thickness (m)

- 0.0 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 15.0
- 15.0 - 20.0
- > 20

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Map A5.3

A3 Thickness

REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 09-Dec-2010; Created By: ccurry

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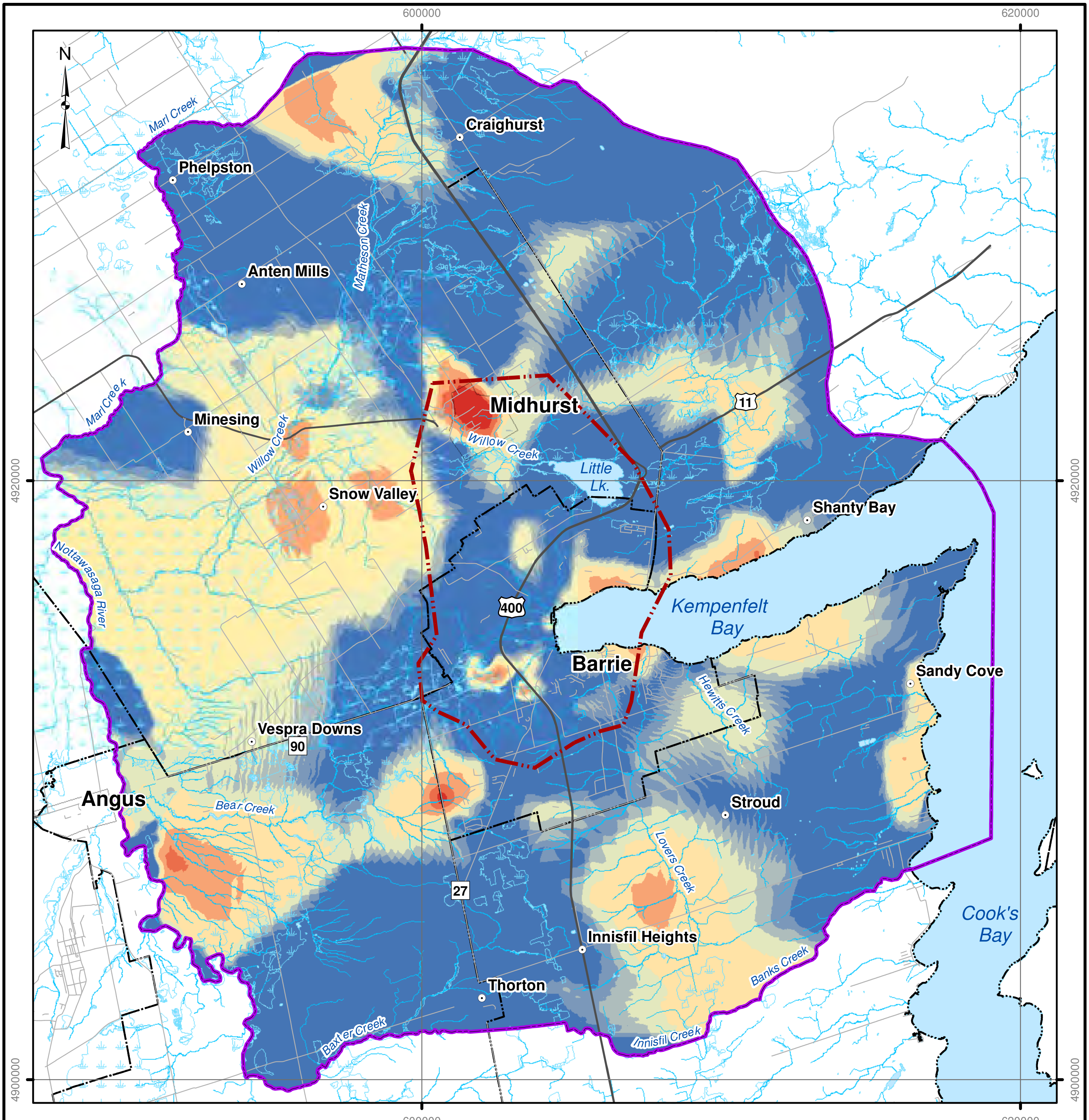
Kilometres



LEGEND

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

Thickness (m)

- 0.0 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 15.0
- 15.0 - 20.0
- 20.0 - 25.0

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REFERENCES

Base Data - NVCA, 2009

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Projection: UTM Zone 17N, NAD 83

Map Version: 1; Map Date: 09-Dec-2010; Created By: ccurry

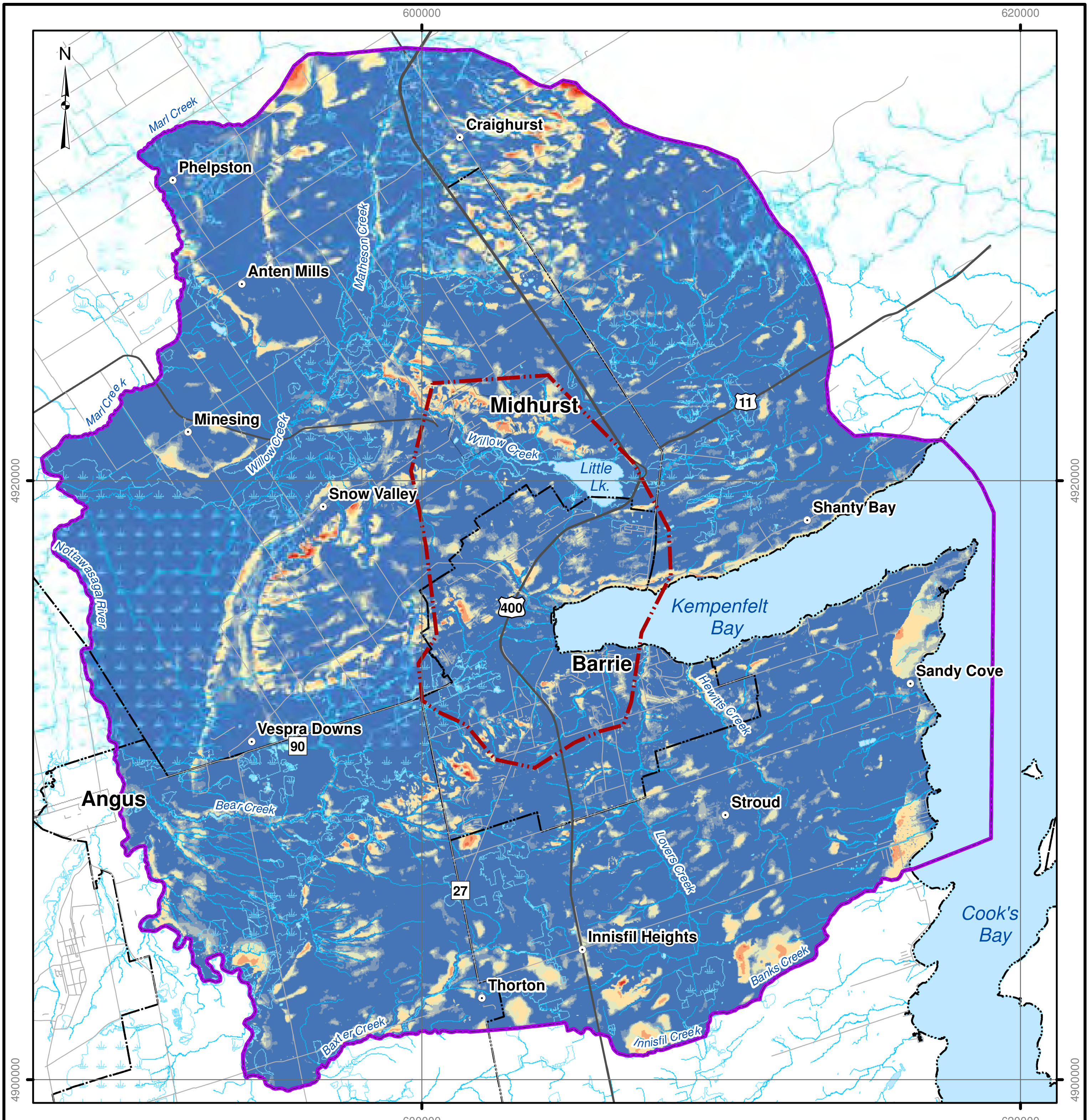
2 0 2 4

Scale 1:180,000

Kilometres

Map A5.4

A4 Thickness



LEGEND

- Towns/Villages
- Isopach Contours - Interval 10m
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary
- Focus Areas

Thickness (m)

- 0.0 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 15.0
- 15.0 - 20.0
- > 20

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Map A5.5

UC Thickness

REFERENCES

Base Data - NVCA, 2009

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Projection: UTM Zone 17N, NAD 83

Map Version: 1; Map Date: 09-Dec-2010; Created By: ccurry

Scale 1:180,000

2 0 2 4

Kilometres

C:\Projects\2010007_BarrieTier3\GIS\ArcView\MXDs\PeerReviewReport\FigE-5_IsopachUC.mxd

Project: 2010007 BarrieTier3

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

APPENDIX A6: STREAMFLOW MONITORING GAUGE SUMMARIES

Gauge Information

Gauge: 02ED009 **Description:** Willow Creek above Little Lake (Historic) **Operating Agency[7]:** WSC

Period of Record: 1973-1995 **Drainage Area (km²):** 95 **UTM:** 607923 4920015 **Regulated Upstream:** No

Location Map

Site Photo

Flow Statistics

Based on 1973-1995 Data

Annual Streamflow		(m^3/s)	(mm/yr)
Mean Annual Flow		0.88	294
Mean Annual Baseflow	High Est	0.52	172
	Low Est	0.28	94

Baseflow Statistics and Indicies		
Baseflow Index (%)[2]	High Est	59%
	Low Est	32%
Recession Constant (days)[3]		23.6

Low Flow Statistics[4]			(m^3/s)
7Q2	0.02	30Q2	0.04
7Q5	0.01	30Q5	0.02
7Q10	0.01	30Q10	0.02
7Q20	0.01	30Q20	0.02

Monthly Statistics

Month	Mean Flow (m3/s)	Mean Baseflow[1] (m^3/s)		Exceedance Flows[5] (m^3/s)			Peakiness[6]
		High Est	Low Est	10%	50%	90%	
Jan	0.64	0.43	0.29	1.17	0.38	0.19	6.2
Feb	0.75	0.42	0.27	1.26	0.33	0.18	7.0
Mar	2.72	1.25	0.57	6.82	1.23	0.28	24.4
Apr	2.47	1.67	0.82	5.51	1.52	0.48	11.5
May	0.63	0.42	0.26	1.31	0.42	0.15	8.7
June	0.30	0.18	0.10	0.60	0.14	0.04	15.0
July	0.18	0.09	0.05	0.34	0.07	0.02	17.0
Aug	0.11	0.06	0.03	0.23	0.05	0.02	11.5
Sept	0.38	0.19	0.09	0.68	0.08	0.02	34.0
Oct	0.50	0.32	0.19	1.14	0.29	0.08	14.3
Nov	1.03	0.59	0.35	2.19	0.66	0.20	11.0
Dec	0.89	0.59	0.39	1.60	0.56	0.24	6.7

1 - Separated baseflow utilizing the BFLOW program. High estimate is 1st pass output. Low estimate is 3rd pass output
2 - The proportion of baseflow to total flow
3 - Is the number of days for baseflow to recede by one log cycle. Indication of the watershed's baseflow response time
4 - Low flow statistics are presented as the lowest 7, or 30-day, average flow for a particular return period (years). Eg. 7Q20 is the lowest 7-day average flow expected in a 20 year period
5 - Percentage of time streamflow is exceeded. 50th% is the median flow, 90th is the flow which is exceeded 90% of the time
6 - Indication of varibility of streamflow = 10%/90%. A higher value indicates higher variability

Gauge Information

Gauge: 02ED010 **Description:** Willow Creek at Midhurst (Historic) **Operating Agency[7]:** WSC

Period of Record: 1973-1998 **Drainage Area (km²):** 127 **UTM:** 601090 4922045 **Regulated Upstream:** Yes

Location Map

PHOTO NOT AVAILABLE

Site Photo

Flow Statistics

Based on 1973-1998 Data

Annual Streamflow		(m^3/s)	(mm/yr)
Mean Annual Flow		1.20	298
Mean Annual Baseflow	High Est	0.87	216
	Low Est	0.57	142

Baseflow Statistics and Indicies		
Baseflow Index (%)[2]	High Est	73%
	Low Est	48%
Recession Constant (days)[3]		28.5

Low Flow Statistics[4]	(m^3/s)		(m^3/s)
7Q2	0.07	30Q2	0.09
7Q5	0.04	30Q5	0.06
7Q10	0.04	30Q10	0.05
7Q20	0.03	30Q20	0.05

Monthly Statistics

Month	Mean Flow (m3/s)	Mean Baseflow[1] (m^3/s) High Est	Mean Baseflow[1] (m^3/s) Low Est	Exceedance Flows[5] (m^3/s) 10%	50%	90%	Peakiness[6]
Jan	1.06	0.85	0.65	1.95	0.74	0.48	4.1
Feb	0.98	0.70	0.54	1.52	0.64	0.41	3.7
Mar	2.72	1.52	0.90	6.63	1.78	0.53	12.5
Apr	3.53	2.69	1.49	6.83	2.82	1.03	6.6
May	1.03	0.88	0.58	1.96	0.88	0.26	7.5
June	0.43	0.33	0.22	0.90	0.30	0.08	11.3
July	0.30	0.22	0.15	0.70	0.17	0.06	11.7
Aug	0.24	0.18	0.13	0.43	0.15	0.06	7.2
Sept	0.51	0.33	0.21	1.30	0.24	0.07	18.6
Oct	0.93	0.66	0.44	1.84	0.58	0.18	10.2
Nov	1.39	1.02	0.73	2.51	1.14	0.50	5.0
Dec	1.27	1.06	0.80	2.14	1.07	0.58	3.7

1 - Separated baseflow utilizing the BFLOW program. High estimate is 1st pass output. Low estimate is 3rd pass output
2 - The proportion of baseflow to total flow
3 - Is the number of days for baseflow to recede by one log cycle. Indication of the watershed's baseflow response time
4 - Low flow statistics are presented as the lowest 7, or 30-day, average flow for a particular return period (years). Eg. 7Q20 is the lowest 7-day average flow expected in a 20 year period
5 - Percentage of time streamflow is exceeded. 50th% is the median flow, 90th is the flow which is exceeded 90% of the time
6 - Indication of varibility of streamflow = 10%/90%. A higher value indicates higher variability

Gauge Information

Gauge: 02ED032 **Description:** Willow Creek near Minesing **Operating Agency[7]:** WSC

Period of Record: 2006-2008 **Drainage Area (km^2):** 242 **UTM:** 595534 4921730 **Regulated Upstream:** Yes

Location Map

Site Photo

Flow Statistics

Based on 2006-2008 Data

Annual Streamflow		(m^3/s)	(mm/yr)
Mean Annual Flow		2.59	337
Mean Annual Baseflow	High Est	2.02	263
	Low Est	1.54	201

Baseflow Statistics and Indicies		
Baseflow Index (%)[2]	High Est	78%
	Low Est	60%
Recession Constant (days)[3]		33.9

Low Flow Statistics[4]			(m^3/s)
7Q2	N/A	30Q2	N/A
7Q5	N/A	30Q5	N/A
7Q10	N/A	30Q10	N/A
7Q20	N/A	30Q20	N/A

Monthly Statistics

Month	Mean Flow (m3/s)	Mean Baseflow[1] (m^3/s)		Exceedance Flows[5] (m^3/s)			Peakiness[6]
		High Est	Low Est	10%	50%	90%	
Jan	3.87	2.81	1.97	6.91	2.75	1.73	4.0
Feb	1.92	1.68	1.56	2.53	1.70	1.49	1.7
Mar	3.46	2.16	1.66	7.76	2.25	1.62	4.8
Apr	7.21	4.92	2.70	13.30	5.33	3.18	4.2
May	2.27	2.07	1.70	3.27	1.97	1.46	2.2
June	1.42	1.32	1.20	1.86	1.35	1.08	1.7
July	1.32	1.19	1.09	1.73	1.34	0.85	2.0
Aug	1.06	1.01	0.96	1.42	1.08	0.68	2.1
Sept	1.13	1.02	0.96	1.37	1.12	0.75	1.8
Oct	1.57	1.26	1.11	2.45	1.35	1.10	2.2
Nov	2.67	2.19	1.74	4.46	2.84	1.30	3.4
Dec	3.16	2.55	1.87	5.35	2.65	1.77	3.0

1 - Separated baseflow utilizing the BFLOW program. High estimate is 1st pass output. Low estimate is 3rd pass output
2 - The proportion of baseflow to total flow
3 - Is the number of days for baseflow to recede by one log cycle. Indication of the watershed's baseflow response time
4 - Low flow statistics are presented as the lowest 7, or 30-day, average flow for a particular return period (years). Eg. 7Q20 is the lowest 7-day average flow expected in a 20 year period
5 - Percentage of time streamflow is exceeded. 50th% is the median flow, 90th is the flow which is exceeded 90% of the time
6 - Indication of varibility of streamflow = 10%/90%. A higher value indicates higher variability

Gauge Information

Gauge: LS0101 **Description:** Lovers Creek at Tollendal **Operating Agency[7]:** LSRCA

Period of Record: 2001-2008 **Drainage Area (km^2):** 60 **UTM:** 607527 4914403 **Regulated Upstream:** No

Location Map

Site Photo

Flow Statistics

Based on 2001-2008 Data

Annual Streamflow		(m^3/s)	(mm/yr)
Mean Annual Flow		0.76	400
Mean Annual Baseflow	High Est	0.44	230
	Low Est	0.29	152

Baseflow Statistics and Indicies		
Baseflow Index (%)[2]	High Est	57%
	Low Est	38%
Recession Constant (days)[3]		24.4

Low Flow Statistics[4]			(m^3/s)
7Q2	0.10	30Q2	0.16
7Q5	0.06	30Q5	0.10
7Q10	N/A	30Q10	N/A
7Q20	N/A	30Q20	N/A

Monthly Statistics

Month	Mean Flow (m3/s)	Mean Baseflow[1] (m^3/s) High Est	Mean Baseflow[1] (m^3/s) Low Est	Exceedance Flows[5] (m^3/s) 10%	50%	90%	Peakiness[6]
Jan	0.75	0.45	0.32	1.40	0.40	0.27	5.1
Feb	0.87	0.56	0.41	1.64	0.49	0.28	5.8
Mar	1.62	0.87	0.55	3.04	0.88	0.46	6.6
Apr	1.65	0.91	0.50	4.31	0.72	0.20	21.2
May	0.99	0.54	0.30	2.55	0.42	0.22	11.7
June	0.62	0.31	0.19	0.94	0.27	0.12	7.7
July	0.44	0.22	0.16	0.57	0.19	0.10	5.8
Aug	0.31	0.21	0.16	0.49	0.18	0.08	5.8
Sept	0.37	0.21	0.16	0.52	0.20	0.12	4.4
Oct	0.33	0.25	0.20	0.52	0.28	0.14	3.6
Nov	0.47	0.29	0.22	0.80	0.32	0.13	6.3
Dec	0.69	0.43	0.30	1.30	0.46	0.25	5.1

1 - Separated baseflow utilizing the BFLOW program. High estimate is 1st pass output. Low estimate is 3rd pass output
2 - The proportion of baseflow to total flow
3 - Is the number of days for baseflow to recede by one log cycle. Indication of the watershed's baseflow response time
4 - Low flow statistics are presented as the lowest 7, or 30-day, average flow for a particular return period (years). Eg. 7Q20 is the lowest 7-day average flow expected in a 20 year period
5 - Percentage of time streamflow is exceeded. 50th% is the median flow, 90th is the flow which is exceeded 90% of the time
6 - Indication of varibility of streamflow = 10%/90%. A higher value indicates higher variability

Gauge Information

Gauge: Bunkers Creek | **Operating Agency**[7]: City of Barri

Period of Record: 2004-2010 | **Drainage Area (km²):** 3.5 | **UTM:** 603787 4915224 | **Regulated Upstream:** No

Location Map

Site Photo

Flow Statistics

Based on 2004-2010 Data from March to December

Annual Streamflow (Mar-Oct)		(m^3/s)	(mm/yr)
Mean Annual Flow		0.10	872
Mean Annual Baseflow	High Est	0.06	574
	Low Est	0.04	397

Baseflow Statistics and Indicies		
Baseflow Index (%)[2]	High Est	66%
	Low Est	46%
Recession Constant (days)[3]		N/A

Low Flow Statistics[4]			(m^3/s)
7Q2	N/A	30Q2	N/A
7Q5	N/A	30Q5	N/A
7Q10	N/A	30Q10	N/A
7Q20	N/A	30Q20	N/A

Monthly Statistics

Month	Mean Flow (m3/s)	Mean Baseflow[1] (m^3/s) High Est	Mean Baseflow[1] (m^3/s) Low Est	Exceedance Flows[5] (m^3/s) 10%	50%	90%	Peakiness[6]
Jan							
Feb							
Mar	0.12	0.05	0.02	0.15	0.10	0.08	2.0
Apr	0.12	0.08	0.05	0.26	0.08	0.03	9.5
May	0.08	0.06	0.04	0.18	0.06	0.03	6.9
June	0.07	0.04	0.03	0.12	0.06	0.01	11.0
July	0.08	0.05	0.04	0.14	0.05	0.03	4.3
Aug	0.06	0.04	0.04	0.11	0.05	0.02	4.5
Sept	0.08	0.05	0.04	0.17	0.05	0.04	4.9
Oct	0.08	0.06	0.05	0.14	0.07	0.02	7.8
Nov	0.12	0.08	0.06	0.26	0.10	0.03	8.2
Dec	0.13	0.11	0.05	0.21	0.14	0.03	6.5

1 - Separated baseflow utilizing the BFLOW program. High estimate is 1st pass output. Low estimate is 3rd pass output
2 - The proportion of baseflow to total flow
3 - Is the number of days for baseflow to recede by one log cycle. Indication of the watershed's baseflow response time
4 - Low flow statistics are presented as the lowest 7, or 30-day, average flow for a particular return period (years). Eg. 7Q20 is the lowest 7-day average flow expected in a 20 year period
5 - Percentage of time streamflow is exceeded. 50th% is the median flow, 90th is the flow which is exceeded 90% of the time
6 - Indication of varibility of streamflow = 10%/90%. A higher value indicates higher variability

Gauge Information

Gauge: Dyments Creek | **Operating Agency[7]:** City of Barri

Period of Record: 2004-2010 | **Drainage Area (km^2):** 5.4 | **UTM:** 604022 4914730 | **Regulated Upstream:** No

Location Map

Site Photo

Flow Statistics

Based on 2004-2010 Data from March to December

Annual Streamflow (Mar-Nov)		(m^3/s)	(mm/yr)
Mean Annual Flow		0.09	531
Mean Annual Baseflow	High Est	0.06	346
	Low Est	0.04	245

Baseflow Statistics and Indicies		
Baseflow Index (%)[2]	High Est	65%
	Low Est	46%
Recession Constant (days)[3]		N/A

Low Flow Statistics[4]			(m^3/s)
7Q2	N/A	30Q2	N/A
7Q5	N/A	30Q5	N/A
7Q10	N/A	30Q10	N/A
7Q20	N/A	30Q20	N/A

Monthly Statistics

Month	Mean Flow (m3/s)	Mean Baseflow[1] (m^3/s) High Est	Low Est	Exceedance Flows[5] (m^3/s) 10%	50%	90%	Peakiness[6]
Jan							
Feb							
Mar	0.09	0.06	0.05	0.11	0.08	0.07	1.7
Apr	0.13	0.08	0.05	0.23	0.10	0.05	4.4
May	0.11	0.08	0.06	0.25	0.08	0.04	6.6
June	0.10	0.07	0.05	0.20	0.08	0.03	5.7
July	0.10	0.06	0.04	0.21	0.07	0.04	5.8
Aug	0.06	0.04	0.03	0.13	0.05	0.02	8.3
Sept	0.07	0.04	0.03	0.16	0.06	0.00	-
Oct	0.07	0.05	0.03	0.12	0.06	0.04	3.5
Nov	0.08	0.05	0.04	0.16	0.08	0.01	16.1
Dec	0.08	0.06	0.04	0.11	0.07	0.04	2.7

1 - Separated baseflow utilizing the BFLOW program. High estimate is 1st pass output. Low estimate is 3rd pass output
2 - The proportion of baseflow to total flow
3 - Is the number of days for baseflow to recede by one log cycle. Indication of the watershed's baseflow response time
4 - Low flow statistics are presented as the lowest 7, or 30-day, average flow for a particular return period (years). Eg. 7Q20 is the lowest 7-day average flow expected in a 20 year period
5 - Percentage of time streamflow is exceeded. 50th% is the median flow, 90th is the flow which is exceeded 90% of the time
6 - Indication of varibility of streamflow = 10%/90%. A higher value indicates higher variability

Gauge Information

Gauge: Hotchkiss Creek

Operating Agency[7]: City of Barri

Period of Record: 2004-2010 **Drainage Area (km²):** 4.4 **UTM:** 603984 4914339 **Regulated Upstream:** No

Location Map

Site Photo (Left - looking downstream; Right - looking upstream)

Flow Statistics

Based on 2004-2010 Data from March to December

Annual Streamflow (Mar-Oct)		(m^3/s)	(mm/yr)
Mean Annual Flow		0.08	533
Mean Annual Baseflow	High Est	0.05	338
	Low Est	0.04	250

Baseflow Statistics and Indicies		
Baseflow Index (%)[2]	High Est	63%
	Low Est	47%
Recession Constant (days)[3]		N/A

Low Flow Statistics[4]			(m^3/s)
7Q2	N/A	30Q2	N/A
7Q5	N/A	30Q5	N/A
7Q10	N/A	30Q10	N/A
7Q20	N/A	30Q20	N/A

Monthly Statistics

Month	Mean Flow (m3/s)	Mean Baseflow[1] (m^3/s) High Est	Mean Baseflow[1] (m^3/s) Low Est	Exceedance Flows[5] (m^3/s) 10%	Exceedance Flows[5] (m^3/s) 50%	Exceedance Flows[5] (m^3/s) 90%	Peakiness[6]
Jan							
Feb							
Mar	0.09	0.04	0.03	0.12	0.06	0.05	2.5
Apr	0.09	0.07	0.05	0.16	0.08	0.03	4.7
May	0.08	0.05	0.04	0.20	0.06	0.02	9.9
June	0.07	0.04	0.03	0.19	0.04	0.01	17.0
July	0.06	0.03	0.02	0.13	0.04	0.01	14.6
Aug	0.05	0.03	0.02	0.10	0.03	0.01	17.3
Sept	0.06	0.04	0.03	0.12	0.05	0.00	59.1
Oct	0.07	0.04	0.03	0.10	0.06	0.01	8.7
Nov	0.09	0.06	0.05	0.12	0.08	0.04	2.7
Dec	0.10	0.07	0.05	0.13	0.07	0.05	2.5

1 - Separated baseflow utilizing the BFLOW program. High estimate is 1st pass output. Low estimate is 3rd pass output
2 - The proportion of baseflow to total flow
3 - Is the number of days for baseflow to recede by one log cycle. Indication of the watershed's baseflow response time
4 - Low flow statistics are presented as the lowest 7, or 30-day, average flow for a particular return period (years). Eg. 7Q20 is the lowest 7-day average flow expected in a 20 year period
5 - Percentage of time streamflow is exceeded. 50th% is the median flow, 90th is the flow which is exceeded 90% of the time
6 - Indication of varibility of streamflow = 10%/90%. A higher value indicates higher variability

Gauge Information

Gauge: Kidds Creek | **Operating Agency**[7]**:** City of Barri

Period of Record: 2004-2010 | **Drainage Area (km^2):** 4.2 | **UTM:** 603553 4916100 | **Regulated Upstream:** No

Location Map

Site Photo

Flow Statistics

Based on 2004-2010 Data from March to December

Annual Streamflow (Mar-Nov)		(m^3/s)	(mm/yr)
Mean Annual Flow		0.08	601
Mean Annual Baseflow	High Est	0.05	402
	Low Est	0.04	328

Baseflow Statistics and Indicies		
Baseflow Index (%)[2]	High Est	67%
	Low Est	55%
Recession Constant (days)[3]		N/A

Low Flow Statistics[4]			(m^3/s)
7Q2	N/A	30Q2	N/A
7Q5	N/A	30Q5	N/A
7Q10	N/A	30Q10	N/A
7Q20	N/A	30Q20	N/A

Monthly Statistics

Month	Mean Flow (m3/s)	Mean Baseflow[1] (m^3/s)		Exceedance Flows[5] (m^3/s)			Peakiness[6]
		High Est	Low Est	10%	50%	90%	
Jan							
Feb							
Mar	0.03	0.01	0.01	0.04	0.01	0.00	21.8
Apr	0.09	0.06	0.04	0.19	0.05	0.02	8.2
May	0.09	0.06	0.05	0.15	0.07	0.02	7.0
June	0.10	0.06	0.05	0.16	0.07	0.02	9.6
July	0.10	0.06	0.05	0.17	0.08	0.02	7.7
Aug	0.08	0.06	0.05	0.15	0.08	0.02	9.5
Sept	0.08	0.06	0.05	0.18	0.07	0.01	15.1
Oct	0.08	0.06	0.05	0.15	0.06	0.02	6.0
Nov	0.06	0.04	0.04	0.13	0.04	0.02	5.1
Dec	0.09	0.06	0.05	0.16	0.08	0.03	5.8

1 - Separated baseflow utilizing the BFLOW program. High estimate is 1st pass output. Low estimate is 3rd pass output
2 - The proportion of baseflow to total flow
3 - Is the number of days for baseflow to recede by one log cycle. Indication of the watershed's baseflow response time
4 - Low flow statistics are presented as the lowest 7, or 30-day, average flow for a particular return period (years). Eg. 7Q20 is the lowest 7-day average flow expected in a 20 year period
5 - Percentage of time streamflow is exceeded. 50th% is the median flow, 90th is the flow which is exceeded 90% of the time
6 - Indication of varibility of streamflow = 10%/90%. A higher value indicates higher variability

Gauge Information

Gauge: Sophia Creek **Operating Agency[7]:** City of Barri

Period of Record: 2004-2010 **Drainage Area (km^2):** 3.0 **UTM:** 604596 4916814 **Regulated Upstream:** No

Location Map

Site Photo

Flow Statistics

Based on 2004-2010 Data from March to December

Annual Streamflow (Mar-Oct)		(m^3/s)	(mm/yr)
Mean Annual Flow		0.031	333
Mean Annual Baseflow	High Est	0.014	148
	Low Est	0.007	78

Baseflow Statistics and Indicies		
Baseflow Index (%)[2]	High Est	44%
	Low Est	23%
Recession Constant (days)[3]		N/A

Low Flow Statistics[4]			(m^3/s)
7Q2	N/A	30Q2	N/A
7Q5	N/A	30Q5	N/A
7Q10	N/A	30Q10	N/A
7Q20	N/A	30Q20	N/A

Monthly Statistics

Month	Mean Flow (m3/s)	Mean Baseflow[1] (m^3/s) High Est	Mean Baseflow[1] (m^3/s) Low Est	Exceedance Flows[5] (m^3/s) 10%	50%	90%	Peakiness[6]
Jan							
Feb							
Mar	0.026	0.008	0.007	0.045	0.010	0.007	6.5
Apr	0.042	0.021	0.010	0.103	0.023	0.002	51.7
May	0.033	0.018	0.010	0.084	0.020	0.002	42.0
June	0.033	0.013	0.007	0.084	0.016	0.002	42.0
July	0.036	0.016	0.007	0.074	0.018	0.000	-
Aug	0.021	0.009	0.004	0.053	0.011	0.000	-
Sept	0.025	0.010	0.005	0.069	0.009	0.000	-
Oct	0.030	0.014	0.008	0.074	0.014	0.000	-
Nov	0.043	0.022	0.013	0.107	0.034	0.002	53.4
Dec	0.026	0.009	0.003	0.086	0.009	0.000	-

1 - Separated baseflow utilizing the BFLOW program. High estimate is 1st pass output. Low estimate is 3rd pass output
2 - The proportion of baseflow to total flow
3 - Is the number of days for baseflow to recede by one log cycle. Indication of the watershed's baseflow response time
4 - Low flow statistics are presented as the lowest 7, or 30-day, average flow for a particular return period (years). Eg. 7Q20 is the lowest 7-day average flow expected in a 20 year period
5 - Percentage of time streamflow is exceeded. 50th% is the median flow, 90th is the flow which is exceeded 90% of the time
6 - Indication of varibility of streamflow = 10%/90%. A higher value indicates higher variability

Gauge Information

Gauge: Whiskey Creek — **Operating Agency[7]:** City of Barri

Period of Record: 2004-2010 — **Drainage Area (km^2):** 7.2 — **UTM:** 606169 4914341 — **Regulated Upstream:** No

Location Map

Site Photo

Flow Statistics

Based on 2004-2010 Data from March to December

Annual Streamflow (Mar-Nov)		(m^3/s)	(mm/yr)
Mean Annual Flow		0.08	371
Mean Annual Baseflow	High Est	0.06	255
	Low Est	0.05	198

Baseflow Statistics and Indicies		
Baseflow Index (%)[2]	High Est	69%
	Low Est	53%
Recession Constant (days)[3]		N/A

Low Flow Statistics[4]			(m^3/s)
7Q2	N/A	30Q2	N/A
7Q5	N/A	30Q5	N/A
7Q10	N/A	30Q10	N/A
7Q20	N/A	30Q20	N/A

Monthly Statistics

Month	Mean Flow (m3/s)	Mean Baseflow[1] (m^3/s) High Est	Mean Baseflow[1] (m^3/s) Low Est	Exceedance Flows[5] (m^3/s) 10%	50%	90%	Peakiness[6]
Jan							
Feb							
Mar	0.06	0.05	0.04	0.09	0.06	0.02	4.7
Apr	0.10	0.07	0.05	0.17	0.08	0.02	11.6
May	0.09	0.06	0.04	0.16	0.08	0.02	8.9
June	0.08	0.05	0.04	0.14	0.07	0.01	9.1
July	0.08	0.05	0.03	0.18	0.05	0.02	9.9
Aug	0.06	0.04	0.03	0.12	0.06	0.01	14.4
Sept	0.07	0.05	0.04	0.13	0.06	0.01	12.7
Oct	0.10	0.07	0.06	0.17	0.10	0.04	4.7
Nov	0.12	0.09	0.07	0.18	0.11	0.04	4.5
Dec	0.13	0.10	0.09	0.20	0.11	0.08	2.7

1 - Separated baseflow utilizing the BFLOW program. High estimate is 1st pass output. Low estimate is 3rd pass output
2 - The proportion of baseflow to total flow
3 - Is the number of days for baseflow to recede by one log cycle. Indication of the watershed's baseflow response time
4 - Low flow statistics are presented as the lowest 7, or 30-day, average flow for a particular return period (years). Eg. 7Q20 is the lowest 7-day average flow expected in a 20 year period
5 - Percentage of time streamflow is exceeded. 50th% is the median flow, 90th is the flow which is exceeded 90% of the time
6 - Indication of varibility of streamflow = 10%/90%. A higher value indicates higher variability

AquaResource
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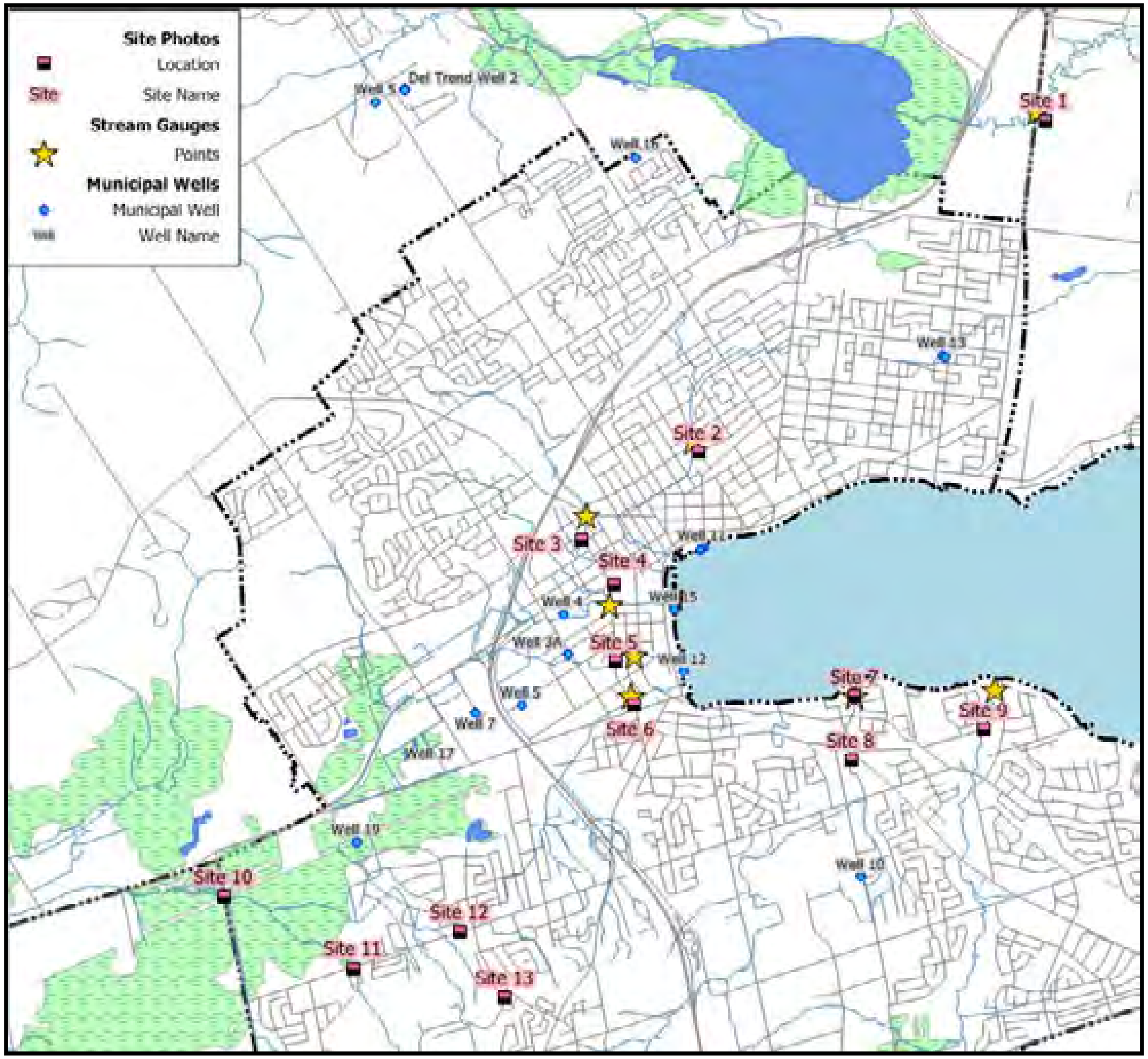
BARRIE TIER THREE WATER BUDGET AND

LOCAL AREA RISK ASSESSMENT

CONCEPTUAL UNDERSTANDING MEMORANDUM

APPENDIX A7: FIELD SITE PHOTOGRAPHS



Map A7. 1: Site Photos Locations

Figure A7.1: Site 1- Willow Creek Gauge

Figure A7. 2: Site 1- Willow Creek Looking Upstream

Figure A7. 3: Site 1- Willow Creek Looking Downstream

Figure A7..4: Site 1- Willow Creek Looking Downstream

SITE 2

Figure A7.5: Site 2- Sophia Creek Looking Downstream

Figure A7.6 : Site 2- Sophia Creek Downstream Side of Culvert

SITE 3

Figure A7. 7: Site 3- Kidds Creek Looking Upstream

Figure A7.8: Site 3- Kidds Creek Looking Downstream

SITE 4

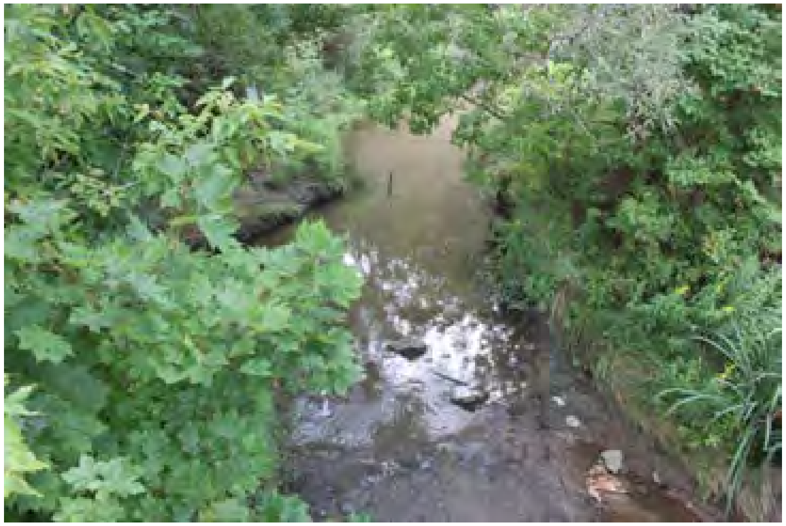


Figure A7. 9: Site 4- Bunkers Creek Looking Upstream

Figure A7. 10: Site 4- Bunkers Creek Looking Downstream

SITE 5

Figure A7. 11: Site 5- Dyments Creek Looking Upstream

Figure A7. 12: Site 5- Dyments Creek Looking Downstream

Figure A7. 13: Site 6- Hotchkiss Creek Looking Upstream

Figure A7. 14: Site 6- Hotchkiss Creek Looking Upstream

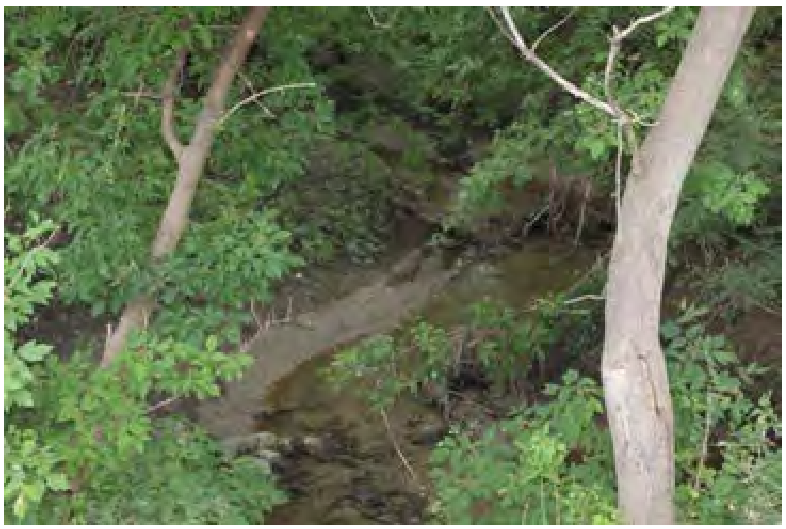


Figure A7. 15: Site 6- Hotchkiss Creek Looking Upstream

Figure A7.16: Site 6- Hotchkiss Creek Looking Downstream

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BARRIE TIER THREE WATER BUDGET AND

LOCAL AREA RISK ASSESSMENT

APPENDIX B: RECHARGE ESTIMATION USING MIKE SHE

(COMPANION REPORT)

AquaResource
A Division of Matrix Solutions Inc.

CITY OF BARRIE TIER THREE

RECHARGE ESTIMATION USING MIKE SHE

TECHNICAL MEMORANDUM

Report Prepared for:

LAKE SIMCOE REGION CONSERVATION AUTHORITY

Prepared by:

AQUARESOURCE
A Division of
MATRIX SOLUTIONS INC.

June 2012
Breslau, Ontario

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DISCLAIMER

We certify that we supervised and carried out the work as described in this report. The report is based on and limited by circumstances and conditions referred to throughout the report and on information available at the time of the site investigation. AquaResource has exercised reasonable skill, care and diligence to assess the information acquired during the preparation of this report. AquaResource believes this information is accurate but cannot guarantee or warrant its accuracy or completeness. Information provided by others was believed to be accurate but cannot be guaranteed.

This report is prepared for the sole benefit of Lake Simcoe Region Conservation Authority, and is solely warranted for the purposes outlined in this report. Any uses which a third party makes of this report, or any reliance on decisions made based on it, are the responsibility of such third parties. AquaResource, a Division of Matrix Solutions Inc. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

Janna Hamilton, B.Eng., E.I.T.
Hydrologist

reviewed by
Sam Bellamy, P.Eng.
Senior Water Resource Engineer

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LIST OF FIGURES

LIST OF MAPS

LIST OF TABLES

APPENDIX

1.0 OVERVIEW

This letter report documents the processes that were undertaken to develop groundwater recharge estimates for the City of Barrie Tier Three Study Area.

Groundwater recharge is defined as water which infiltrates into the upper soil zone, and percolates downward past the vegetative rooting zone. Once past the vegetative rooting zone, where evaporative losses occur, the remaining water will continue moving downwards until it reaches the saturated zone and enters the groundwater flow system. A groundwater recharge map illustrates the spatial distribution and amount of water entering the groundwater flow system over a given region and is typically expressed as an average annual depth over an area (mm/yr). The amount and timing of groundwater recharge is dependent on a number of factors, including: precipitation, surficial geology, soil moisture conditions, and evapotranspiration. Accurately estimating groundwater recharge requires the characterization and consideration of all major hydrologic processes.

For the City of Barrie Tier Three study, groundwater recharge was estimated by building and calibrating an integrated model using MIKE SHE (DHI 2011a, b). The groundwater recharge estimates were used as input to the three-dimensional groundwater flow model utilized in the Tier Three Local Area Risk Assessment. This memorandum outlines the methodology used to construct and calibrate the MIKE SHE model and subsequently create the groundwater recharge map. The memorandum contains the following sections:

1. **Overview.** This section provides an overview of the memo contents.

2. **MIKE SHE Background.** This section includes a brief description of the MIKE SHE modelling software and how it represents the hydrologic cycle.

3. **Model Construction.** This section provides details on all model input data and the parameters used to describe the physical system.

4. **Model Calibration.** This section describes the calibration and verification procedures and results.

5. **Model Output.** This section presents the results of the modelling exercise, including the annual average water budget and the spatial distribution of the simulated groundwater recharge.

6. **Summary and Recommendations.** This section provides a brief summary of the memorandum as well as recommendations as they pertain to the groundwater recharge estimates.

2.0 MIKE SHE BACKGROUND

MIKE SHE is a distributed hydrologic model that provides physically-based representations of the hydrologic cycle. It is an extension of the Systéme Hydrologique Européen (SHE) model and is maintained and distributed by DHI. The process schematic for MIKE SHE is shown in Figure 2-1. All land-based phases of the hydrologic cycle, including precipitation, overland flow, unsaturated flow, and saturated flow are calculated on the same (uniform) grid basis. Channel routing is the exception, for which MIKE SHE links to MIKE-11, a 1-D hydraulic model.

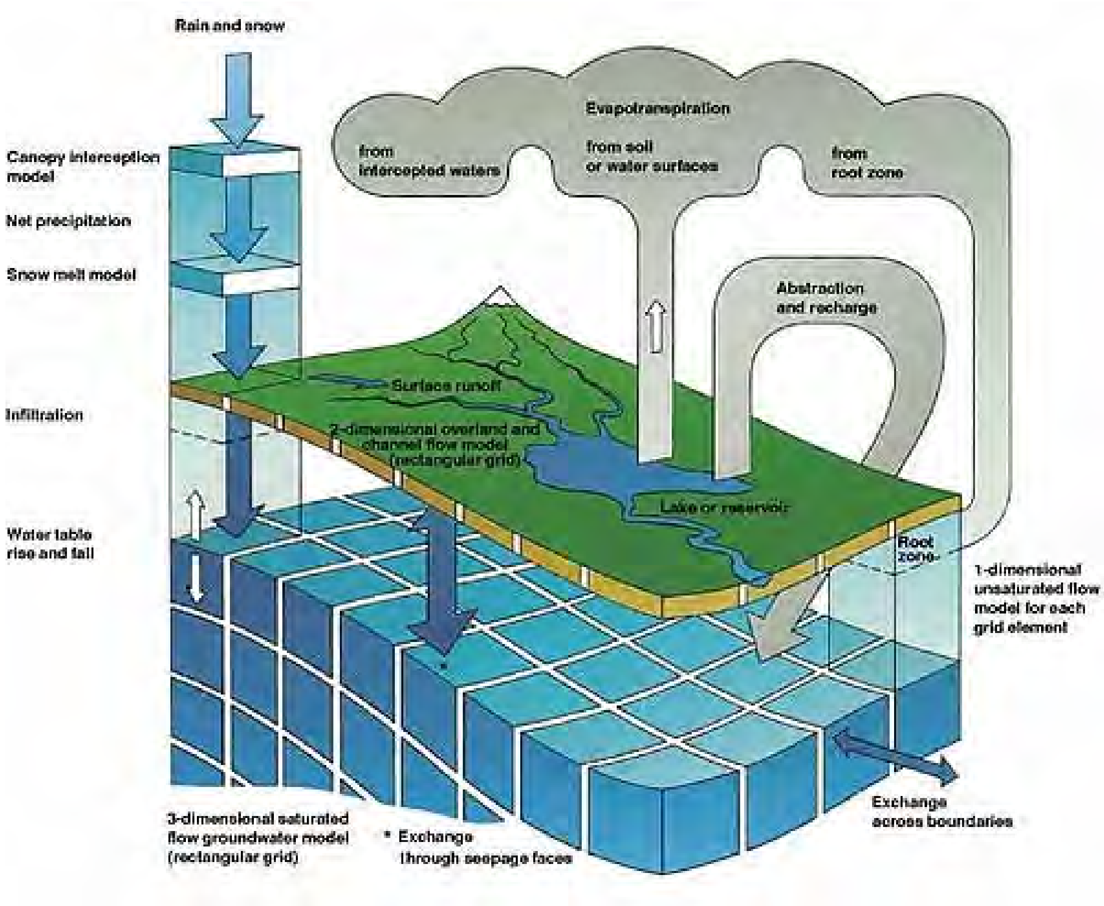

FIGURE 2-1 Process Schematic for MIKE SHE (DHI, 2011a)

MIKE SHE offers the flexibility to implement complex or simple approximations to hydrologic processes, as shown in Figure 2-2. The method selection depends on the main purpose or goal of the model and the availability of input data. This flexibility allows the modeller to operate the model with the minimum degree of complexity needed to accurately reproduce the behaviour of the system of interest. For example, if the main goal of the model is to produce groundwater recharge estimates, the modeller can select simple approximations for processes such as channel routing and complex approximations for saturated zone processes that simulate groundwater-surface water interaction. The methods selected for the Barrie Tier Three model are summarized in Table 2-1 and are discussed below.

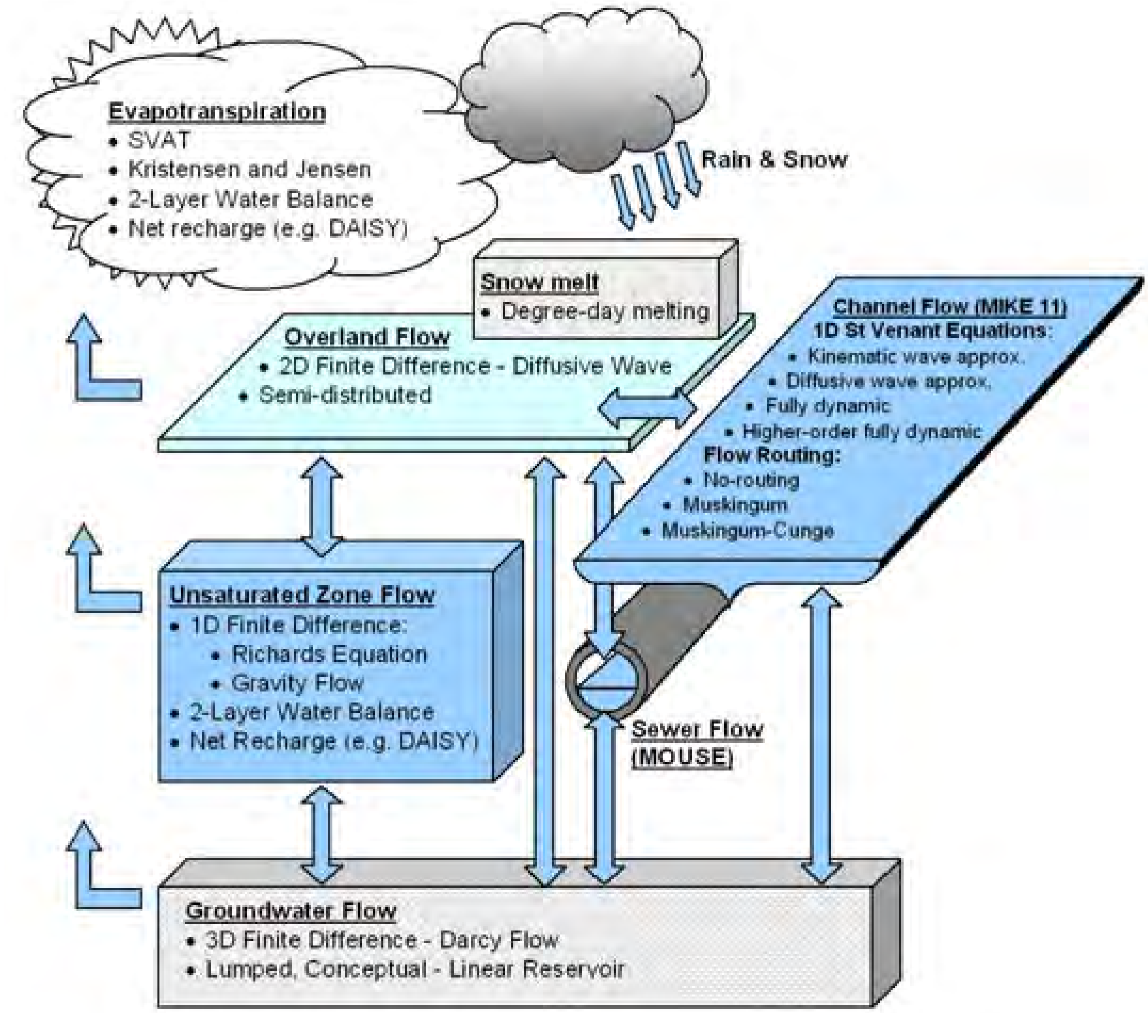

FIGURE 2-2 Available Computational Methods for Major Processes in MIKE SHE (DHI, 2011a)

Within MIKE SHE, liquid water is supplied to the ground surface after accounting for canopy interception and snowmelt processes. Overland runoff is generated when the rate of net precipitation is greater than the rate of infiltration. The algorithms available for infiltration in the unsaturated zone include: a 1-D finite difference approximation of the Richards equation; gravity flow; or a 2-layer water balance with or without the Green and Ampt infiltration routine. The Barrie Tier Three model utilizes the 2-layer water balance with Green and Ampt infiltration. All flow is assumed to be vertical in the unsaturated zone, with the depth of the unsaturated zone determined by groundwater heads (if utilizing the 3-D finite difference method for saturated flow) for that timestep. Water exchange from the unsaturated zone to the saturated zone is termed groundwater recharge.

Evaporation removes soil water content from the two layer unsaturated zone based on the specified potential evapotranspiration rate for that period, and the availability of soil water content. Potential evapotranspiration rates are supplied with a spatial distribution and generated outside of MIKE SHE. A root depth for differing land covers is also specified, which represents the depth of soil which water can be removed by evaporative processes. Water is removed via evaporation from the following storage elements: water held in canopy interception; water on the soil surface; or uptake of soilwater by vegetation from the root zone. Once the reservoirs all are emptied through evapotranspiration, no more water is removed until a precipitation event or increased groundwater elevations replenish water content. Evaporation and sublimation also occur from the snowpack.

Once overland runoff is generated, there are two approximations available for overland routing: a lumped semi-distributed approach or a fully distributed approach. The lumped approach uses an empirical relationship between flow depth and surface detention and the Manning equation. The distributed approach relies on a 2-D diffusive wave approximation of the St. Venant equations, and is the method employed in the Barrie Tier Three model. In this approach, overland runoff is routed cell by cell over the ground surface until a MIKE-11 channel is reached. Runoff flowing from one cell to another is also available for infiltration. Runoff flowing to low areas that do not drain directly to a watercourse will pond, and will either evaporate or infiltrate into the unsaturated zone.

There are two methods available to represent saturated flow. The first is a lumped, subwatershed based method that relies on the linear reservoir approximation. All outflow from the linear reservoir is supplied to MIKE-11 as baseflow to streams within that catchment. This method is an extremely simplified representation of the groundwater system, and is common to most hydrologic models (e.g., GAWSER, HSPF, HEC-HMS). This method does not simulate groundwater flow, heads, or interactions with the surface water system. The second method relies on the solution of the 3-dimensional Darcy equation, using an iterative implicit finite difference technique, and is used in the Barrie Tier Three model.

Channel flow is handled through a two-way linkage between MIKE SHE and MIKE-11. Overland runoff, interflow and groundwater discharge enters the stream channel and is routed downstream. A variety of routing algorithms are available, ranging from relatively simple kinematic routing to the Dynamic Wave formulation of the Saint Venant equations. The Barrie Tier Three model utilizes the kinematic routing method to represent stream routing. Groundwater discharge/leakage into or out of the channel, is calculated based on the surface water elevation, groundwater head, and a river-bed conductance term. Leakage from the watercourse to the saturated zone is limited by the volume of water within the stream.

TABLE 2-1 Hydrologic Process Approximations in Barrie Tier Three Model

Hydrologic Process	Process Approximation
Overland Flow	Two-Dimensional - Diffusive Wave Approximation of St. Venant equations of flow
Channel Flow	Kinematic Routing
Evapotranspiration	Two-layer water balance model (mass balance approach)
Unsaturated Zone	One dimensional, two-layer water balance model Infiltration based on soilwater content parameters, soil conductivity and suction head
Saturated Zone	Three-Dimensional Finite Difference implementation of Darcy's equation
Timestep	Fixed at 1 hour

3.0 MODEL DEVELOPMENT

The following sections describe the setup of the Barrie Tier Three MIKE-SHE model, including the simulation period, model domain and spatial discretization, as well as the required input datasets.

3.1 Simulation Period

The time period selected for simulation should be reasonably consistent with the time frame of input datasets considered (e.g. land use data). Observation data should also be available during this period for model calibration and verification purposes. With this in mind, the most recent 20 years were used as the simulation period, i.e., 1990-2009. This period is reflective of available input data including climate data (Section 3.3), land use data (Section 3.6), pumping data (Section 3.9), and observed calibration data (Section 4.0).

The model was run for three years prior to the start of model simulation, i.e., 1987, to account for a 'warm-up' period wherein the model transitions from initial conditions to the dynamic conditions dictated by model inputs. Initial conditions were derived from a steady state simulation.

The Tier Three process requires the reliability of groundwater supply wells to be tested in a variety of climatic conditions. To do this, the transient groundwater recharge rates must be estimated and supplied to the FEFLOW model. To allow consideration of a longer time period, and subsequently a larger range of climate variability, the simulation period was extended to 1950-2009. This 60-year period includes two significant drought periods, the 1960s and the late 1990s. The first three years were excluded to account for a warm up period. These recharge rates are shown in Section 5.2.

TABLE 3-1 Time periods used for MIKE SHE modelling

Time Period	Model Use
1987-1990	Model 'Warm-Up' Period
1990-2009	Model Calibration/Verification Period (20 years consistent with timeframe of input datasets)
1950-2009	Model Simulation of Groundwater Recharge Rates (over large but reasonable range of expected climate variability)

3.2 Model Domain and Grid Resolution

The model domain was based on the Barrie Tier Three FEFLOW groundwater model domain, as shown on Map 3-1. Where the FEFLOW groundwater model domain coincided with streams (i.e., Marl Creek, Nottawasaga River, Baxter Creek and Banks Creek along the western and southern boundary), the MIKE SHE model included a 1 km buffer to ensure the lateral extent of the streams were captured within the MIKE SHE model. Kempenfelt Bay, and other portions of Lake Simcoe, were excluded from the MIKE SHE model domain as it is unnecessary for modelling and recharge mapping purposes (recharge assumed to be zero). The MIKE SHE model domain encompasses a total of 800 km^2 and is referred to in the following text as the 'Study Area'.

The grid resolution of the model is adaptable and can be set to any multiple integer of the input data. As the model resolution is a significant factor in the model run time, a balance between resolution and run time is needed. For the Barrie Tier Three model, a 200x200 m grid resolution was used.

3.3 Climate Data

Climate data was available for the period of 1950-2005 for a selection of Environment Canada climate stations, sourced from the Land Information Ontario (LIO) infilled climate dataset (LIO, 2008). This dataset was infilled to remove all data gaps and erroneous data by Schroeter and Associates (2007) based on the methodology outlined in Schroeter et al. (2000). Although the raw dataset included large gaps of data and was infilled, the resulting dataset was found to be acceptable and representative of climate for the time period it covered, thus an acceptable source for modelling data. Available climate data for the infilled stations include:

- Daily maximum and minimum temperature;
- Daily rainfall and snowfall; and
- Hourly rainfall.

From these datasets hourly precipitation and temperature time series were derived as model input. A synthetic hourly temperature dataset was derived assuming the maximum daily temperature occurred at 3:00 pm with the minimum daily temperature occurring at 3:00 am. Daily potential evapotranspiration rates were generated according to the Hamon Method (Hamon, 1961), which uses mean daily temperature, the climate station latitude and a monthly coefficient. The monthly coefficient used for the Hamon method in this model was 0.2095. The annual average temperature, precipitation and potential evapotranspiration over the 1990-2005 period are listed in Table 3-2.

TABLE 3-2 Summary of Climate Input Data for 1990-2005 Period

AES ID	Station Name	Latitude	Longitude	Mean Annual Temperature 1990-2005 (0C)	Mean Annual Precipitation 1990-2005 (mm/yr)	Mean Annual PET* 1990-2005 (mm/yr)
6111859	Cookstown	44.21	-79.69	6.5	820	676
6110275	Angus Camphill	44.28	-79.85	6.8	838	692
6115099	Midhurst	44.45	-79.77	7.5	889	706
6112340	Essa Ont Hydro	44.35	-79.82	7.1	889	728
6110557	Barrie WPCC	44.38	-79.69	7.1	931	712

*Note: PET is potential evapotranspiration and is computed according to the Hamon Method (Hamon, 1961). It is not climate data that is measured directly, but rather a hypothetical maximum evapotranspiration value calculated from available climate data.

Climate data from the above stations was spatially distributed throughout the model according to Thiessen polygons as shown in Map 3-2. The assumption inherent in the use of Thiessen polygons to distribute climate data, is that the data recorded at the climate station is representative for the entire area within that Thiessen polygon. As it is known that point measured climate data is often not representative of climate occurring over a large area (e.g., particularly during the summer thunderstorm season), this is a source of uncertainty.

For the 2006-2009 period, AquaResource completed an internal data fill-in exercise for hourly climate data obtained from Environment Canada. Within the Study Area, only the Barrie WPCC climate station had hourly data for the 2006-2009 period, which could be obtained from Environment Canada. Therefore, data from this station was used to represent the entire Study Area during this period. The data fill-in procedure was similar to the one utilized for the above mentioned 1950-2005 LIO infilled dataset. The annual average temperature, precipitation and evapotranspiration over the 2006-2009 period are listed in Table 3-3.

TABLE 3-3 Summary of Climate Data for 2006-2009 Period

AES ID	Station Name	Latitude	Longitude	Mean Annual Temperature 2006-2009 (0C)	Mean Annual Precipitation 2006-2009 (mm/year)	Mean Annual PET* 2006-2009 (mm/year)
6110557	Barrie WPCC	44.38	-79.69	7.7	905	809

*Note: PET is potential evapotranspiration and is computed according to the Hamon Method (Hamon 1961)

The Nottawasaga Valley Conservation Authority (NVCA) operates a snow course survey near Colwell, approximately 4 km east of Angus (Map 3-2). The snow course is located in a forested area (Tiffin Swamp) with snow depth measurements taken on the first and fifteenth of the winter months (December 1st to May 1st) from 1972-2010. There are significant data gaps from 1992-1997, with only about two measurements taken per year during this time. This snow survey data was used as a secondary calibration target, as discussed in Section 4.4.

In the model, actual evapotranspiration is estimated using a 2-layer water balance method. The method splits the unsaturated zone into two layers – one layer representing the root zone, from which evapotranspiration can occur, and the lower layer representing unsaturated zone storage, from where evapotranspiration cannot be extracted. This method requires an input of root depth time series and leaf area index time series (both shown in Table 3-4) as well as the reference evapotranspiration given in

LEGEND

- Towns/Villages
- Highways
- Roads
- River / Stream
- MIKE SHE River Network
- Open Water
- Wetlands
- Barrie Tier 3 FEFLOW Boundary
- Barrie Tier 3 MIKE SHE Boundary
- Urban Centres
- Township Boundary

Barrie Tier 3 Groundwater Recharge Estimation

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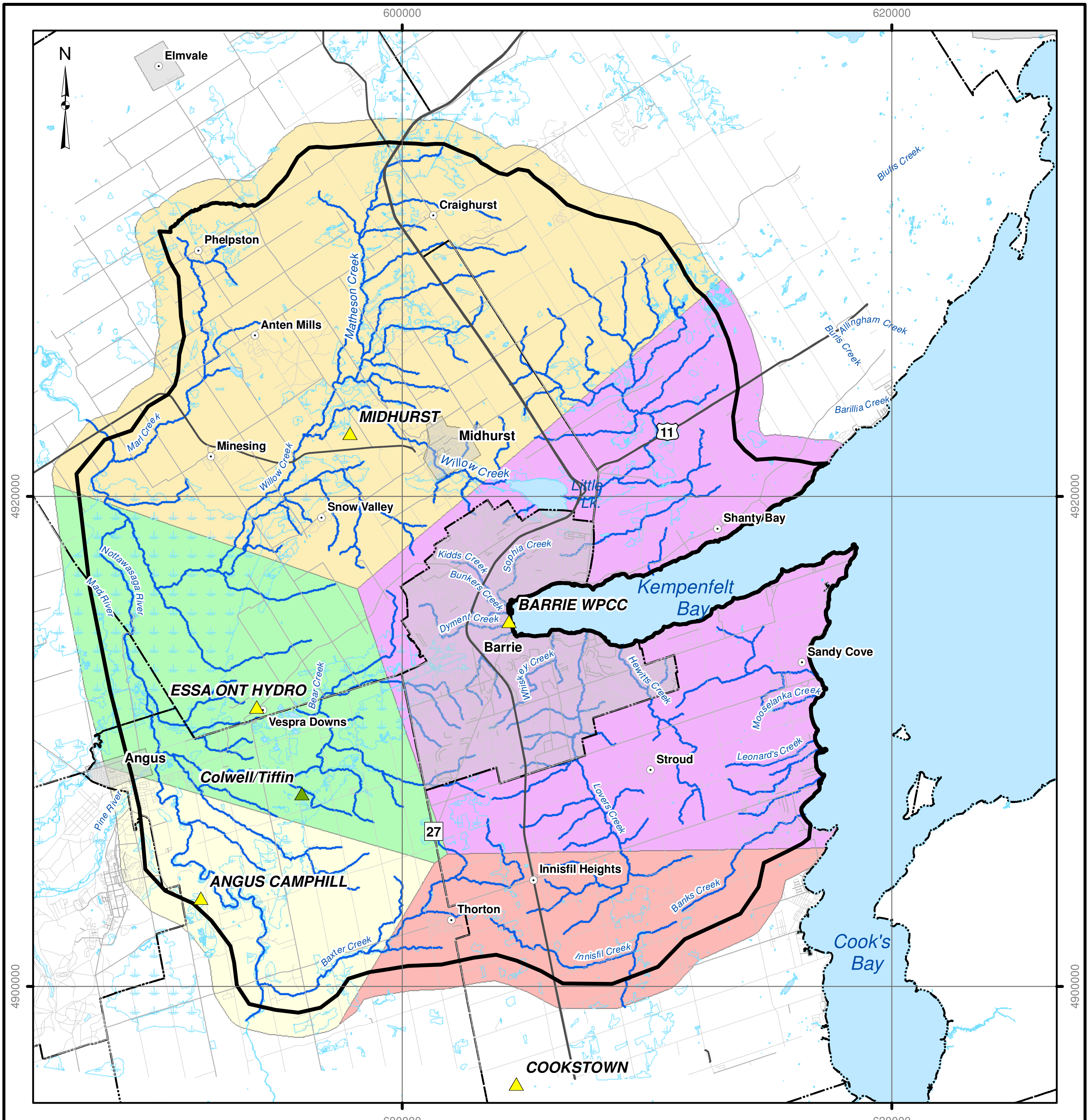
Golder Associates

IWC International Water Consultants Ltd.

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: 01-Jun-2011; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

Map 3.1
MIKE SHE Model Domain



LEGEND

- Towns/Villages
- Environment Canada Climate Stations
- NVCA Climate Stations
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Urban Centres
- Township Boundary
- Barrie Tier 3 MIKE SHE Boundary

Climate Stations Areas

- Angus Camphill
- Barrie WPCC
- Cookstown
- Essa Ont Hydro
- Midhurst

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REFERENCES
Base Data - NVCA, 2009
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Scale 1:220,000
2 0 2 4
Kilometres

Map 3.2
Spatial Distribution of Climate Data

Table 3-2. It calculates evapotranspiration by first extracting from intercepted water (using the leaf area index), then ponded water, and finally from the root zone.

3.4 Topography and Drainage

A 5 m resolution Digital Elevation Model (DEM) supplied by the LSRCA was utilized to capture the topography of the Study Area, and is shown in Map 3-3. Dominant features in the Study Area include the Oro Moraine at a high of 412 metres above sea level (masl), the Innisfil Highlands at a high of 320 masl, the Minesing Wetland at a low of 181 masl and Kempenfelt Bay at 218 masl.

The Study Area encompasses two watersheds: the Nottawasaga River watershed and the Lake Simcoe watershed. The drainage divide follows the highlands of the Oro Moraine in the north, through Midhurst, along the western edge of the City of Barrie, to the Innisfil Highlands in the south. Major watercourses within the Study Area include Willow Creek and Matheson Creek in the north, which collect drainage from the Oro Moraine and flow into Minesing Wetland; and Lovers Creek in the south, which drains directly to Kempenfelt Bay.

3.5 River Network

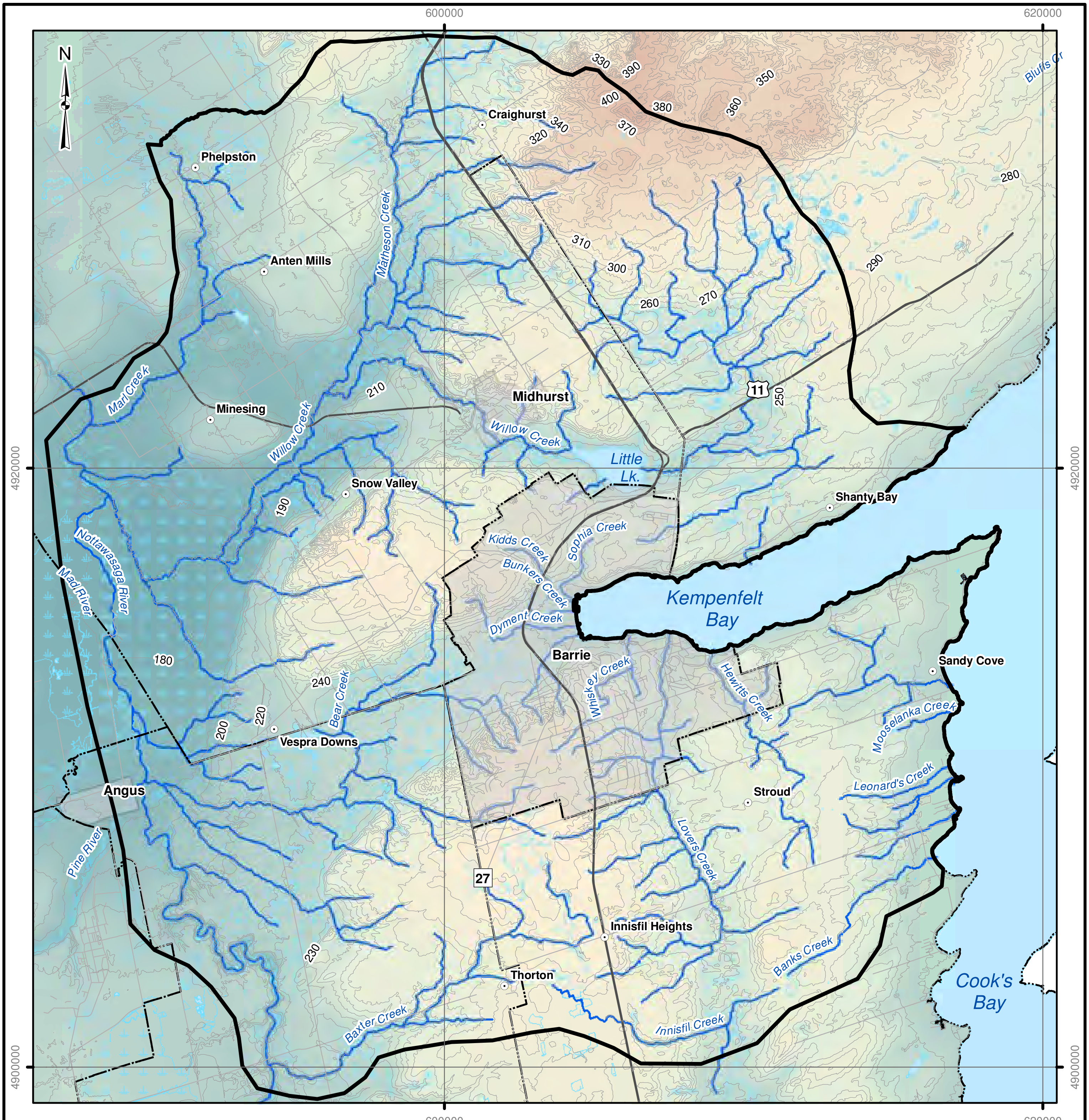
A drainage layer describing the river network for the model region is required to simulate channel flow in the MIKE 11 modelling system. A simplified river network was created for use in both the FEFLOW and MIKE SHE/MIKE 11 models. Rivers were filtered based on orthoimagery, proximity to one another (>500 m apart), stream order (Strahler classification number ≥3) and stream length (>700 m). This filtering resulted in a simplified river network which captured the major streams within the model region. Slight differences exist between the drainage network used in the FEFLOW model and the MIKE SHE model, and are related to differing model requirements between the two models. The simplified stream network in MIKE SHE is shown in Map 3-4.

Cross sections of the water courses were developed at 500 m to 1,000 m intervals along the streams according to the 5 m DEM elevations. The cross sections are used in MIKE 11 for hydraulic routing computations. Discrepancies can exist between the ground surface elevations of the distributed model and the bank elevations of the hydraulic model. This is due to the relative coarseness of the distributed model resolution (200 m) relative to the high resolution data cross section elevations are derived from (5 m). To address this issue, cross section bank elevations were adjusted to better match the elevations of the distributed model. The cross sections are approximately 100 m wide.

Channel routing is performed through simple kinematic routing. The kinematic routing uses a Manning's roughness coefficient of 0.05 for both the channel and floodplain, based on literature values (Bedient and Huber, 2002).

3.6 Land use

A land use map was created during the South Georgian Bay – West Lake Simcoe Tier Two Study (Golder and AquaResource, 2010). The land use mapping was based on land cover data from the LSRCA published in 2008 and from the Nottawasaga Valley Conservation Authority (NVCA) published in 2007. Similar to the Tier Two Study, in areas of overlap, the LSRCA data was used as it was the most recent data, and better overall data quality. Eight land use classes were created from the land use data, listed in Table 3-4 and shown on Map 3-5.



LEGEND

- Towns/Villages
- 300 Ground Surface Contours and Values - Interval 10m
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Urban Centres
- Township Boundary
- Barrie Tier 3 MIKE SHE Boundary

Ground Surface Elevation (m)
High: 412
375
325
275
225
Low: 173

Barrie Tier 3 Groundwater Recharge Estimation

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REFERENCES

Base Data - NVCA, 2009

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Projection: UTM Zone 17N, NAD 83

Map Version: 1; Map Date: 01-Jun-2011; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

Map 3.3

5m Digital Elevation Model (DEM)

LEGEND

- Towns/Villages
- MIKE SHE Cross Section
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Barrie Tier 3 MIKE SHE Boundary
- Urban Centres
- Township Boundary

Barrie Tier 3 Groundwater Recharge Estimation

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Scale 1:180,000
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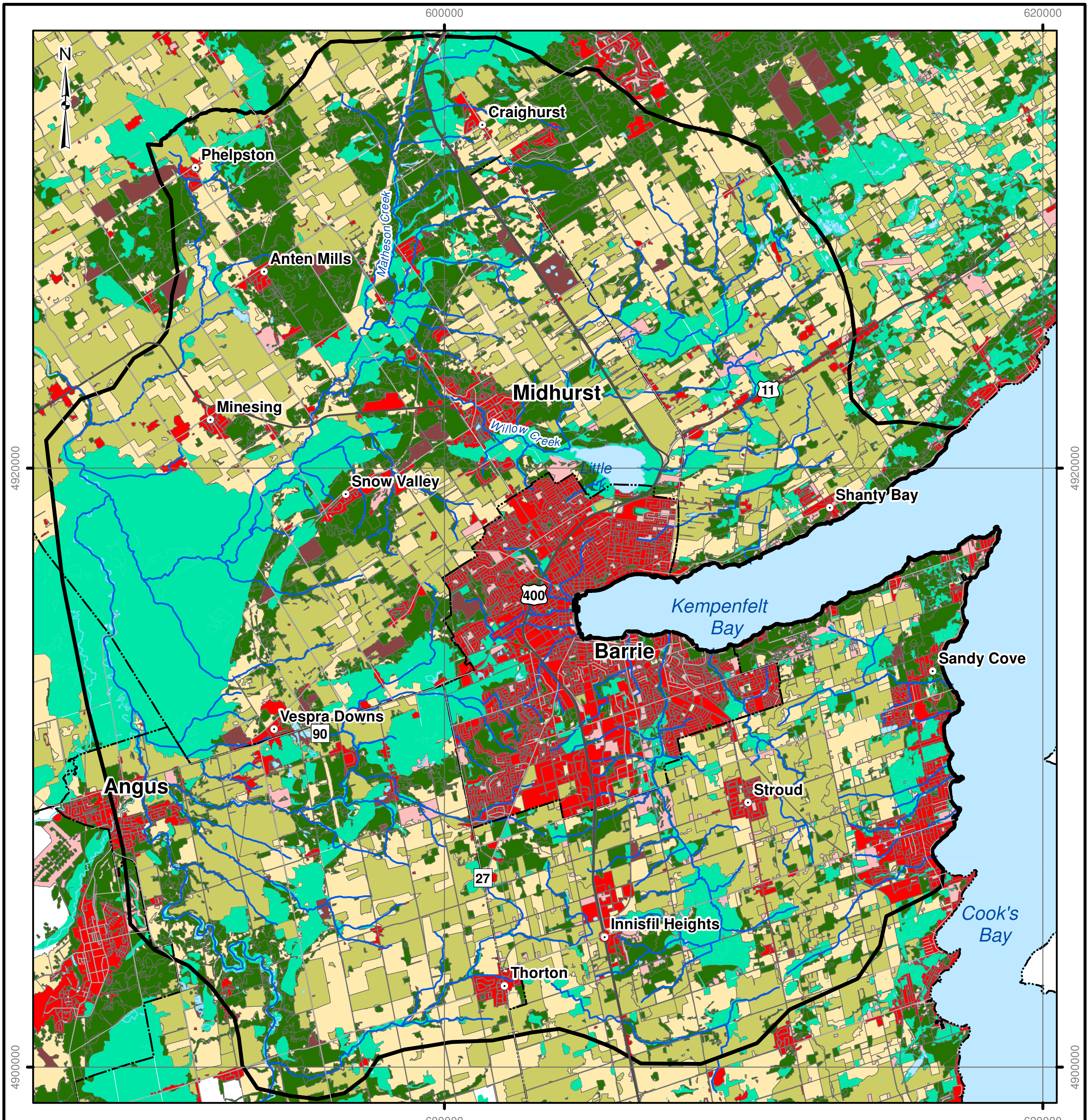
Kilometres

Map 3.4
River Network and Cross Sections



LEGEND

- Towns/Villages
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Township Boundary
- Barrie Tier 3 MIKE SHE Boundary

Current Landuse

- Water
- Low Intensity Developed
- High Intensity Developed
- Hay / Pasture
- Row Crop
- Mixed Forest
- Wetland
- Quarries

Barrie Tier 3 Groundwater Recharge Estimation

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Map 3.5

Land Use Classes

REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 01-Jun-2011; Created By: ccurry

Scale 1:180,000
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Kilometres

C:\Projects\2010007_BarrieTier3\GIS\ArcView\MXDs\MikeSHE\Fig3.5_GeneralizedLandUse.mxd

Project: 2010007 BarrieTier3

Vegetation parameters were assigned according to the land use class. These include a leaf area index and rooting depth time series to characterize the growth cycle of the vegetation. These parameters affect evapotranspiration and overland flow processes and are shown in Table 3-4. These parameters were based on literature values and previous modelling experience in the Grand River watershed using MIKE SHE.

TABLE 3-4 Vegetation Parameters for Land Use Classes in MIKE SHE Model

Land Use Class	Range of Monthly LAI* Values	Range of Monthly Root Depth Values (mm)
Low Density Urban/Rural Areas	2 - 4	750
High Density Urban	0.8 - 1.45	750
Hay/Pasture/Idle/Transitional	2.5 - 5	50 - 1000
Row Crops/ Intensive Agriculture	2.5 - 5	50 - 1000
Forests/Mixed Woods	5 - 7	1000 - 2000
Wetlands	2 - 4	200
Water, Pits, & Quarries	0	0

*LAI is Leaf Area Index

Overland flow parameters were also assigned based on each land use class and include surface roughness, depression storage, and a paved runoff coefficient, as shown in Table 3-5. Surface roughness is used to approximate surface friction and is given by Manning's n coefficient. Depression storage represents the portion of rainfall trapped by surface topography which is left to infiltrate or evaporate following a rainfall event. Values were assigned based on literature (Chin, 2006) and modelling experience, and were adjusted during calibration.

A paved runoff coefficient was applied to highly urbanized areas to represent the fraction of directly connected impervious areas. The paved runoff coefficient defines the fraction of overland flow that is not infiltrated but instead is drained directly to storm sewers via the saturated zone drainage network. This is to simulate that paved areas typically drain to storm sewers, which drain directly to streams. The rural areas and highways did not contain significant directly connected impervious area under a 200 m grid resolution to be simulated as paved areas. A paved runoff coefficient of 0.3 was used for the Barrie Tier Three model.

TABLE 3-5 Land Use Classes and Parameters

Land Use Class	Surface Roughness (Manning's n)	Depression Storage (mm)	Paved Runoff Coefficient
Water	0.06	10	Null
Low Density Urban / Rural Areas	0.15	2	Null
High Density Urban	0.09	2	0.3
Hay / Pasture / Idle / Transitional	0.37	5	Null
Row Crops / Intensive Agriculture	0.37	2	Null
Forests / Mixed Woods	0.42	10	Null
Wetlands	0.42	9	Null
Pits /Quarries	0.05	1	Null

3.7 Unsaturated zone

The unsaturated zone in MIKE SHE represents the upper soil zone, in which infiltration, overland runoff, and the majority of evapotranspiration is generated. The unsaturated zone in the Barrie Tier Three MIKE

SHE model is characterized using the Quaternary geology from the Ontario Geological Survey (OGS, 2003). Further detail is described in the Conceptual Understanding Memorandum (AquaResource et al., 2011). The Quaternary geology classifications were simplified into four soil classes: gravel, sand, silt / till, and clay. The soil classes are shown in Map 3-6.

The soil classes are characterized in MIKE SHE according to their hydrologic properties, including infiltration rates and soilwater holding capacities. Soil parameter values were based on previous modelling experience in the region and through calibration. The calibrated soil parameters are listed in Table 3-6.

TABLE 3-6 Calibrated Soil Parameters

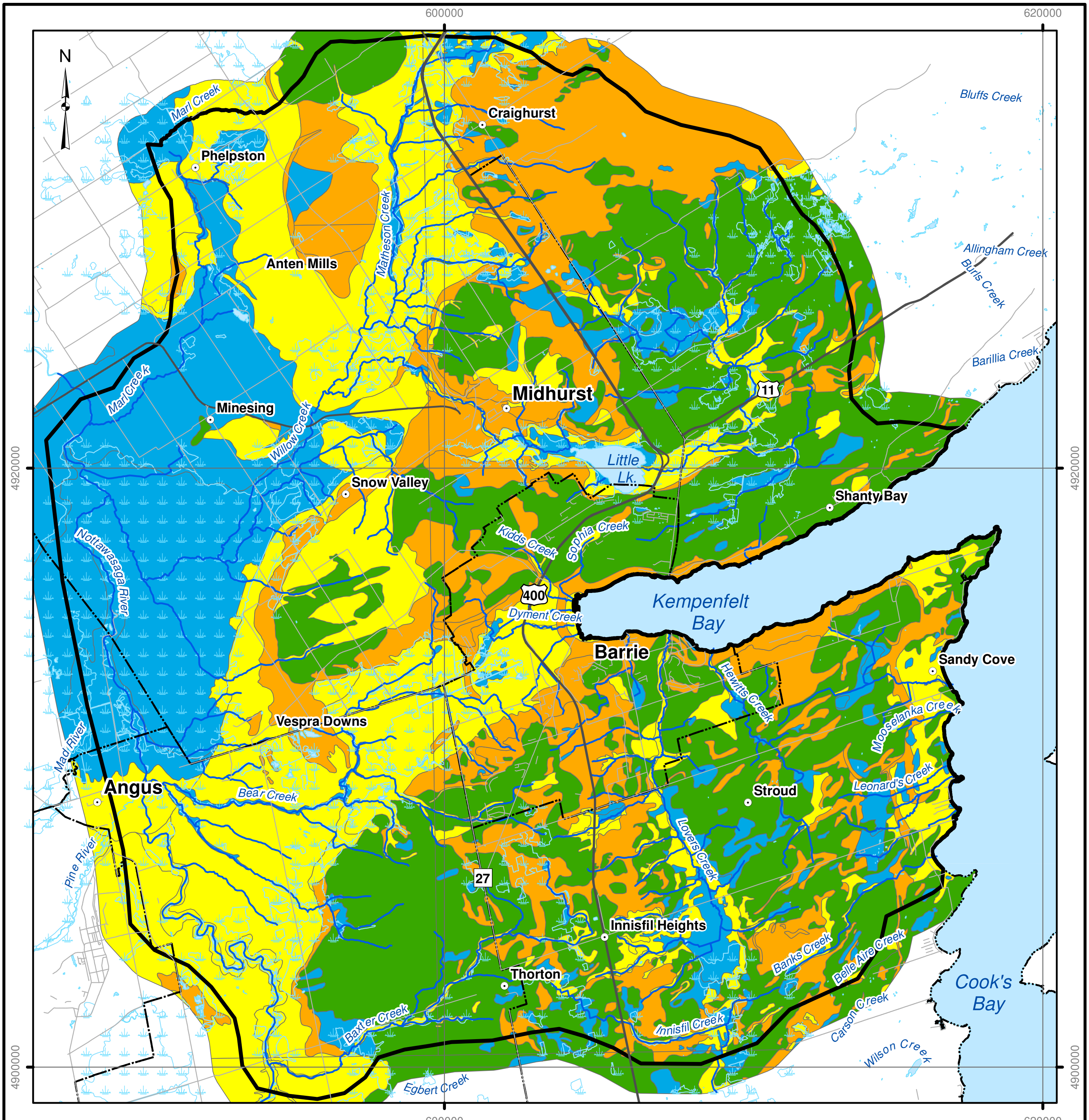
Soil Parameter	Gravel	Sand	Silt + Tills	Clays
Saturation Point	0.30	0.46	0.56	0.56
Field Capacity	0.20	0.23	0.46	0.46
Wilting Point	0.04	0.07	0.27	0.27
Infiltration Rate (m/s)	6E-6	4E-6	4E-8	1E-8
Suction Head (m)	-0.20	-0.25	-0.20	-0.20

A limitation of the unsaturated zone representation in MIKE SHE is that it only considers flow in the vertical dimension. In areas with thick unsaturated materials this assumption of one-dimensional vertical flow may not be correct. Intervening low permeability lenses may promote horizontal rather than vertical flow, and cause water to be directed towards local watercourses, rather than the deeper groundwater flow system. It should also be noted that quaternary geology classifications are typically based on the first few meters of soil. Due to the thickness of the unsaturated zone in the highland areas (10-20 m), the geology classification may not be representative for the entire depth.

3.8 Saturated Zone

MIKE SHE represents the groundwater system through a three-dimensional representation of the subsurface using Darcy's equation. The layer structure and spatial hydraulic characteristics used in the Barrie Tier Three MIKE SHE model are based on the geologic layers and properties included in the FEFLOW 3-D groundwater flow model. The 9-layer structure found in the FEFLOW model was simplified to a 3-layer structure in MIKE SHE, as illustrated in Figure 3-1. The first layer represents a shallow aquifer system where the majority of interaction between groundwater and surface water occurs. This corresponds to the combination of the upper unconfined (UC) layer, aquifer 1 (A1), confining layer 1 (C1), and aquifer 2 (A2) in the FEFLOW model. The second layer is a confining layer corresponding to C2 in FEFLOW. The third layer represents the deep aquifer system, where most of the municipal wells are pumping from. This corresponds to the FEFLOW aquifers A3 and A4, with confining layers C3 and C4. The purpose of this simplified layer structure in MIKE SHE was to include sufficient layers to accurately characterize the subsurface, while keeping simulation times to reasonable lengths.

Aquifers A1 and A2 are modelled in the same layer due to having similar hydraulic heads and having limited data available in each aquifer. Water levels within these units are considered to represent the "shallow" water levels. "Deep" water levels are represented by Aquifers A3 and A4. As a result, it was important to accurately represent Aquitard C2, the primary aquitard between them. Having it represented in at least one unique model layer, the role of the aquitard is captured explicitly instead of being lumped in with surrounding aquifers.



LEGEND

- ⊙ Towns/Villages
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Urban Centres
- Township Boundary
- Barrie Tier 3 MIKE SHE Boundary

Generalized Soil Class

- Sand
- Gravel
- Silt/Till
- Clay

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Map 3.6

Soil Classes

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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Scale 1:180,000
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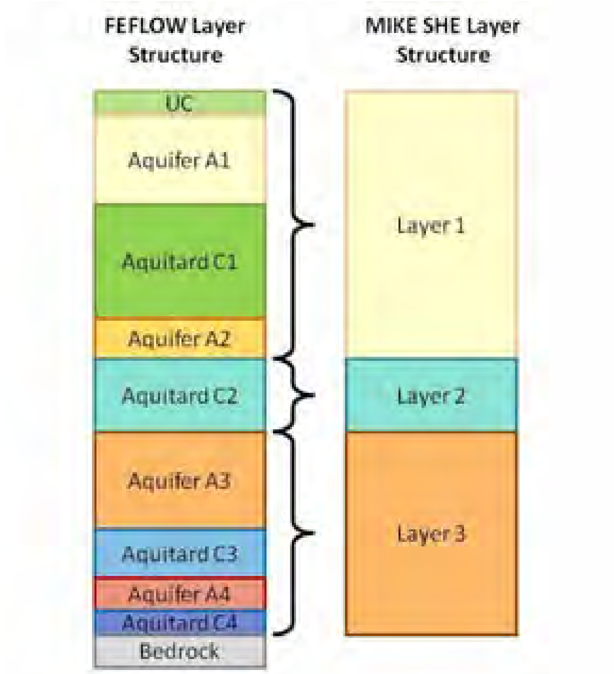


FIGURE 3-1 Simplified Saturated Zone Layer Structure

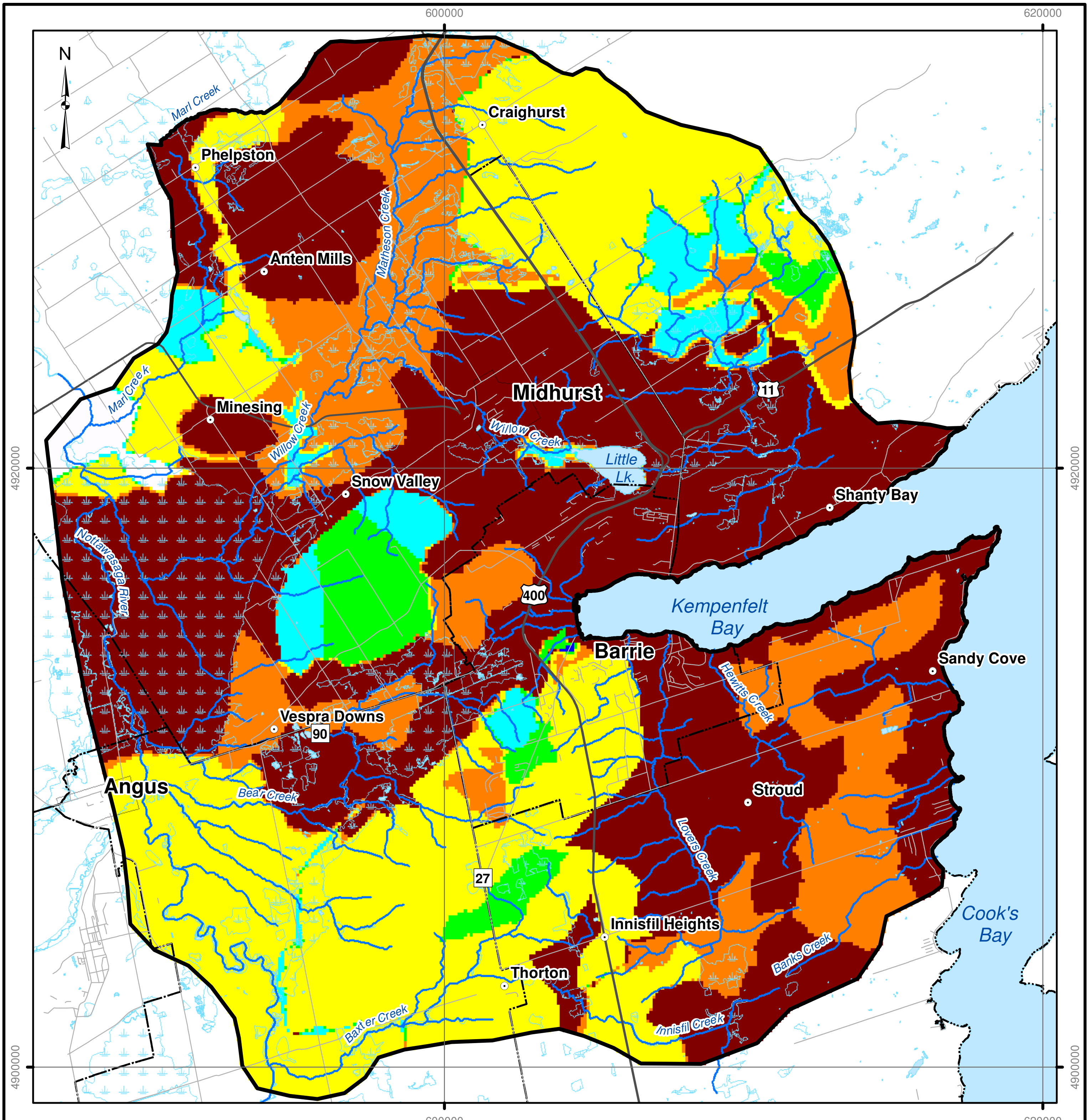
The saturated zone properties required in MIKE SHE include the horizontal (Kx) and vertical (Kz) hydraulic conductivities, initial water level elevations, as well as specific yield and specific storage. The hydraulic conductivities assigned to each layer reflect the controlling layer properties from the FEFLOW model layer. These are listed in Table 3-7. MIKE SHE was run in steady state mode to obtain initial groundwater elevations. A specific yield of 0.2 and specific storage of 1e-5 were used in the model.

TABLE 3-7 MIKE SHE Saturated Zone Horizontal (Kx) and Vertical (Kz) Hydraulic Conductivities as Related to FEFLOW

MIKE SHE Layer	FEFLOW Kx Layer	FEFLOW Kz Layer
1	A1	C1
2	C2	C2
3	A3	C3

The simplification of the saturated zone was a limitation in the ability of the MIKE SHE model to accurately simulate groundwater flow. For example, in the highland areas, Layer 1 could represent a depth of up to 100 m of subsurface using a single geologic property (a single hydraulic conductivity). In reality there could be lenses of tighter materials that impede flow and that create preferential flow pathways. As such, the hydraulic conductivities of Layer 1 were adjusted during calibration in an attempt to account for the variation in geologic materials. The adjustments consisted of decreasing the hydraulic conductivity in the highland areas by a factor of 10 in the horizontal direction and a factor of 50 in the vertical direction. The layering structure of the saturated zone (i.e., Layer 1 is still very thick in those areas) remained a limitation of the model. The horizontal and vertical hydraulic conductivities in Layer 1 are shown in Map 3-7 and Map 3-8, respectively. Layer 2 and Layer 3 hydraulic conductivities did not differ from the FEFLOW properties and are therefore not shown here.

The boundary conditions specified in the MIKE SHE model are based on those used in the FEFLOW model and are shown in Map 3-9 for Layers 1 and 2 and Map 3-10 for Layer 3. Fixed head boundary



LEGEND

- Towns/Villages
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Urban Centres
- Township Boundary
- Barrie Tier 3 MIKE SHE Boundary

Hydraulic Conductivity (m/s)

- 0 - 1e-06
- 1e-06 - 5e-06
- 5e-06 - 1e-05
- 1e-05 - 5e-05
- 5e-05 - 1e-04
- 1e-04 - 5e-04
- 5e-04 - 1e-03
- > 1e-03

Barrie Tier 3 Groundwater Recharge Estimation

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REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 01-Jun-2011; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

Map 3.7
Horizontal Hydraulic Conductivity in MIKE SHE Layer 1

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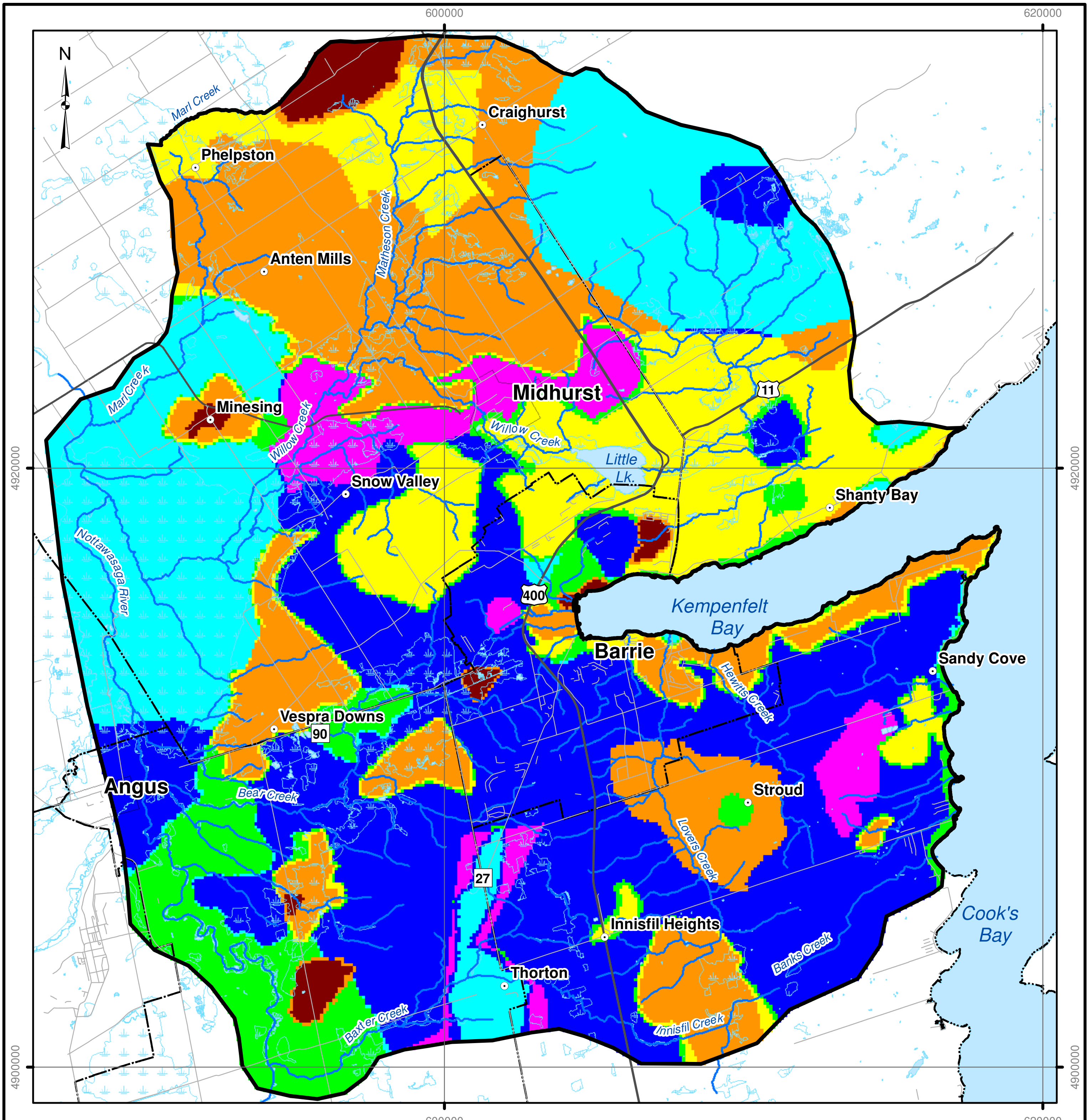
Project: 2010007 BarrieTier3



LEGEND

- Towns/Villages
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Urban Centres
- Township Boundary
- Barrie Tier 3 MIKE SHE Boundary

Hydraulic Conductivity (m/s)

- 1e-9 - 1e-8
- 1e-8 - 1e-7
- 1e-7 - 1e-6
- 1e-6 - 1e-5
- 1e-5 - 1e-4
- 1e-4 - 1e-3
- > 1e-3

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REFERENCES
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Map Version: 1; Map Date: 01-Jun-2011; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

Map 3.8
Vertical Hydraulic Conductivity in MIKE SHE Layer 1

LEGEND

- Towns/Villages
- Highways
- Roads
- MIKE SHE River Network

Boundary Conditions for MIKE SHE Layers 1 & 2

- Fixed Head
- No Flow
- Open Water
- Wetlands
- Urban Centres
- Township Boundary

181 Boundary Condition Value

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Map 3.9

Boundary Conditions in MIKE SHE Layer 1 and 2

REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 01-Jun-2011; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

LEGEND

- Towns/Villages
- Highways
- Roads
- MIKE SHE River Network

181 Boundary Condition Value

Boundary Conditions for MIKE SHE Layer 3

- Fixed Head
- No Flow
- Open Water
- Wetlands
- Urban Centres
- Township Boundary

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Map 3.10

Boundary Conditions in MIKE SHE Layer 3

REFERENCES
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Scale 1:180,000
2 0 2 4
Kilometres

conditions were specified under the Minesing Wetland according to the shallow (181 masl for Layers 1 and 2) and deep (192 masl for Layer 3) water table contours included in the Conceptual Understanding Memorandum (AquaResource et al., 2011). Along Lake Simcoe, a fixed head boundary condition was specified at 218 masl for Layers 1 and 2. For Layer 3 only a portion of Kempenfelt Bay, mainly within the City of Barrie, was specified as a fixed head to coincide with observed water levels. Additional fixed head boundary conditions were set in Layer 3 at the Oro Moraine (296.5 masl) and Innisfil Highlands (244.7 masl) to account for the flux of water to and from the model boundary at these locations. Fixed head values were taken from observed water levels included in the Conceptual Understanding Memorandum (AquaResource et al., 2011).

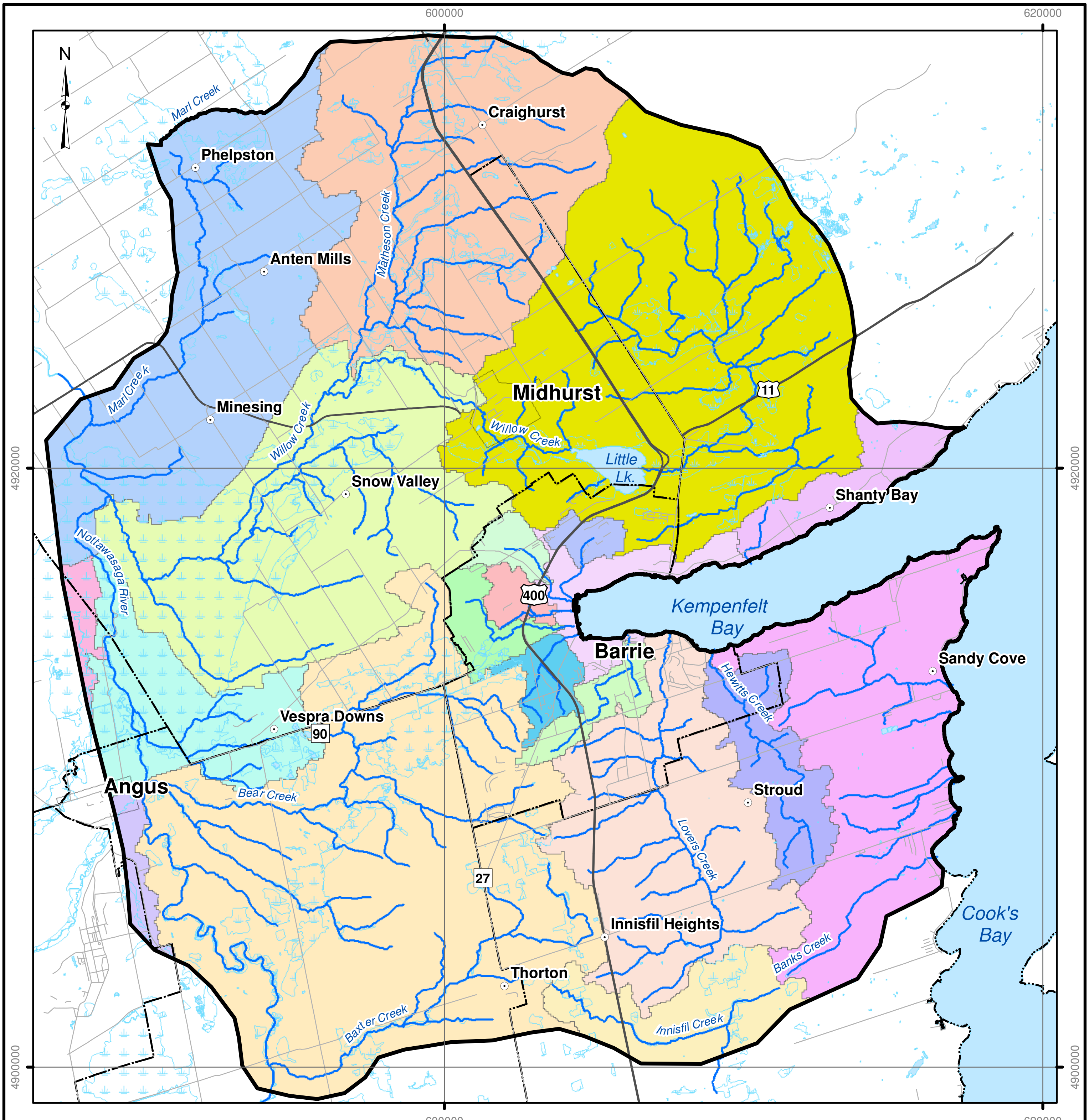
The saturated zone in MIKE SHE also includes modelled subsurface “drains” which are used to represent the quick response of the groundwater system (interflow) to local streams. Overland runoff from paved areas is also sent to the subsurface drains. Subsurface drain flow occurs mainly after large rainfall events. When recharge to the saturated zone causes the water table level to rise above a user-defined drainage depth (drain level), a portion of that excess water from the saturated zone is routed to a river node to augment streamflow. Subsurface drain flow is routed to a river node using a linear reservoir technique, based on the drain level (steady state water table elevation) and leakage rate (1e-6 s^{-1}). One of the difficulties in simulating the Study Area was representing the interflow component in the highland areas. The best attempt was by placing the drains at or near the steady state water table. This way, when the transient water table was above the drains, drain flow is active and supplies water to the streams via ‘interflow’ and when the water table is below the drains, drain flow is inactive.

Subsurface drainage is determined spatially through user-defined drainage boundaries, called drain codes. All drainage generated within the same drain code is discharged to the nearest river node within that drainage boundary. The drain codes in the Barrie Tier Three model follow surface water subwatershed boundaries and are shown in Map 3-11.

3.9 Pumping Wells

MIKE SHE has the ability to include water withdrawals in the model. The Barrie Tier Three MIKE SHE model includes all groundwater withdrawals associated with a Permit To Take Water from the Ontario Ministry of Environment (MOE), and are shown in Map 3-12. The colour of the point reflects which layer in the model the well is pumping from and the size of the point reflects the rate of pumping. The depth of the well screens are the same as those used in the FEFLOW model. The modelled pumping rates are described in the Conceptual Understanding Memorandum (AquaResource et al., 2011). The municipal pumping rates are the average annual reported rates for 2008. Non-municipal (private) pumping rates are the average annual consumptive rates for 2008. These are based on the reported water use in the MOE’s Water Taking Reporting System (WTRS) for 2008; or, where this data is not available, the maximum permitted rate was combined with the estimated months of active pumping based on the purpose of the water taking. The pumping rate is then adjusted by a consumptive use factor to estimate the water which is consumed and not returned to the same source. The modelled pumping rates for all wells in the Study Area are included in Appendix B1.

There is a need for a long term record of reported rates that should be satisfied with the continued use of the WTRS. This would increase confidence in using a long term average pumping rates in model simulations. However, as the WTRS was being phased from 2005-2008, there is limited available reported data for non-municipal users. As the 2009 WTRS reported rates became available during the



LEGEND

- Towns/Villages
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Urban Centres
- Township Boundary
- Barrie Tier 3 MIKE SHE Boundary

Subwatersheds

- Bunkers Ck
- Dyments Ck
- Hewitts Ck
- Hotchkiss Ck
- Innisfil Ck
- Innisfil Creeks
- Kempenfelt Bay
- Kidds Ck
- Lovers Ck
- Lower Nottawasaga River
- Lower Willow Ck
- Mad River
- Matheson Ck
- Mid-Lower Nottawasaga River
- Middle Nottawasaga River
- Oro Creeks
- Pine River
- Sophia Ck
- Upper Willow Ck
- Whiskey Ck

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Map 3.11

Subwatershed Boundaries

REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 01-Jun-2011; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

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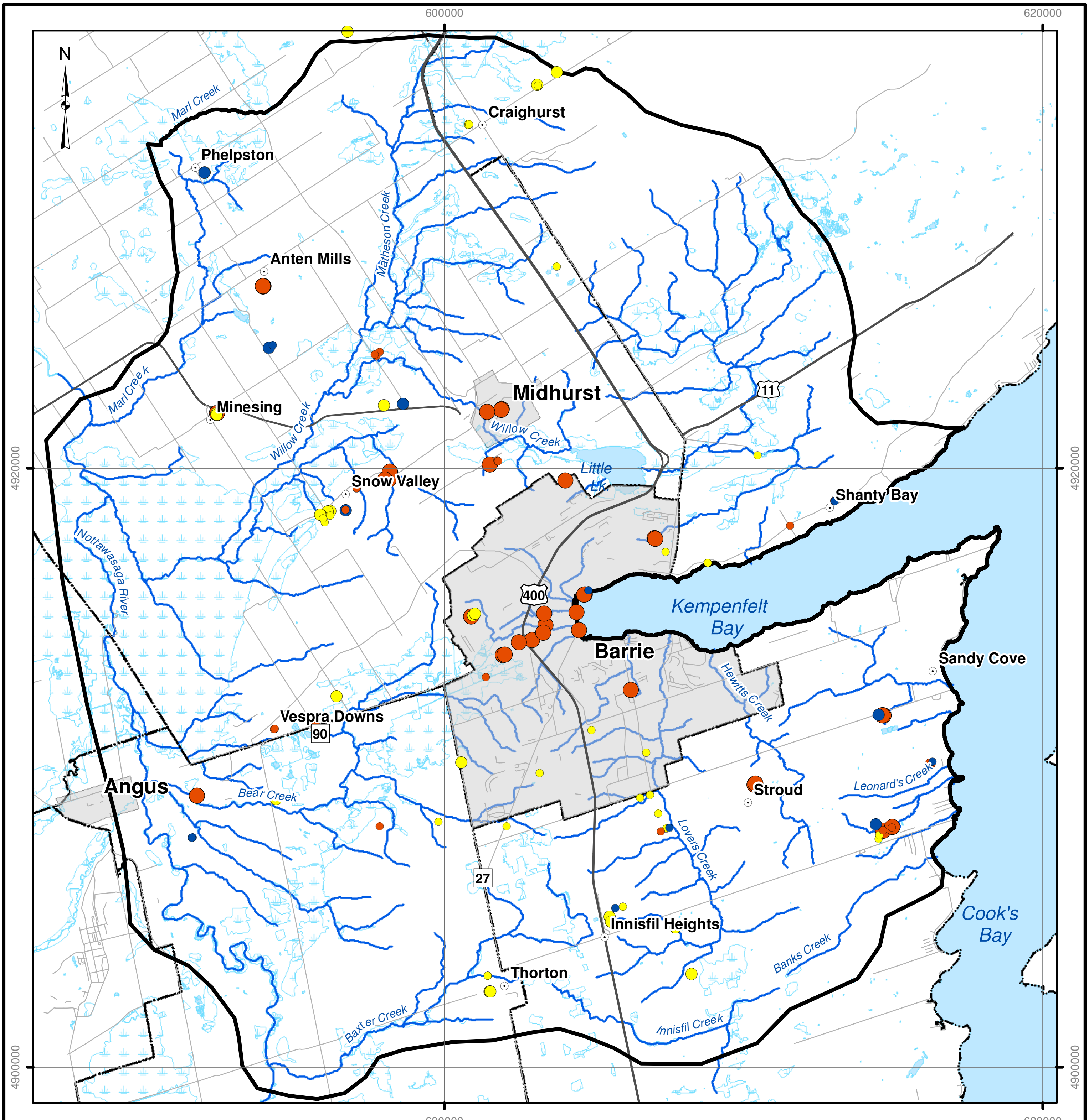
Project: 2010007 BarrieTier3



Index Map

LEGEND

- Towns/Villages

Average Use (m^3/day)

- 0 - 100
- 100 - 1000
- > 1000

MIKE SHE Model Layers

- Layer 1
- Layer 2
- Layer 3

- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Barrie Tier 3 MIKE SHE Boundary
- Urban Centres
- Township Boundary

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Map 3.12

Modelled Pumping Wells

REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 12-Apr-2011; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

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Project: 2010007 BarrieTier3

course of this study, a comparison between the 2008 and 2009 consumptive rates was included to ensure the 2008 rates were representative pumping rates for model calibration (Appendix B1).

The municipal demand for the City of Barrie comprises 73% of the total consumptive demand in the Study Area (AquaResource et al., 2011). As seen in Figure 3-2, there has appeared to be a reduction in average water demand occurring after 2007. Water demand after 2007 is fairly stable, averaging approximately 40,000 m^3/day. Figure 3-2 illustrates that the 2008 municipal rates are representative of the recent pumping conditions in the City of Barrie.

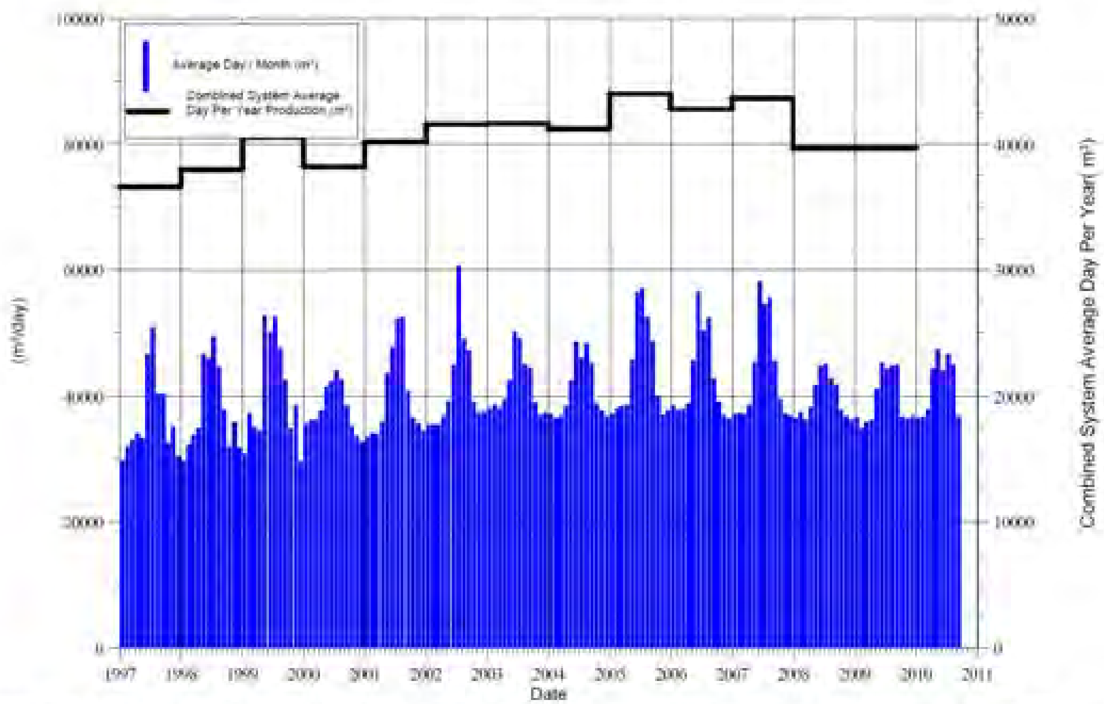


FIGURE 3-2 City of Barrie Combined Well System Annual Production Summary (IWC, 2010)

The remaining water demand consists of other municipalities water use (9%), commercial use (11%; i.e., mainly golf course irrigation and snowmaking), and other uses (7%; e.g., industrial, remediation and recreational). For these permits a comparison between the 2008 and 2009 consumptive rates is shown in Figure 3-3. Appendix B1 lists all wells in the Study Area and their 2008 and 2009 rates and data sources. Generally, the 2009 rates show a reduction in estimated pumping from 2008. This is mainly due to more permit holders reporting their pumping rates in the 2009 WTRS, whose pumping rates were estimated in 2008. As the 2008 rates are a more conservative estimate, these were used for steady state model calibration. It is clear that the non-municipal pumping rates are a source of uncertainty; however, as they amount to less than 20% of the total consumptive demand, it is unlikely that this uncertainty will significantly impact the model calibration. The uncertainty associated with the non-municipal pumping estimates, as it relates to the overall study objectives will be considered in the Local Area Risk Assessment.

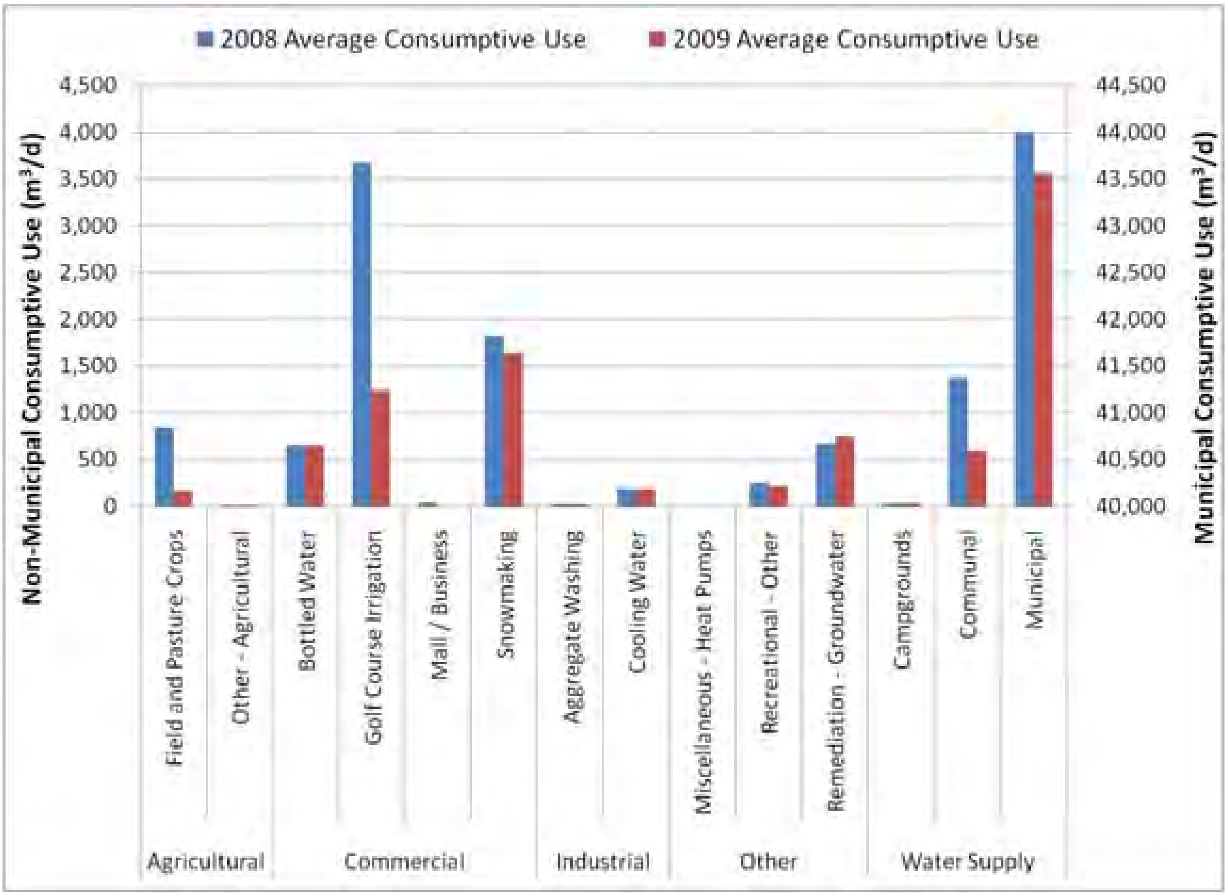


FIGURE 3-3 Comparison of Average Annual Consumptive Water Use for 2008 and 2009 by Water Use Sector

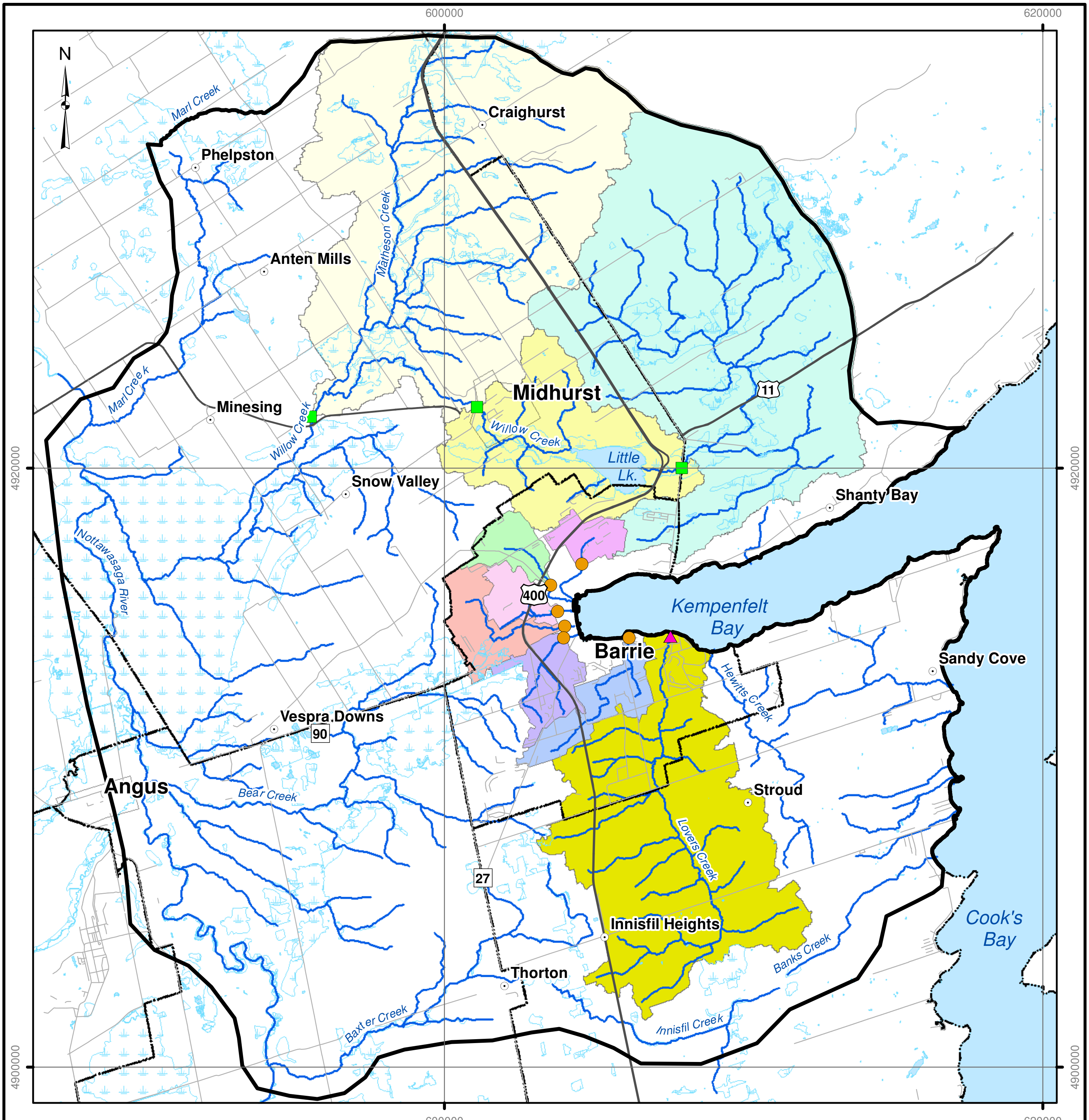
4.0 MODEL CALIBRATION

Model calibration involves adjusting hydrologic parameters to minimize differences between simulated and observed conditions. For this study, observed data included streamflow data from monitoring gauges, groundwater elevations from the MOE water well database, and snow depths from the NVCA snow course survey. The model calibration data, procedure and results are discussed below.

4.1 Overview of Calibration Targets and Procedure

The 1950-2009 simulation period was split into a calibration period, whereby the parameters were adjusted to match groundwater elevations, streamflow and annual water budget values; and a verification period, whereby the parameters were tested against a new set of input data. Due to the availability of observed streamflow and climate data, the model was calibrated over the 1990-2005 period and verified over the 2006-2009 period.

The primary calibration targets are streamflow monitoring gauges, listed in Table 4-1 and shown in Map 4-1. The groundwater levels are secondary targets as they represent average steady state groundwater elevations, whereas the MIKE SHE model is transient (changing over time). The groundwater levels were used to match general flow patterns and elevations. The snow depths



LEGEND

- City of Barrie Stream Gauges
- LSRCA Stream Gauges
- WSC Stream Gauges
- Towns/Villages
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Barrie Tier 3 MIKE SHE Boundary
- Urban Centres
- Township Boundary

Stream Gauge Drainage Areas

- Bunkers Ck
- Dyments Ck
- Hotchkiss Ck
- Kidds Ck
- Lovers Ck
- Sophia Ck
- Whiskey Ck
- Willow Ck above Little Lake - 02ED009
- Willow Ck at Midhurst - 02ED010
- Willow Ck near Minesing - 02ED032

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REFERENCES
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 01-Jun-2011; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

Map 4.1

Calibration Targets

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Project: 2010007 BarrieTier3

recorded at the snow course survey are tertiary targets, as there is only a single survey location in the Study Area which may not be representative of the entire area.

Streamflow calibration exercises for hydrologic modelling are typically approached in a structured hierarchical manner. Models are calibrated to a longer temporal scale (e.g., annual streamflow), and then sequentially moved to a shorter temporal scale (e.g., monthly streamflow). This approach ensures that regional processes, such as climate and evapotranspiration are well represented by the model, before effort is spent calibrating to local processes, such as channel routing. As groundwater recharge is generally an indication of the baseflow component of streamflow, the calibration also focused on matching the low flow months during the summer, and not on matching peaks flows. The streamflow monitoring gauges are listed in Table 4-1.

TABLE 4-1 Streamflow Monitoring Gauges and Calibration Targets

Station Name	Agency	Streamflow Record	Calibration (C) or Verification (V) Period	Drainage Area (km^2)	Mean Annual Flow (m^3/s)
02ED009 - Willow Creek above Little Lake	Water Survey Canada	1973- 1995*	Jan 1990 - July 1995 (C)	95	0.88
02ED010 - Willow Creek at Midhurst	Water Survey Canada	1973- 1998*	Jan 1990 - May 1998 (C)	127	1.20
02ED032 – Willow Creek near Minesing	Water Survey Canada	2006*-2008	Apr 2006 - Dec 2008 (V)	242	2.59
LS0101 - Lovers Creek at Tollendal	LSRCA	2001-2008	Jan 2001 – Dec 2004 (C)	60	0.76
Sophia Creek	City of Barrie	Mar-Dec 2004-2010	N/A	2.3	0.03
Kidds Creek	City of Barrie	Mar-Dec 2004-2010	N/A	4.5	0.08
Bunkers Creek	City of Barrie	Mar-Dec 2004-2010	N/A	3.2	0.10
Dyments Creek	City of Barrie	Mar-Dec 2004-2010	N/A	5.4	0.09
Hotchkiss Creek	City of Barrie	Mar-Dec 2004-2010	N/A	4.5	0.08
Whiskey Creek	City of Barrie	Mar-Dec 2004-2010	N/A	6.7	0.08

*Data is incomplete for this year.

Once the calibration process began, a number of challenges were encountered with the streamflow data. The streamflow data at the Barrie Creeks gauges were recorded after the main spring freshet each year – some years starting in March and some as late as May. This prevented the comparison of simulated and observed mean annual flows. There were also some concerns with the accuracy of the applied rating curves in the relationship between river stage and discharge (e.g., due to vandalism and during high flow events). More confidence was given to the 2009-2010 data, as streamflow monitoring methods were improved and new instruments were implemented during this monitoring period (i.e., from leveloggers to ultrasonic sensors). Additional documentation on the streamflow monitoring program can be found in Stantec (2010) and Golder (2009). In addition, the urbanized hydrology of these catchments (i.e., channelized streams, storm sewers, and storm water management ponds) could not be included in the MIKE SHE model. As such, the Barrie Creeks gauges could not be used as calibration targets.

The Lovers Creek at Tollendal gauge is operated by LSRCA and there are measured streamflow data from 2001-2009. However, as outlined in the Conceptual Understanding Memorandum (AquaResource et al., 2011), the 2009 streamflow data has not been corrected for ice and was not used in this assessment. Prior to 2001, streamflow records at this location were synthetic estimates, and were estimated using a regression relationship and areally weighting flow from all gauged areas. Due to the uncertainty associated with this synthetic data, these data were not used in the assessment. While corrected streamflow data was available from 2001-2008, the calibration only considered data from 2001-2004. This was due to potential issues with the data from 2005-2008, as discussed further in Section 4.2.2.

Consideration was also given to spot flow measurements, as outlined in the Conceptual Understanding Memorandum (AquaResource et al., 2011). However, the majority of the low flow spot flow measurements were taken only on one date and represent a single snap shot in time that may not be representative of actual baseflow conditions, as suggested by coldwater stream mapping. Additional flow measurements were taken on several dates at three locations; however, these were not necessarily taken during baseflow conditions. As there is considerable uncertainty associated with the spot flow measurements, they were not used as calibration targets.

4.2 Streamflow Calibration and Verification Results

This section includes the calibration and verification results for the 1990-2005 period. The calibration targets include two Water Survey Canada stream gauges: 02ED009 - Willow Creek above Little Lake (Jan 1990 - July 1995), and 02ED010 - Willow Creek at Midhurst (Jan 1990 - May 1998); as well as one LSRCA stream gauge: Lovers Creek at Tollendal (Jan 2001 - Dec 2004). The verification target is the Water Survey Canada stream gauge 02ED032 - Willow Creek near Minesing (Apr 2006 - Dec 2008). The years with incomplete data are not included in the annual totals; however, the available data for those years are included in the monthly means and ranked duration curves.

4.2.1 <u>Overview of Calibration and Verification Metrics</u>

The calibration and verification portion of the modelling focuses on metrics to gauge the appropriateness of the model. This approach recognizes that no single metric is adequate to describe the model's ability to replicate observed flows. The calibration and verification metrics presented are as follows:

- Annual streamflow expressed as depth (mm) over the upstream area;

- Mean monthly streamflow expressed as depth (mm) over the upstream area;
- Daily hydrograph comparisons shown for a sample year;
- Ranked duration daily streamflow; and
- Monthly calibration statistics (log Nash-Sutcliffe and R^2 Coefficients).

Due to the log-normal distribution of streamflow, a normal Nash-Sutcliffe coefficient is heavily weighted towards higher flows. To provide a more accurate assessment of the overall model performance, the log Nash-Sutcliffe coefficient was calculated for this modelling exercise. According to Chiew and McMahon (1993) and Nash and Sutcliffe (1970), a Nash-Sutcliffe coefficient:

- Equal to 1 is a perfect fit;
- Greater than 0.8 is considered good;
- Greater than 0.6 is considered reasonable; and
- Less than zero implies the observed mean is a better predictor than the model.

These published ranges are not based on log-transferred values, so should be considered general guidelines for the log Nash-Sutcliffe coefficient calculated for this model evaluation.

The R^2 value is another indicator of data agreement. A value equal to 1 is a perfect fit. In this model evaluation, the log R^2 value was computed and used.

4.2.2 Calibration Results

The streamflow calibration results are illustrated in Figure 4-1 and Figure 4-2 below. Figure 4-1 shows the mean annual streamflow in the left column and the mean monthly streamflow in the right column. The top row is the Willow Creek above Little Lake gauge, the middle is the Willow Creek at Midhurst gauge, and the bottom is the Lovers Creek gauge. Observed streamflow is shown in blue and simulated is shown in red. As mentioned above, years with incomplete records of streamflow are not shown in the annual plots, but are included in the monthly plots. In the mean annual streamflow plots, the average annual is shown in the far right.

These calibration graphs show that generally the model is under predicting mean annual streamflow, primarily due to the lower spring flows. This is particularly evident at the Willow Creek above Little Lake gauge, where the majority of the drainage area is the Oro Moraine. As described earlier, the Oro Moraine has a significant depth of unsaturated materials. It is suspected that the assumption of only vertical flow in the unsaturated zone is lending itself to insufficient water being directed towards local streams on the Oro Moraine, and too much water being supplied to the deeper groundwater system.

Errors may also be introduced due to the spatial distribution of climate data. The climate data recorded at the climate station may not be representative of the climate over the entire watershed, particularly with respect to lake effect snow. Lake effect snow is often highly spatially variable, and is typically difficult to properly characterize given a sparse climate station network. This would lead to differences in the snow pack and therefore in the spring melt. In the summer months, the model is able to replicate low-flows much better, although simulated mean monthly flows are slightly higher than observed.

The main difference between the Willow Creek above Little Lake gauge and the Willow Creek at Midhurst gauge is the routing impacts of Little Lake; the drainage areas are very similar (95 and 127 km^2). This is evident in the daily hydrographs shown for these two gauges in Figure 4-2. The observed streamflow for Willow Creek above Little Lake shows a peakier and more rapid response to storm events; whereas the Willow Creek at Midhurst gauge shows a much more muted, delayed response with lower peaks and a slow recession of streamflow. As the objective of the Barrie Tier Three MIKE SHE model is estimating recharge, not replicating hydraulic effects, the routing effects of Little Lake, which do not influence groundwater recharge estimates, were not taken into account.

For the Lovers Creek gauge, mean annual flows match very well, with the exception years after 2004 (Figure 4-3). Mean annual flow volumes increase from an approximate average of 300 mm/yr in 2001-2004 to 450 mm/yr in 2005 and greater than 700 mm/yr for following. Given mean annual precipitation rate is approximately 900 mm/yr and evapotranspiration is 500-550 mm/yr, streamflow yields of these magnitudes are not felt to be realistic. It is possible that changes in urban development over the upstream area changed the stage-discharge relationship that the existing rating curve was based on; or possibly the data are not corrected for ice impacts (as is known to be the case for 2009). From this it was determined that the observed data at Lovers Creek from 2005 onward was not reasonable for model calibration use. As such, the mean monthly flow depth was computed for 2001-2004. This shows a reasonable fit between simulated and observed data, with simulated flow for the month of August being slightly higher than observed. This is likely due to summer thunderstorms, as the low flows match very well in the daily hydrograph (Figure 4-2) and it is mainly differences in peaks that are affecting the overall average flow depth.

Also included in Figure 4-2 are the ranked daily duration curves for the three gauges. A ranked duration curve compares the ranked daily simulated streamflow and ranked daily observed streamflow. It provides the viewer with the ability to determine model performance over the entire flow regime. Periods of extreme low flow are represented by those flows exceeded 90-100% of the time, with high flows exceeded 0-10% of the time. The ranked duration curve for Willow Creek above Little Lake shows an acceptable fit between simulated and observed daily flows with high flows a bit too low and low flows a bit too high. The Willow Creek at Midhurst gauge is impacted by routing effects of Little Lake which are not included in the model. The ranked duration curve for the Lovers Creek gauge shows a very good match between simulated and observed flows.

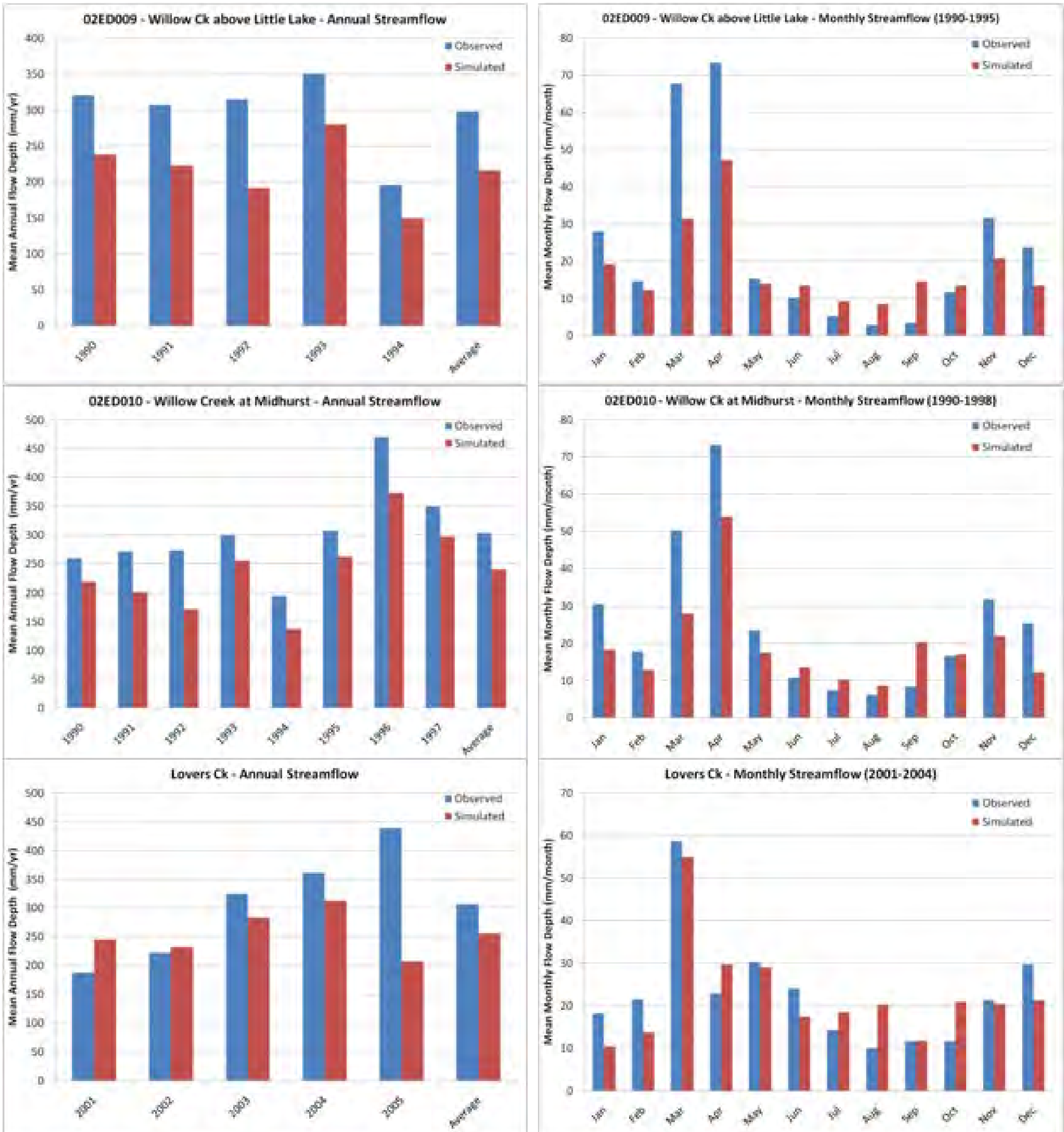


FIGURE 4-1 Annual and Monthly Streamflow Depths for Streamflow Calibration Results

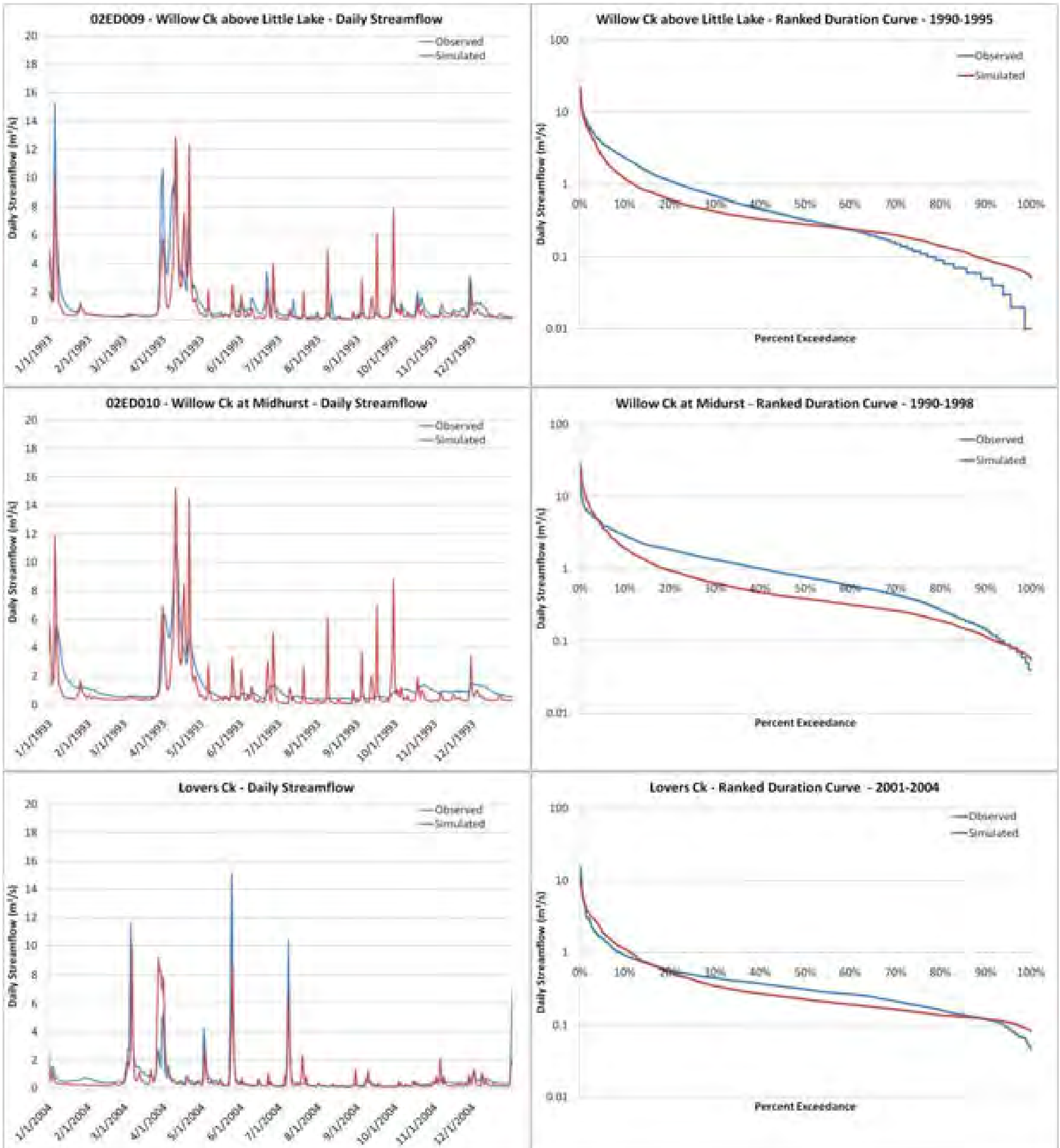


FIGURE 4-2 Daily Streamflow Hydrograph and Ranked Duration Curves for Streamflow Calibration Results

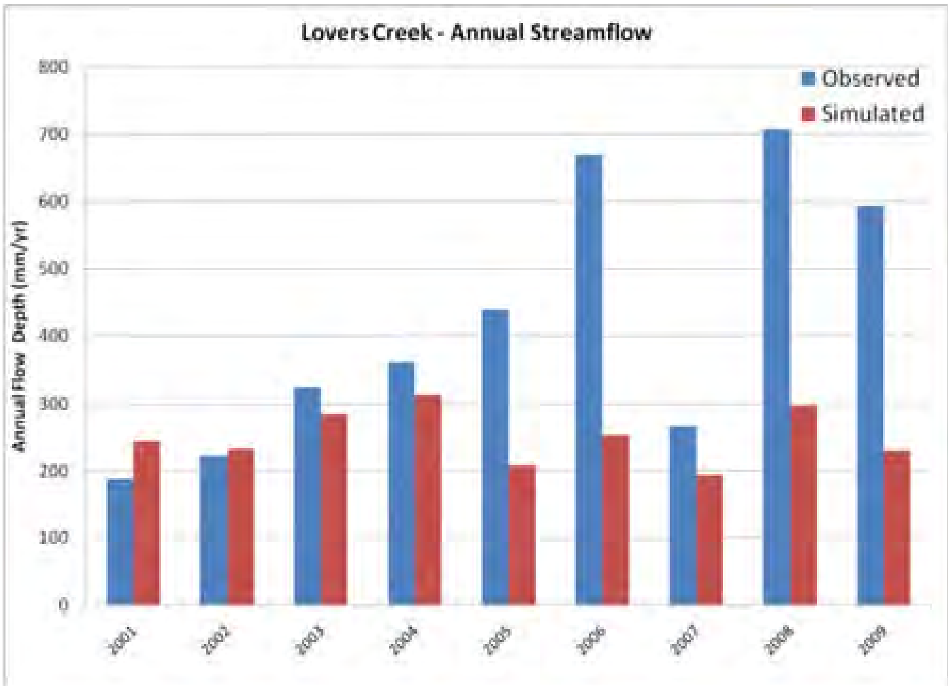


FIGURE 4-3 Annual Streamflow Depth at Lovers Creek Gauge from 2001-2009

The monthly calibration statistics for the three streamflow gauges are shown in Table 4-2. The R^2 values are reasonable for Willow Creek and a bit lower for Lovers Creek but still fairly reasonable. The Nash-Sutcliffe coefficients are fairly reasonable for the three gauges.

TABLE 4-2 R^2 and Nash-Sutcliffe Coefficients for Comparison of Monthly Streamflow for Calibration Period

Station Name	Calibration Period	Log R2	Log Nash-Sutcliffe
02ED009 - Willow Creek above Little Lake	1990 - July 1995	0.73	0.61
02ED010 - Willow Creek at Midhurst	1990 - May 1998	0.75	0.50
LS0101 - Lovers Creek at Tollendal	2001-2004	0.57	0.53

4.2.3 Verification Results

With the omission of the Lovers Creek gauge streamflow data from 2005 onward (Figure 4-3), the only streamflow data available for the verification period is the Willow Creek near Minesing gauge from April 2006 to December 2008. This gauge is located at Willow Creek below the confluence with Matheson Creek (Map 4-1) and therefore adds a new portion of the Study Area with which to validate the model.

Figure 4-4 shows the mean annual streamflow depth for 2007 and 2008 and the mean monthly streamflow depth for 2006-2008. The limited time period associated with observed streamflow values from this gauge limit the usefulness of this comparison, as a single misrepresented rainfall or snowmelt event may significantly skew the comparison. That being said, these figures show a reasonable match between simulated and observed streamflow. Similarly to the Willow Creek above Little Lake gauge, the spring flows are low; however the summer flows are matching well. Figure 4-5 shows the daily hydrograph for 2008 and the ranked duration curve. The summer low flows are matching reasonably well; the main differences in the summer hydrographs appear to be due to climate (localized thunderstorms). The winter and spring low flows are lower than observed, which is also seen in the ranked duration curve.

Overall, the streamflow calibration and verification results show that the model is able to reasonably replicate observed streamflow conditions, particularly in the summer months when baseflow conditions are indicative of groundwater recharge.

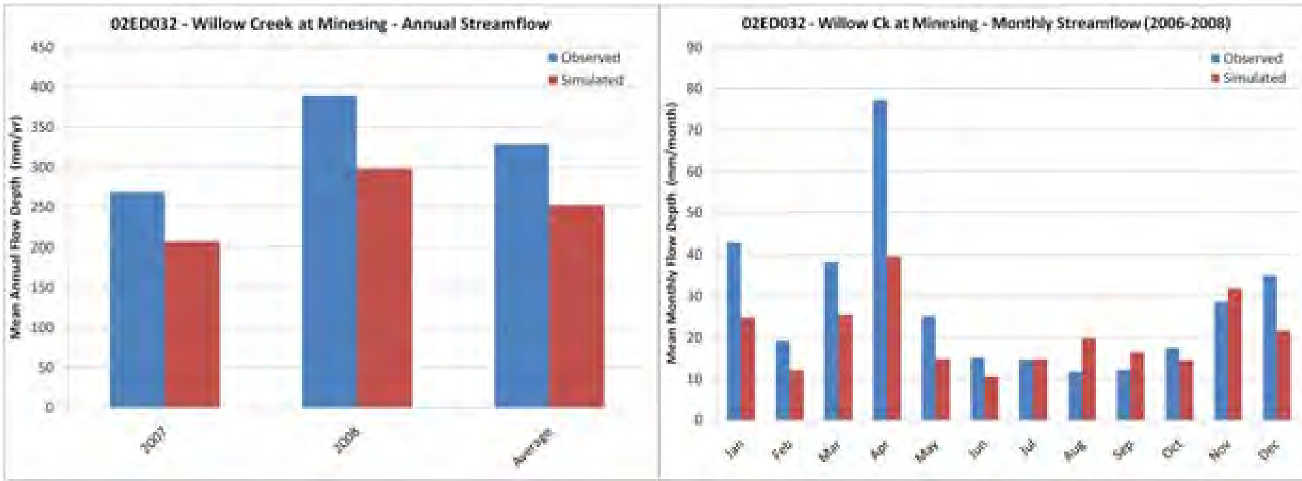


FIGURE 4-4 Annual and Monthly Streamflow Depths for Streamflow Verification Results

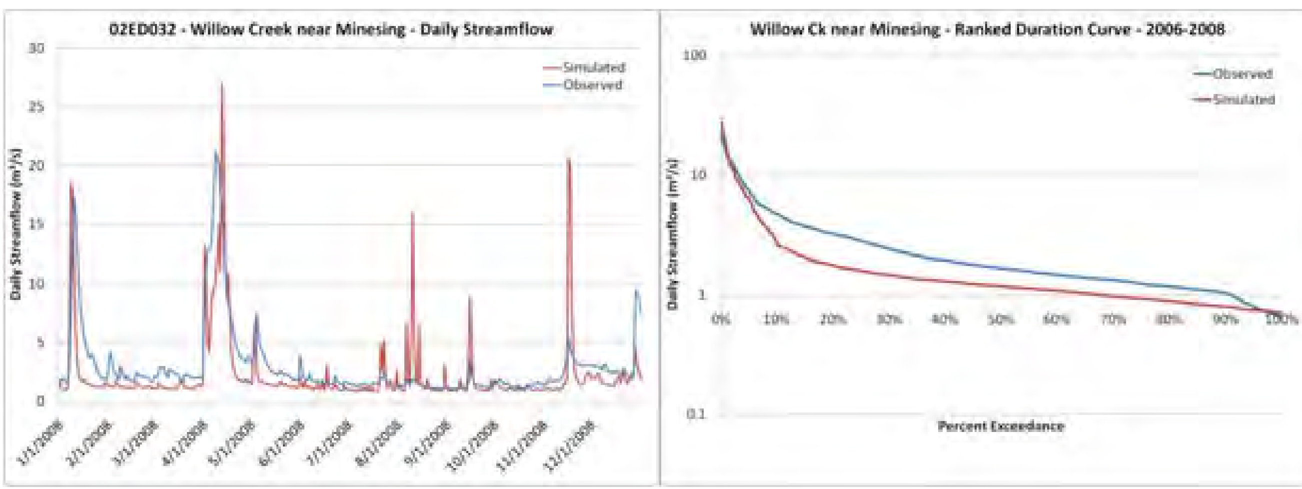


FIGURE 4-5 Daily Streamflow Hydrograph and Ranked Duration Curve for Streamflow Verification Results

4.3 Groundwater Calibration Results

To provide an indication of how well the MIKE SHE model is replicating groundwater conditions, simulated groundwater levels were compared to observed levels. It should be noted that groundwater conditions were not a primary observation set used during model calibration, but were rather used as a secondary confirmation of model performance. The following maps/metrics were used in the consideration of how well the MIKE SHE model was replicating saturated conditions:

- Simulated (Map 4-2) and interpreted (Map 4-3) groundwater level contours for Layer 1; and
- Groundwater performance statistics (Table 4-3).

The simulated water table contours are shown in Map 4-2 (i.e., the groundwater elevation for Layer 1) and the interpreted water table contours based on observed water levels in boreholes within Layer 1 are shown on Map 4-3. The borehole locations are also shown in Map 4.3. As shown on this map, there is a lack of data within the Minesing Wetland. The general patterns between the simulated and observed groundwater elevation contours are very similar. The Oro Moraine matches well, while the details in the observed water level contours are not replicated in the simulated contours. The smoothing of water level contours can be expected due to the simplification of the hydrostratigraphic layer structure in the MIKE SHE model.

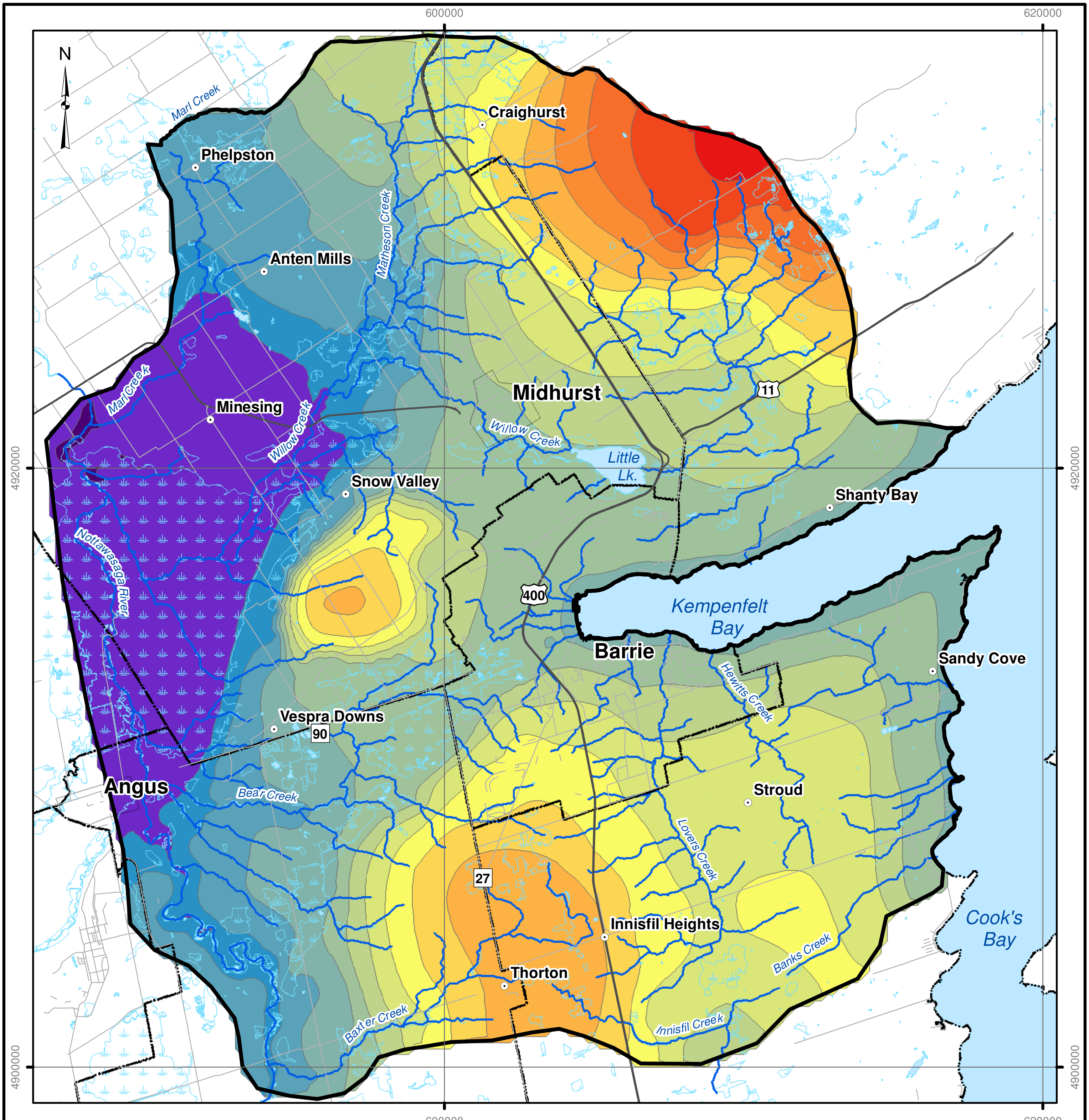
A number of performance statistics were computed for both the shallow aquifer (Layer 1) and deep aquifer (Layer 3) as shown in Table 4-3. The normalized root mean square for both Layer 1 and 3 are less than 10%.

TABLE 4-3 Groundwater Performance Statistics

Metric	MIKE SHE Layer 1	MIKE SHE Layer 3
Number of Wells	1698	330
Mean Error	-7.3 m	-4.0 m
Mean Absolute Error	9.0 m	6.9 m
Root Mean Square Error (RMSE)	13.4 m	9.3 m
Normalized RMS	9.3 %	8.5%
Min Head	186.8 masl	181.4 masl
Max Head	331.0 masl	290.4 masl
R^2	0.82	0.63

4.4 Snow Depth Results

The snow depths recorded from the NVCA snow course survey near Colwell (Map 3-2) are shown in Figure 4-6 for 1990-2009. Measurements are taken on the first and fifteenth of the winter months (December 1st to May 1st). As seen from the figure, observed data is missing from 1992-1997. The snow depths were exported from MIKE SHE for the grid cell matching the snow course survey. The snow depths were compared by snow water equivalent (in mm). Due to the data gap in the observed timeseries, the mean monthly snow depths were compared from 1998-2009, as shown in Figure 4-7. There is very good agreement between the simulated and observed snow depths. This increases our confidence in the model's ability to simulate snow processes, although this confirmation is limited to the southern region. As this is the only snow survey in the Study Area, it was not possible to verify other portions of the Study Area, such as the northern region, where different climatic patterns occur.



LEGEND

- Towns/Villages
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Barrie Tier 3 MIKE SHE Boundary
- Urban Centres
- Township Boundary

Simulated Groundwater Level Contours (m)

- 180 - 190
- 190 - 200
- 200 - 210
- 210 - 220
- 220 - 230
- 230 - 240
- 240 -250
- 250 - 260
- 260 - 270
- 270 - 280
- 280 - 290
- 290 - 300
- 300 - 310
- 310 - 320
- 320 - 330

Barrie Tier 3 Groundwater Recharge Estimation

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Map 4.2

Simulated Groundwater Level Contours

REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 01-Jun-2011; Created By: ccurry

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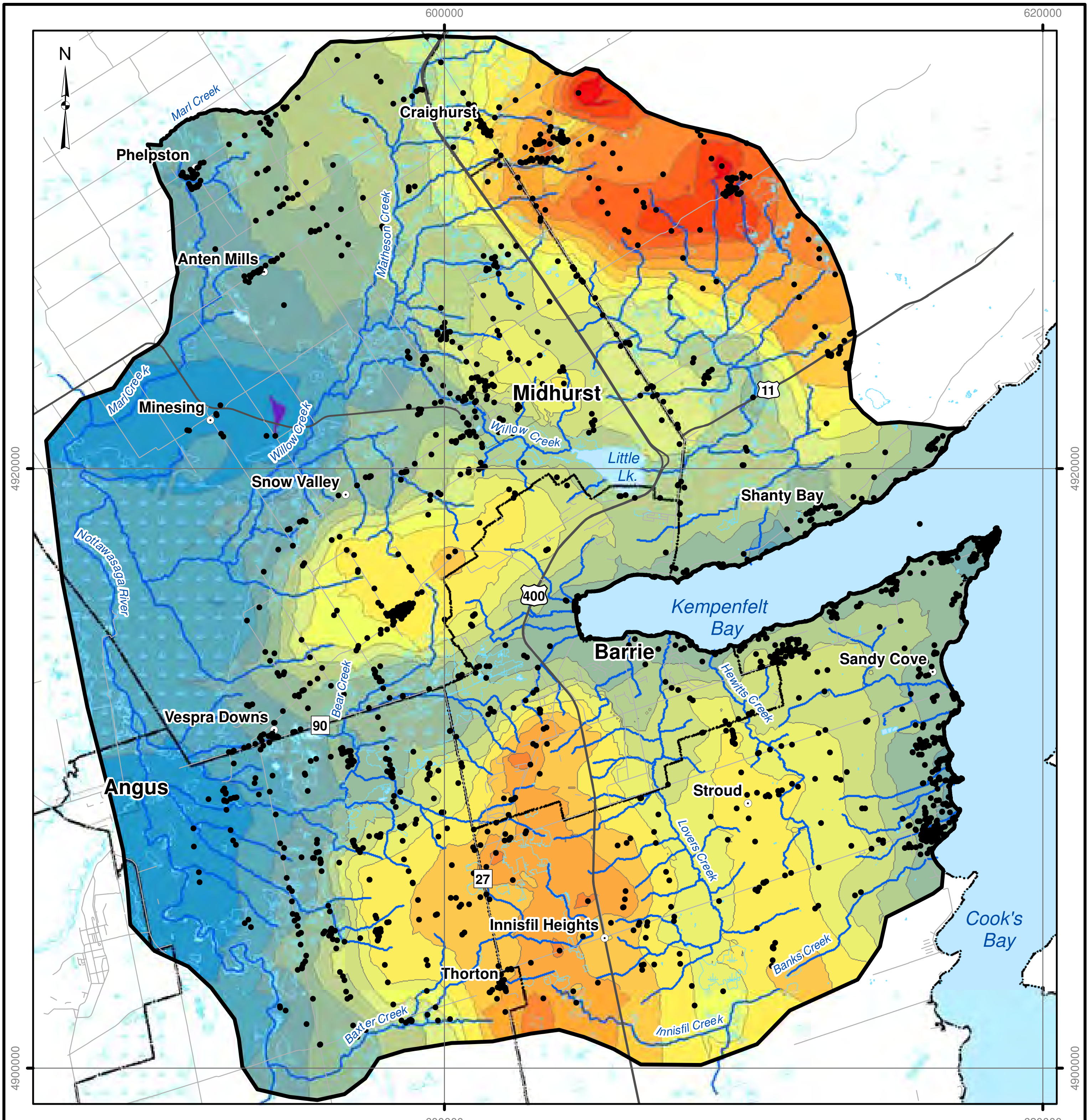
Kilometres



LEGEND

- MOE Water Well Records
- Towns/Villages
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Barrie Tier 3 MIKE SHE Boundary
- Urban Centres
- Township Boundary

Observed Groundwater Level Contours (m)

- 180 - 190
- 190 - 200
- 200 - 210
- 210 - 220
- 220 - 230
- 230 - 240
- 240 - 250
- 250 - 260
- 260 - 270
- 270 - 280
- 280 - 290
- 290 - 300
- 300 - 310
- 310 - 320
- 320 - 330

Barrie Tier 3 Groundwater Recharge Estimation

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REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 08-Jun-2011; Created By: ccurry

Scale 1:180,000
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Kilometres

Map 4.3

Interpreted Water Table Elevations

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Project: 2010007 BarrieTier3

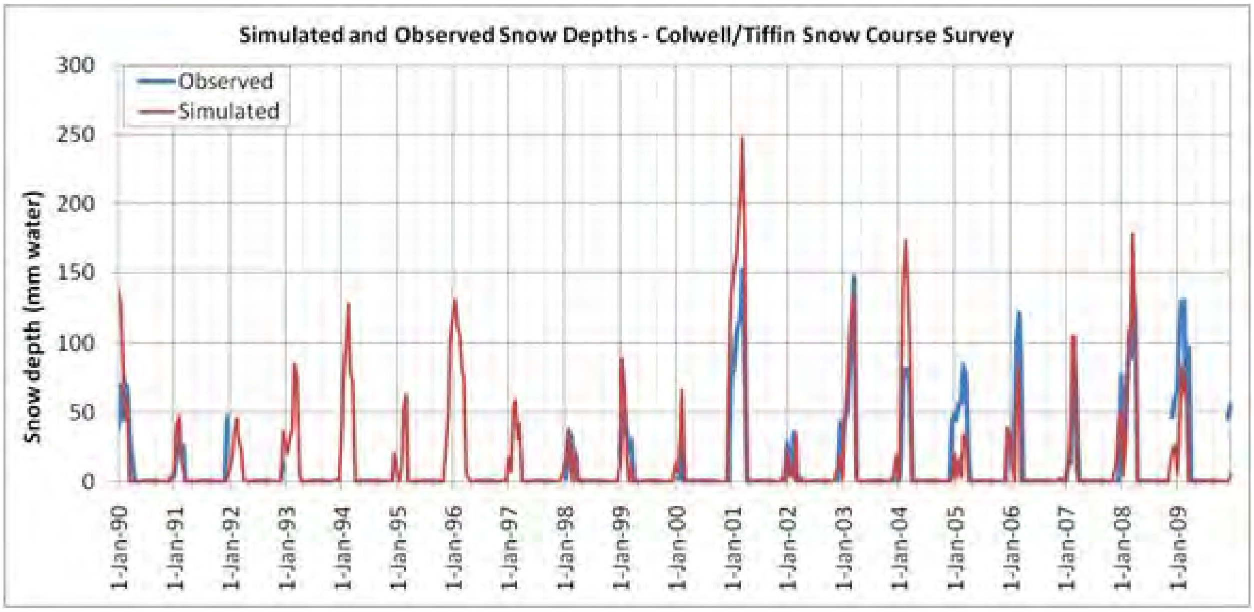


FIGURE 4-6 Timeseries of Simulated and Observed Snow Depth measurements

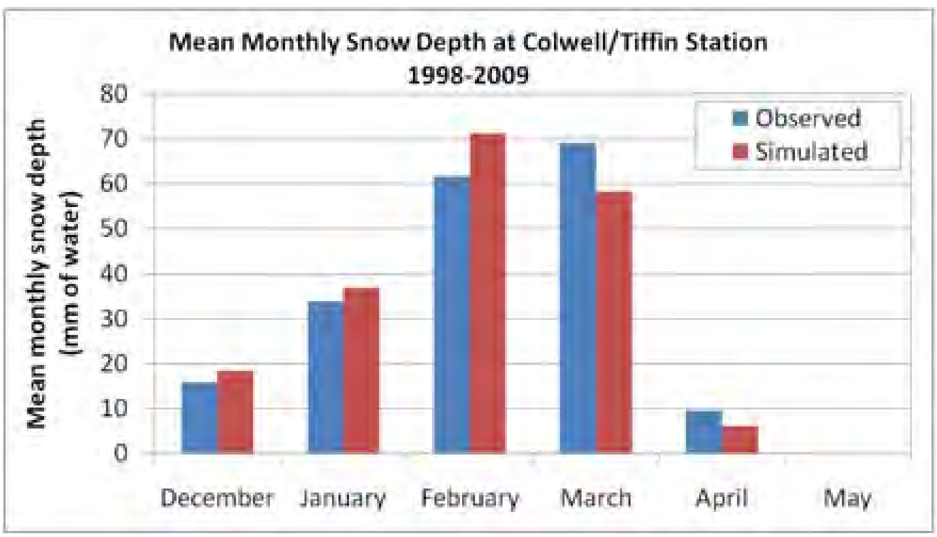


FIGURE 4-7 Mean Monthly Observed and Simulated Snow Depth for 1998-2009

5.0 MODEL OUTPUT

The model was run from 1987-2009 and output was taken for 1990-2009 to determine long-term water budget conditions. The mean annual water budget is presented in tabular and spatially distributed (mapping) formats below.

5.1 Water Budget

A water budget consists of computing the inflows and outflows to the model as well as any changes in storage. The mean annual water budget for 1990-2009 is listed in Table 5-1. The inflows to the model are precipitation plus inflow through the model boundary. The total mean annual inflow to the model is 899 mm/yr. The outflow from the model includes evapotranspiration, any model boundary outflow, pumping from the groundwater system and streamflow. The total mean annual outflow from the model is 907 mm/yr. The total inflow (899 mm/yr) minus the total outflow (907 mm/yr) equals the change in storage (-8 mm/yr). Negative change in storage indicates a reduction in internal storage, whereby 8 mm/yr of outflow is from storage.

TABLE 5-1 Overall Mean Annual Water Budget of MIKE SHE Model (1990-2009)

	Water Budget Component	Mean Annual Rate (mm/yr)
Inflow	Precipitation	895
	Boundary Inflow	4
	Total Inflow	**899**
Outflow	Evapotranspiration	549
	Boundary Outflow	52
	Pumping	23
	Streamflow	281
	Total Outflow	**907***
Change in Storage	Canopy Storage Change	0
	Snow Storage Change	-5
	Overland Storage Change	0
	Subsurface Storage Change	-3
	Total Change in Storage	**-8**

*Note: Addition of outflow values may not equal total outflow value. Difference due to rounding.

The equation used for evaluating the change in storage of the water budget includes factors for precipitation, evapotranspiration, streamflow, groundwater flow, and pumping that move water across the model boundaries (Equation 3.1). Because groundwater recharge/discharge is an internal process in this integrated model, it is not included in the equation.

Equation 5.1 MIKE SHE Water Balance

$$\Delta S = P - ET - Q_{SW} - Q_{GW} - PU$$

$$\Delta S = 895 - 549 - 281 - (52 - 4) - 23$$

$$\therefore \Delta S = -8 \frac{mm}{year} *$$

*Note: Values may not balance exactly due to rounding.

ΔS - Change in Storage
P - Precipitation
ET - Evapotranspiration
Q_{SW} - Streamflow or Surface Water Flow
Q_{GW} - Groundwater flow
PU - Pumping
E - Error

A summary of the key hydrologic processes is listed in Table 5-2, including precipitation, evapotranspiration, groundwater recharge and groundwater discharge; the processes are shown for each soil class and for the entire Study Area. These key processes are defined in Table 5-3 as they are computed in MIKE SHE.

The spatial distribution of evapotranspiration, groundwater recharge and groundwater discharge are shown on Map 5-1, Map 5-2, and Map 5-3, respectively. These maps illustrate the direct model output and are intended to show the regional trends in evapotranspiration, groundwater recharge and groundwater discharge; they reflect idealized local conditions and thus are not intended to be used for the precise cell-by-cell values. The groundwater recharge map is only recommended to be used as input in to the FEFLOW groundwater flow model.

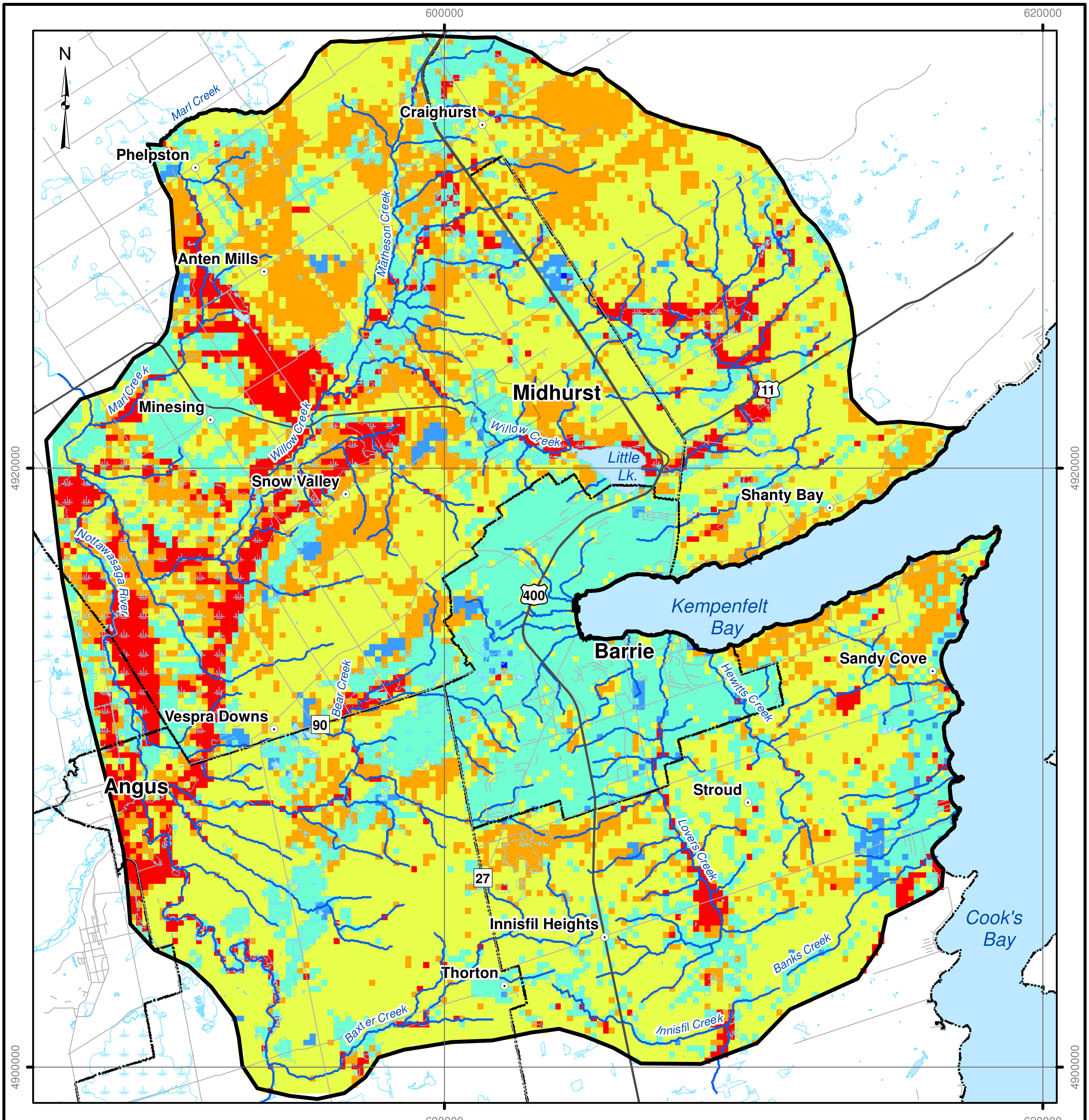
Evapotranspiration is highest in areas where ponded water occurs (groundwater discharge areas) along Willow Creek, Lovers Creek and in Minesing Wetland. Evapotranspiration is also high in forested areas, such as within the Oro Moraine and near Anten Mills. Due to impervious land cover reducing soilwater content, evapotranspiration is lowest within the urban areas of the City of Barrie.

As can be expected, groundwater recharge is higher in areas with high permeability soils, i.e. sands and gravels, and lower in tighter soils, i.e., silts/tills, and clays. The urbanized areas within the City of Barrie have lower recharge rates due to the impervious fraction which limits the volume of water that can infiltrate. In the Study Area, the groundwater system plays a major role in determining groundwater recharge. In groundwater discharge areas (e.g., wetlands), recharge is zero or very low as the water table is at or near ground surface. The integrated model also provides insight regarding areas with very high recharge rates (e.g., >500 mm/yr). These areas are along the boundaries between soils of high permeability (gravels and sands) and low permeability (silts/ tills and clays). In these areas, the low permeability soils generate overland runoff that flows onto high permeability soils, where it infiltrates and recharges the groundwater system.

Groundwater discharge occurs when the water table is at ground surface, mainly in wetland areas. The highest discharge areas are along the main branches of Willow Creek, Matheson Creek, Bear Creek, Lovers Creek, Innisfil Creek and the Nottawasaga River. Groundwater discharge occurs at a lesser rate throughout the Minesing Wetland.

TABLE 5-2 Summary of Key Hydrologic Processes by Soil Class (1990-2009)

Soil Class	Total Area (km^2)	Percent of Study Area (%)	Precipitation (mm/yr)	Evapotranspiration (mm/yr)	Groundwater Recharge (mm/yr)	Groundwater Discharge (mm/yr)
Gravel	168	21	899	546	370	5
Sand	238	30	889	561	351	249
Silt/Till	241	30	899	523	181	26
Clay	151	19	892	576	30	241
Study Area	797	100	895	549	243	129



LEGEND

- Towns/Villages
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Barrie Tier 3 MIKE SHE Boundary
- Urban Centres
- Township Boundary

Annual Evapotranspiration (mm/yr)

- < 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- > 700

NOTE: Must be read in conjunction with associated report.

Barrie Tier 3 Groundwater Recharge Estimation

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Map 5.1

Simulated Average Annual Evapotranspiration

REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 01-Jun-2011; Created By: ccurry

Scale 1:180,000
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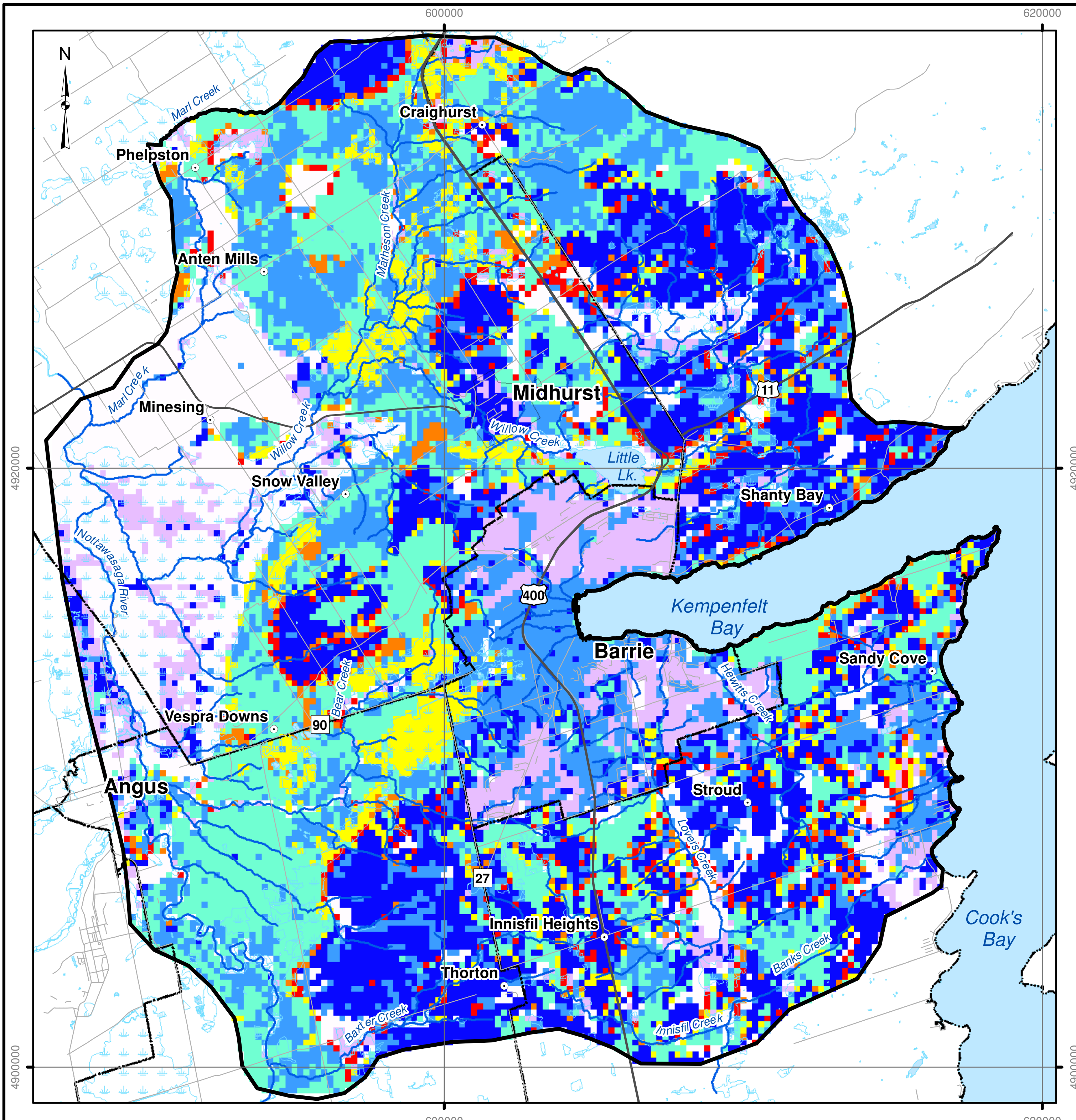

LEGEND

- Towns/Villages
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Barrie Tier 3 MIKE SHE Boundary
- Urban Centres
- Township Boundary

Annual Recharge (mm/yr)

- 0 - 50
- 50 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- > 600

NOTE: Must be read in conjunction with associated report.

Barrie Tier 3 Groundwater Recharge Estimation

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Map 5.2

Simulated Average Annual Groundwater Recharge

REFERENCES

Base Data - NVCA, 2009

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Projection: UTM Zone 17N, NAD 83

Map Version: 1; Map Date: 08-Jun-2011; Created By: ccurry

Scale 1:180,000

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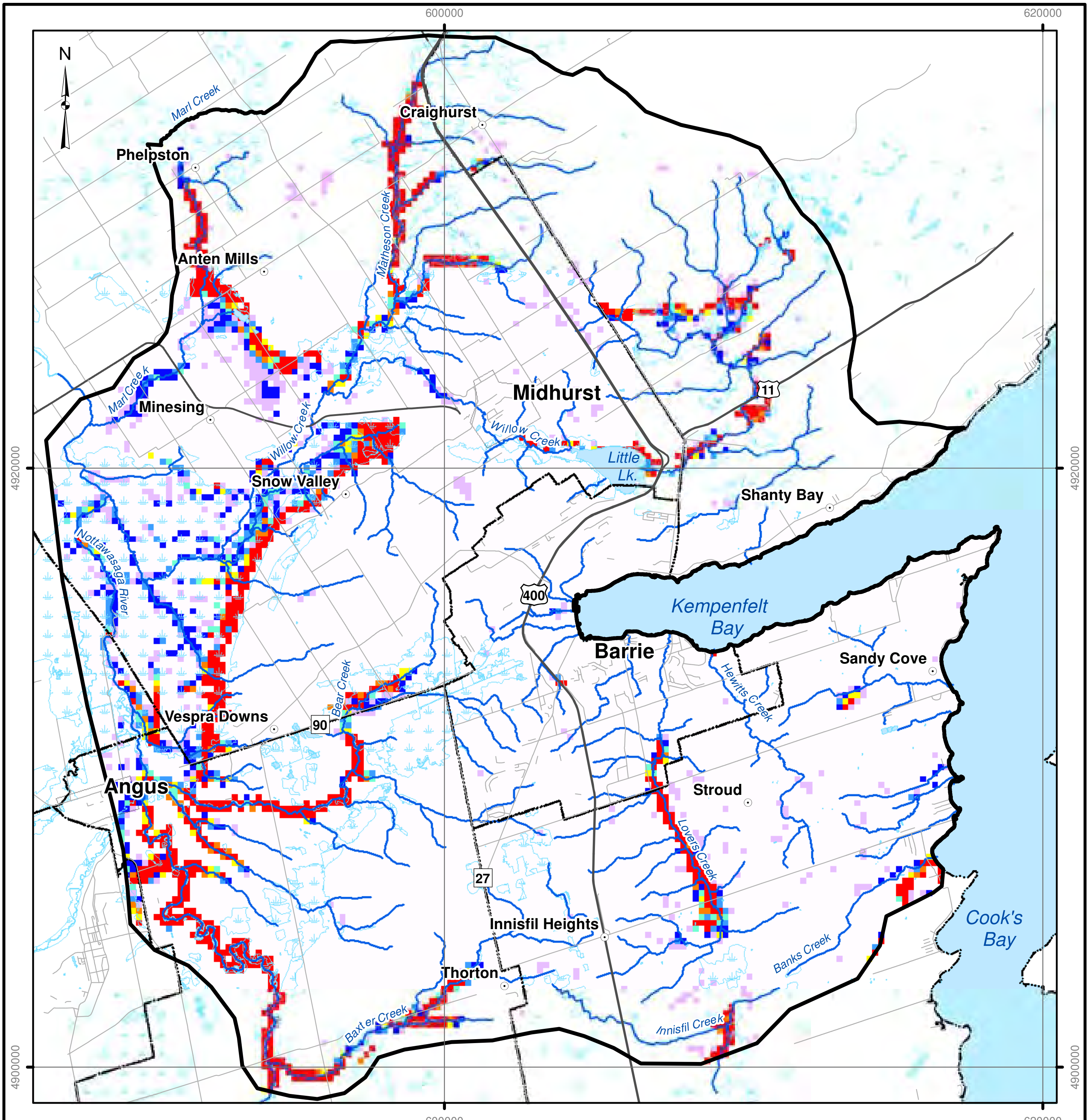

LEGEND

- Towns/Villages
- Highways
- Roads
- MIKE SHE River Network
- Open Water
- Wetlands
- Barrie Tier 3 MIKE SHE Boundary
- Urban Centres
- Township Boundary

Annual Discharge (mm/yr)

- 0 - 50
- 50 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- > 600

NOTE: Must be read in conjunction with associated report.

Barrie Tier 3 Groundwater Recharge Estimation

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REFERENCES
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 08-Jun-2011; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

Map 5.3

Simulated Average Annual Groundwater Discharge

TABLE 5-3 Definition of Key Hydrologic Processes in MIKE SHE

Term	Definition in MIKE SHE
Evapotranspiration	Evaporation from snow, intercepted water, ponded water and soil + Transpiration from root zone + Evapotranspiration from saturated zone
Groundwater Recharge	Infiltration downward from the unsaturated zone to the saturated zone
Groundwater Discharge	Upward flow from saturated zone to overland flow + Saturated zone baseflow to rivers

5.2 Transient Groundwater Recharge Rates

Long-term transient, or time-varying, groundwater recharge rates are used for the transient evaluation of water levels within municipal pumping wells using the FEFLOW groundwater model. To obtain long-term transient groundwater recharge rates, the MIKE SHE model was run using all available climate data, i.e., from 1950-2009, with the first 3 years used as the 'warm up' period. This period includes two significant droughts; the most severe drought is in the 1960s and a less severe drought in the late 1990s. A timeseries of mean monthly groundwater recharge was computed from a representative grid cell for each climate zone (Map 3-2 and soil class (Map 3-6). There are a total of 5 climate zones and 4 soils groups, therefore 20 representative time series were generated. The representative grid cell was selected such that it was not located in a groundwater discharge zone and it was within 10 mm of the mean annual groundwater recharge rate over the represented climate zone/soil group (a few representative clay grid cells were outside this range, as fewer grid cells were located outside discharge areas). An example of the transient recharge is shown in Figure 5-1 for silt/tills in the Barrie climate zone. The monthly recharge varies significantly throughout the period. The black line shows the 12-month moving average which highlights the long-term trends. The early 1960s and late 1990s show lower monthly recharge rates during these periods of drought. As the 1960s had lower groundwater recharge rates, it is recommended that this period be used in the Tier Three Risk Assessment.

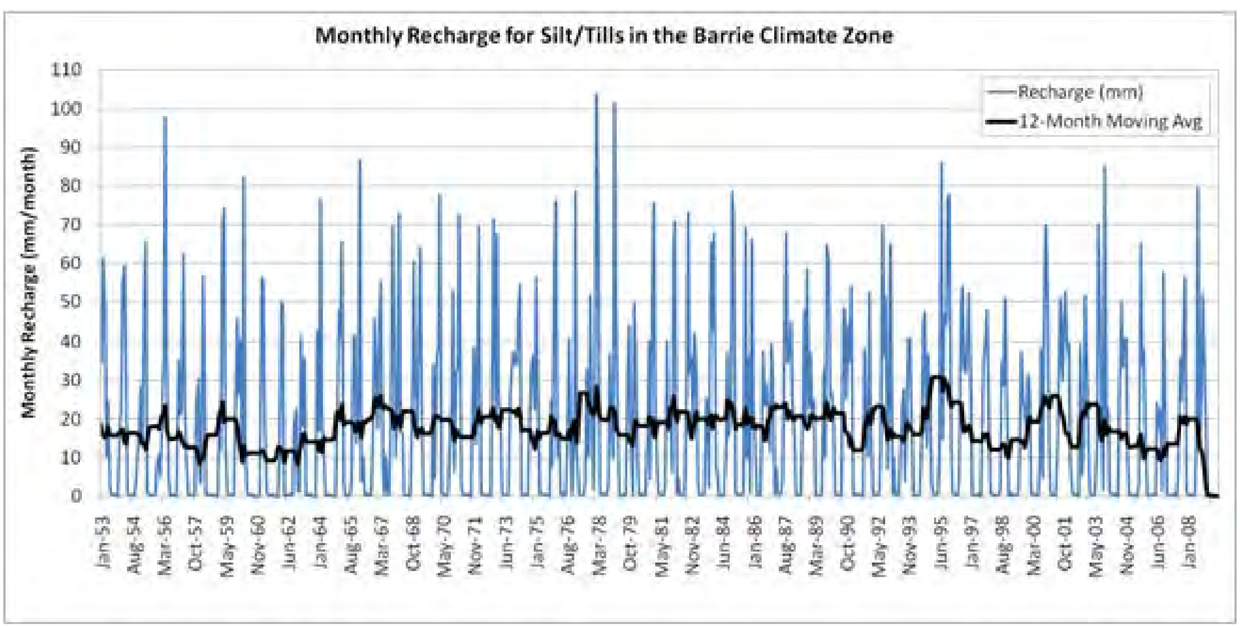

FIGURE 5-1 Example of Transient Groundwater Recharge Rates

6.0 SUMMARY AND RECOMMENDATIONS

A three dimensional, integrated model was constructed for the Barrie Tier Three Study Area (800 km^2) using the MIKE SHE software. The model was calibrated using available streamflow data for three streamflow monitoring gauges:

- Willow Creek above Little Lake (1990-1995);
- Willow Creek at Midhurst (1990-1998); and
- Lovers Creek at Tollendal (2001-2004).

The model was then verified using streamflow data from a fourth stream gauge:

- Willow Creek near Minesing (2006-2008).

An investigation of additional streamflow data at the Barrie Creeks gauges (2004-2009), the Lovers Creek gauge (2005-2009), and at spot flow measurement locations led to the conclusion that these data were not appropriate for model calibration. Additional calibration targets included groundwater elevations throughout the Study Area and snow depths from a snow survey in the southern portion of the Study Area. The calibration resulted in a reasonable match between simulated and observed data which provided confidence that the model output (i.e., groundwater recharge) is appropriate to use in the FEFLOW groundwater model.

The overall water budget and key hydrologic processes were computed and mapped. The mean annual groundwater recharge for the 1990-2009 period was used as input to the steady state FEFLOW groundwater model. Transient recharge rates were computed on a monthly basis from 1953-2009 and were used in the transient calibration of the FEFLOW model.

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BARRIE TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

RECHARGE ESTIMATION USING MIKE SHE

APPENDIX B1: MODELLED PUMPING RATES

Appendix B1 Modelled Pumping Rates

Table B-1 Well Information and 2008 and 2009 Pumping Rates

Major Category	Specific Purpose	Permit Number	Well ID	Model Easting	Model Northing	Top of Screen (m)	Bottom of Screen (m)	Community	Max Permitted (m^3/d)	Well Name	2008 Rep./ Est.	2008 Data Source	2008 Average Consumptive Use (m^3/d)	2009 Rep. /Est.	2009 Data Source	2009 Average Consumptive Use (m^3/d)
Agricultural	Field and Pasture Crops	03-P-1069	69	596398	4912393	0.1	4.0		981.936	Dugout Pond	Est.		161.4	Est.		161.4
Agricultural	Field and Pasture Crops	1664-6W3MCU	158	596761	4934571	81.1	85.7		2589.12	Well 1	Est.		681.0	Rep.	2009 WTRS	0.0
Agricultural	Other - Agricultural	00-P-1210	2	602081	4908050	0.2	3.1		681.372	Dugout Pond	Rep.	2008 WTRS	5.3	Rep.	2009 WTRS	2.5
Commercial	Bottled Water	5524-6PEK3Q	347	605712	4905321	85.3	87.5		354.24	Well 1	Rep.	2008 WTRS	0.0	Rep.	2009 WTRS	0.0
Commercial	Bottled Water	5524-6PEK3Q	348	605968	4905369	71.9	78.0		792	Well 2	Rep.	2008 WTRS	0.0	Rep.	2009 WTRS	0.0
Commercial	Bottled Water	8141-7BYRP2	468	607723	4904671	22.6	25.0		400	Well 2	Est.		200.0	Est.		200.0
Commercial	Bottled Water	8141-7BYRP2	469	607723	4904671	22.6	25.0		400	Well 3	Est.		200.0	Est.		200.0
Commercial	Bottled Water	8531-6ASQXU	483	608252	4903121	62.8	65.8		720	Well 1	Est.		248.6	Est.		248.6
Commercial	Golf Course Irrigation	0040-733RE2	27	603756	4933236	81.7	86.9		981.936	Irrigation Well	Est.		339.0	Est.		339.0
Commercial	Golf Course Irrigation	0040-733RE2	28	603101	4932804	2.0	10.6		2945.808	Irrigation Pond	Rep.	2008 WTRS	138.8	Rep.	2009 WTRS	179.7
Commercial	Golf Course Irrigation	0040-733RE2	29	603126	4932775	66.1	67.1		65.462	Clubhouse Well	Rep.	2008 WTRS	1.3	Rep.	2009 WTRS	1.1
Commercial	Golf Course Irrigation	0386-7AMLUY	81	598132	4919616	62.5	68.9		1636.56	Well 1-4/93	Est.		1145.6	Rep.	2009 WTRS	33.9
Commercial	Golf Course Irrigation	0386-7AMLUY	82	598177	4919891	48.2	57.6		982	Well 2-1/93	Est.		687.4	Rep.	2009 WTRS	21.6
Commercial	Golf Course Irrigation	0386-7AMLUY	83	598008	4919625	48.2	57.6		2618.64	Irrigation Pond	Est.		753.3	Rep.	2009 WTRS	0.0
Commercial	Golf Course Irrigation	3124-6J5T9M	239	594132	4924022	0.7	41.7		564.403	Pump House	Est.		129.9	Rep.	2009 WTRS	2.1
Commercial	Golf Course Irrigation	3474-759GY9	255	610681	4920539	45.4	47.9		200	Heritage Well	Rep.	2008 WTRS	9.9	Rep.	2009 WTRS	19.9
Commercial	Golf Course Irrigation	3474-759GY9	256	610464	4920431	0.3	0.8		2000	Heritage Pond	Rep.	2008 WTRS	42.3	Rep.	2009 WTRS	54.2
Commercial	Golf Course Irrigation	4755-73RHNU	316	606539	4908998	13.7	15.2		6.72	Clubhouse Well	Rep.	2008 WTRS	3.0	Rep.	2009 WTRS	8.0
Commercial	Golf Course Irrigation	4755-73RHNU	317	606872	4909093	0.8	6.6		1091.04	Dugout Pond	Rep.	2008 WTRS	26.8	Rep.	2009 WTRS	129.9
Commercial	Golf Course Irrigation	5447-6QWR7W	343	594380	4908956	0.0	5.4		2561.22	Irrigation Pond	Rep.	2008 WTRS	102.3	Rep.	2009 WTRS	190.3
Commercial	Golf Course Irrigation	5813-6U2S3J	355	607415	4907971	0.2	4.0		1136.5	Irrigation Pond	Rep.	2008 WTRS	62.2	Rep.	2009 WTRS	59.6
Commercial	Golf Course Irrigation	5813-6U2S3J	356	607524	4907993	80.2	82.6		262.08	Well 2	Rep.	2008 WTRS	0.0	Rep.	2009 WTRS	0.0
Commercial	Golf Course Irrigation	5813-6U2S3J	357	607232	4907870	105.2	108.2		1569.6	Well 3	Rep.	2008 WTRS	0.0	Rep.	2009 WTRS	0.0
Commercial	Golf Course Irrigation	5813-6U2S3J	358	607151	4908478	36.6	40.2		31.822	Well 1	Rep.	2008 WTRS	3.0	Rep.	2008 WTRS	3.0

Major Category	Specific Purpose	Permit Number	Well ID	Model Easting	Model Northing	Top of Screen (m)	Bottom of Screen (m)	Community	Max Permitted (m^3/d)	Well Name	2008 Rep./ Est.	2008 Data Source	2008 Average Consumptive Use (m^3/d)	2009 Rep. /Est.	2009 Data Source	2009 Average Consumptive Use (m^3/d)
Commercial	Golf Course Irrigation	6824-68XPUW	404	606744	4910509	0.0	0.2		218.208	Main Irrigation Pond	Est.		50.2	Rep.	2009 WTRS	11.3
Commercial	Golf Course Irrigation	7455-6QPLB5	423	599800	4908200	0.0	1.8		1817.76	Dugout Pond	Rep.	2008 WTRS	65.9	Rep.	2009 WTRS	71.5
Commercial	Golf Course Irrigation	7542-6P8M92	432	600566	4910182	43.9	48.5		327.058	Well 1/94	Est.		112.9	Est.		112.9
Commercial	Mall / Business	5372-6SYPRA	340	603184	4909825	62.5	71.6		715.68	Well 1/06	Est.		39.2	Rep.	2009 WTRS	0.0
Commercial	Snowmaking	6845-6D7NUT	405	596189	4918575	0.0	2.1		13092.48	Pond Winter	Rep.	2008 WTRS	347.8	Rep.	2009 WTRS	155.6
Commercial	Snowmaking	6845-6D7NUT	406	596190	4918418	0.0	1.4		981.936	Pond 1 Winter	Rep.	2008 WTRS	32.0	Rep.	2009 WTRS	27.3
Commercial	Snowmaking	6845-6D7NUT	407	596004	4918188	0.0	1.0		981.936	Pond 2 Winter	Rep.	2008 WTRS	26.8	Rep.	2009 WTRS	26.5
Commercial	Snowmaking	6845-6D7NUT	408	595945	4918328	0.0	0.8		2618.496	Pond 3 Winter	Rep.	2008 WTRS	31.8	Rep.	2009 WTRS	45.7
Commercial	Snowmaking	6845-6D7NUT	409	596095	4918554	0.0	1.8		1309.248	Pond Summer	Est.		143.5	Est.		143.5
Commercial	Snowmaking	6845-6D7NUT	410	595878	4918441	0.0	1.2		523.699	Pond Summer	Est.		322.8	Est.		322.8
Commercial	Snowmaking	6845-6D7NUT	411	595848	4918451	0.0	1.3		5564.304	Berry Hill Pond	Est.		914.7	Est.		914.7
Industrial	Aggregate Washing	4105-7EENGW	272	603760	4926740	0.0	0.4		7980	Source Pond	Rep.	2008 WTRS	19.7	Rep.	2009 WTRS	20.5
Industrial	Cooling Water	6313-5Z4NC5	373	603300	4914507	47.9	52.7		300	Private Well	Est.		180.8	Est.		180.8
Miscellaneous	Heat Pumps	2677-63PK84	216	604912	4911259	19.4	29.3		260	Well 2	Est.		0.0	Est.		0.0
Miscellaneous	Heat Pumps	2677-63PK84	217	608801	4916852	19.3	34.5		0.136	Well 2	Est.		0.0	Est.		0.0
Miscellaneous	Heat Pumps	2677-63PK84	218	608801	4916852	19.3	34.5		0.068	Injection Well 3	Est.		0.0	Est.		0.0
Miscellaneous	Heat Pumps	2677-63PK84	219	608801	4916852	19.3	34.5		0.095	Well 4	Est.		0.0	Est.		0.0
Miscellaneous	Heat Pumps	92-P-3093	548	607394	4917219	45.1	45.7		98.194	Well 2	Est.		0.0	Est.		0.0
Recreational	Other - Recreational	5353-5W4LB8	333	598611	4922161	23.2	27.7		357.12	Artesian Well	Rep.	2008 WTRS	119.5	Rep.	2009 WTRS	212.4
Recreational	Other - Recreational	5353-5W4LB8	334	597977	4922110	23.2	27.7		1889.672	Pond	Rep.	2008 WTRS	126.5	Rep.	2009 WTRS	0.0
Remediation	Groundwater	1315-6W3QAS	135	600889	4915049	88.2	112.4		262.08	Well 1	Rep.	2008 WTRS	163.6	Rep.	2009 WTRS	143.7
Remediation	Groundwater	1315-6W3QAS	136	600950	4915097	19.8	35.1		458	Well 2	Rep.	2008 WTRS	308.3	Rep.	2009 WTRS	310.9
Remediation	Groundwater	1315-6W3QAS	137	601019	4915147	23.5	35.7		360	Well 3	Rep.	2008 WTRS	172.3	Rep.	2009 WTRS	273.2
Remediation	Groundwater	5006-7CVGHZ	322	604814	4915929	17.5	37.1		130.9	Pump Station 1	Rep.	2008 WTRS	0.0	Rep.	2009 WTRS	0.0
Remediation	Groundwater	5006-7CVGHZ	323	604814	4915929	17.5	37.1		589	Pump Station 2	Rep.	2008 WTRS	23.3	Rep.	2009 WTRS	17.5
Water Supply	Campgrounds	3772-6EQGSY	260	597740	4923757	73.1	73.2		38.7	Well 1	Est.		3.8	Est.		3.8
Water Supply	Campgrounds	3772-6EQGSY	261	597843	4923884	73.1	73.2		68.37	Well 3	Est.		6.7	Est.		6.7
Water Supply	Campgrounds	3772-6EQGSY	262	597678	4923800	26.5	33.2		46.44	Well 4	Est.		4.6	Est.		4.6

Major Category	Specific Purpose	Permit Number	Well ID	Model Easting	Model Northing	Top of Screen (m)	Bottom of Screen (m)	Community	Max Permitted (m^3/d)	Well Name	2008 Rep./ Est.	2008 Data Source	2008 Average Consumptive Use (m^3/d)	2009 Rep. /Est.	2009 Data Source	2009 Average Consumptive Use (m^3/d)
Water Supply	Campgrounds	96-P-5022	570	595712	4911521	56.7	57.9		106.04	Well	Est.		12.2	Est.		12.2
Water Supply	Communal	02-P-1193	54	597842	4908046	101.8	122.1		326.88	Well 1	Rep.	2008 WTRS	5.8	Rep.	2009 WTRS	4.9
Water Supply	Communal	1586-62FLP2	151	611554	4918074	59.2	70.7		81	O'Brien House Well	Est.		16.2	Est.		16.2
Water Supply	Communal	6334-72JP7N	377	591987	4929882	36.6	40.2		547.2	Well 1	Est.		109.4	Rep.	2009 WTRS	5.4
Water Supply	Communal	6334-72JP7N	378	591979	4929876	36.3	39.3		655.2	Well 2	Est.		131.0	Rep.	2009 WTRS	4.9
Water Supply	Communal	87-P-3008	494	614679	4911754	74.4	78.0		1113.77	Well 1	Est.		371.3	Rep.	2009 WTRS	184.7
Water Supply	Communal	87-P-3008	495	614638	4911757	73.5	77.1		1113.77	Well 2	Est.		371.3	Rep.	2009 WTRS	182.5
Water Supply	Communal	87-P-3008	496	614512	4911771	43.6	49.7		1113.77	Well 3	Est.		371.3	Rep.	2009 WTRS	190.2
Water Supply	Municipal	00-P-1368	13	610360	4909456	105.8	110.3	Stroud	677.16	Well 1	Rep.	Town of Innisfil	165.6	Rep.	2009 WTRS	3.5
Water Supply	Municipal	00-P-1368	14	610356	4909438	102.1	107.0	Stroud	397.44	Well 2 Standby	Rep.	Town of Innisfil	165.6	Rep.	2009 WTRS	0.8
Water Supply	Municipal	00-P-1368	15	610386	4909474	103.9	109.7	Stroud	1637.28	Well 3	Rep.	Town of Innisfil	165.6	Rep.	2009 WTRS	489.5
Water Supply	Municipal	0421-7B4TCZ	86	591722	4909066	46.6	54.0	Angus	1296	Well 1 (McGeorge)	Rep.	NVCA	305.8	Rep.	2009 WTRS	194.6
Water Supply	Municipal	0421-7B4TCZ	87	591721	4909070	46.3	53.6	Angus	1296	Well 2 (McGeorge)	Rep.	NVCA	283.2	Rep.	2009 WTRS	378.0
Water Supply	Municipal	0421-7B4TCZ	89	591558	4907667	36.3	39.9	Angus	1800	Well 4	Rep.	NVCA	0.0	Rep.	2009 WTRS	3.9
Water Supply	Municipal	0421-7B4TCZ	90	591587	4907673	36.6	39.6	Angus	654.624	Well 5	Rep.	NVCA	0.0	Rep.	2009 WTRS	15.4
Water Supply	Municipal	0421-7B4TCZ	91	591567	4907669	37.8	39.0	Angus	1800	Well 6	Rep.	NVCA	0.0	Rep.	2009 WTRS	97.5
Water Supply	Municipal	0507-6B9S5G	96	601910	4921975	73.2	77.7	Midhurst	622	Well 2	Rep.	NVCA	129.2	Rep.	2009 WTRS	110.9
Water Supply	Municipal	0507-6B9S5G	97	601894	4921956	70.7	78.6	Midhurst	2900	Well 3	Rep.	NVCA	436.7	Rep.	2009 WTRS	386.5
Water Supply	Municipal	0507-6B9S5G	98	601427	4921884	69.8	75.9	Midhurst	2000	Well 4	Rep.	NVCA	209.6	Rep.	2009 WTRS	217.5
Water Supply	Municipal	0507-6B9S5G	99	601513	4920127	79.2	83.5	Midhurst	1068	Well 5	Rep.	NVCA	304.2	Rep.	2009 WTRS	280.8
Water Supply	Municipal	0621-62MR3A	106	594314	4911296	58.2	64.3	Vespra Downs	168.9	Well 1-93	Rep.	NVCA	38.9	Rep.	NVCA	38.9
Water Supply	Municipal	0621-62MR3A	107	594336	4911308	57.6	60.7	Vespra Downs	168.9	Well 1-91	Rep.	NVCA	0.3	Rep.	2009 WTRS	0.2
Water Supply	Municipal	1732-5YHR7D	164	614518	4907629	14.9	17.4	Alcona	262.973	Well 1B	Rep.	Golder	0.0	Rep.	Golder	0.0
Water Supply	Municipal	1732-5YHR7D	165	614540	4907749	16.9	18.8	Alcona	262.973	Well 2	Rep.	Golder	0.0	Rep.	Golder	0.0
Water Supply	Municipal	1732-5YHR7D	166	614659	4907911	78.0	82.6	Alcona	468.846	Well 3	Rep.	Golder	0.0	Rep.	Golder	0.0
Water Supply	Municipal	1732-5YHR7D	167	614663	4907898	76.5	84.1	Alcona	539.149	Well 3B	Rep.	Golder	0.0	Rep.	Golder	0.0
Water Supply	Municipal	1732-5YHR7D	168	614961	4908001	67.1	70.1	Alcona	294.882	Well 4R	Rep.	Golder	0.0	Rep.	Golder	0.0
Water Supply	Municipal	1732-5YHR7D	169	614415	4908117	19.5	22.6	Alcona	306.985	Well 5	Rep.	Golder	0.0	Rep.	Golder	0.0

Major Category	Specific Purpose	Permit Number	Well ID	Model Easting	Model Northing	Top of Screen (m)	Bottom of Screen (m)	Community	Max Permitted (m^3/d)	Well Name	2008 Rep./ Est.	2008 Data Source	2008 Average Consumptive Use (m^3/d)	2009 Rep. /Est.	2009 Data Source	2009 Average Consumptive Use (m^3/d)
Water Supply	Municipal	1732-5YHR7D	170	614967	4908022	71.9	74.9	Alcona	363.101	Well 6	Rep.	Golder	0.0	Rep.	Golder	0.0
Water Supply	Municipal	2372-75VHJ5	201	601784	4920238	68.6	73.2	Midhurst	466.56	Del Trend Well 1	Rep.	NVCA	11.1	Rep.	NVCA	11.1
Water Supply	Municipal	2372-75VHJ5	202	601795	4920244	64.0	68.6	Midhurst	466.56	Del Trend Well 2	Rep.	NVCA	17.7	Rep.	2009 WTRS	4.0
Water Supply	Municipal	2372-75VHJ5	203	601776	4920263	61.3	71.3	Midhurst	786.24	Del Trend Well 3	Rep.	NVCA	75.7	Rep.	2009 WTRS	120.9
Water Supply	Municipal	2828-7GDPJ2	225	603373	4914759	96.0	107.0	Barrie	6552	Well 3A	Rep.	NVCA	2378.6	Rep.	NVCA	2378.6
Water Supply	Municipal	2828-7GDPJ2	226	607015	4917670	80.2	97.2	Barrie	6552	Well 13	Rep.	NVCA	1995.2	Rep.	NVCA	1995.2
Water Supply	Municipal	2828-7GDPJ2	227	603330	4915148	50.0	56.1	Barrie	6552	Well 4	Rep.	NVCA	1695.0	Rep.	NVCA	1695.0
Water Supply	Municipal	2828-7GDPJ2	228	602927	4914267	88.4	106.7	Barrie	6552	Well 5	Rep.	NVCA	2893.7	Rep.	NVCA	2893.7
Water Supply	Municipal	2828-7GDPJ2	229	602484	4914189	85.3	100.6	Barrie	6552	Well 7	Rep.	NVCA	4756.1	Rep.	NVCA	4756.1
Water Supply	Municipal	2828-7GDPJ2	230	607042	4917649	77.1	93.0	Barrie	6552	Well 9	Rep.	NVCA	3457.0	Rep.	NVCA	3457.0
Water Supply	Municipal	2828-7GDPJ2	231	606225	4912601	85.6	93.3	Barrie	4546	Well 10	Rep.	City of Barrie	2124.0	Rep.	City of Barrie	2124.0
Water Supply	Municipal	2828-7GDPJ2	232	604690	4915794	47.2	61.3	Barrie	9100	Well 11	Rep.	NVCA	3248.7	Rep.	NVCA	3248.7
Water Supply	Municipal	2828-7GDPJ2	233	604499	4914593	73.8	88.7	Barrie	9100	Well 12	Rep.	City of Barrie	2124.0	Rep.	City of Barrie	2124.0
Water Supply	Municipal	2828-7GDPJ2	234	604660	4915782	39.6	61.0	Barrie	9100	Well 14	Rep.	NVCA	1634.9	Rep.	NVCA	1634.9
Water Supply	Municipal	2828-7GDPJ2	235	604411	4915199	45.7	51.2	Barrie	9100	Well 15	Rep.	City of Barrie	2124.0	Rep.	City of Barrie	2124.0
Water Supply	Municipal	2828-7GDPJ2	236	604037	4919591	61.3	73.5	Barrie	7862	Well 16	Rep.	NVCA	4778.8	Rep.	NVCA	4778.8
Water Supply	Municipal	2828-7GDPJ2	237	601953	4913766	77.1	86.3	Barrie	11232	Well 17	Rep.	NVCA	3166.4	Rep.	NVCA	3166.4
Water Supply	Municipal	2828-7GDPJ2	238	602010	4913778	87.5	106.1	Barrie	11232	Well 18	Rep.	NVCA	3217.3	Rep.	NVCA	3217.3
Water Supply	Municipal	2828-7GDPJ2	599	601385	4913027	84.4	93.6	Barrie	7862.4	Well 19	Rep.	City of Barrie	0.0	Rep.	City of Barrie	0.0
Water Supply	Municipal	4624-6HKPJW	307	600803	4931465	24.4	27.4	Craighurst	64	Well 1	Rep.	SSEA	0.1	Rep.	2009 WTRS	0.0
Water Supply	Municipal	4624-6HKPJW	308	600807	4931504	24.1	25.9	Craighurst	140	Well 2	Rep.	SSEA	11.5	Rep.	2009 WTRS	11.1
Water Supply	Municipal	4624-6HKPJW	309	600830	4931482	29.0	30.8	Craighurst	229	Well 3	Rep.	SSEA	20.7	Rep.	2009 WTRS	19.8
Water Supply	Municipal	6733-6GDQYK	397	592395	4921852	29.6	34.7	Minesing	327	Well 2	Rep.	Golder	119.0	Rep.	2009 WTRS	73.8
Water Supply	Municipal	6733-6GDQYK	398	592369	4921832	30.5	35.1	Minesing	327	Well 3	Rep.	Golder	119.0	Rep.	2009 WTRS	1.4
Water Supply	Municipal	6733-6GDQYK	399	592390	4921798	34.4	38.1	Minesing	412	Well 4	Rep.	Golder	137.0	Rep.	2009 WTRS	0.0
Water Supply	Municipal	7274-6K8R94	418	601508	4902530	48.5	51.5	Thornton	522.72	Well 1	Rep.	NVCA	106.7	Rep.	NVCA	106.7
Water Supply	Municipal	7274-6K8R94	419	601528	4902528	46.6	49.7	Thornton	522.72	Well 2	Rep.	NVCA	121.6	Rep.	NVCA	121.6
Water Supply	Municipal	7274-6K8R94	420	601457	4903056	27.4	31.1	Thornton	492.48	TW1-69	Rep.	NVCA	82.1	Rep.	2009 WTRS	83.3

Major Category	Specific Purpose	Permit Number	Well ID	Model Easting	Model Northing	Top of Screen (m)	Bottom of Screen (m)	Community	Max Permitted (m^3/d)	Well Name	2008 Rep./ Est.	2008 Data Source	2008 Average Consumptive Use (m^3/d)	2009 Rep. /Est.	2009 Data Source	2009 Average Consumptive Use (m^3/d)
Water Supply	Municipal	7274-6K8R94	421	601446	4903058	25.9	29.0	Thornton	325.32	Tw2-69	Rep.	NVCA	59.8	Rep.	2009 WTRS	61.7
Water Supply	Municipal	7511-5MLRGP	426	593955	4926082	64.9	68.0	Anten Mills	417.6	Well 1	Rep.	Golder	138.0	Rep.	2009 WTRS	0.4
Water Supply	Municipal	7511-5MLRGP	427	593940	4926072	65.2	68.3	Anten Mills	360	Well 2	Rep.	Golder	120.0	Rep.	2009 WTRS	0.4
Water Supply	Municipal	7511-5MLRGP	428	593932	4926084	59.1	66.8	Anten Mills	780	Well 3	Rep.	Golder	283.0	Rep.	2009 WTRS	158.6
Water Supply	Municipal	7520-6LJTGX	429	613036	4918913	54.0	58.5	Shanty Bay	305	Well 1	Rep.	SSEA	42.7	Rep.	2009 WTRS	34.7
Water Supply	Municipal	7520-6LJTGX	430	613042	4918902	40.8	45.4	Shanty Bay	305	Well 2	Rep.	SSEA	48.8	Rep.	2009 WTRS	47.0
Water Supply	Municipal	7520-6LJTGX	431	613027	4918911	58.5	65.8	Shanty Bay	610	Well 3	Rep.	SSEA	54.9	Rep.	2009 WTRS	68.7
Water Supply	Municipal	7650-6CFRPK	435	596698	4918601	62.5	72.5	Snow Valley	1634.4	Well 3	Rep.	NVCA	175.5	Rep.	2009 WTRS	43.2
Water Supply	Municipal	7650-6CFRPK	436	596700	4918617	62.8	72.5	Snow Valley	1634.4	Well 4	Rep.	NVCA	0.5	Rep.	2009 WTRS	135.0
Water Supply	Municipal	7650-6CFRPK	437	597076	4919325	59.4	65.5	Snow Valley	700	Well 1	Rep.	NVCA	53.2	Rep.	2009 WTRS	55.6
Water Supply	Municipal	7650-6CFRPK	438	597075	4919340	61.0	67.1	Snow Valley	700	Well 2	Rep.	NVCA	53.8	Rep.	2009 WTRS	58.1
Water Supply	Municipal	8306-7JYPWU	472	605518	4905031	68.3	77.4	Innisfil Heights	2937.6	Well 2	Rep.	Town of Innisfil	170.1	Rep.	2009 WTRS	219.2
Water Supply	Municipal	8306-7JYPWU	473	605560	4904863	61.3	68.9	Innisfil Heights	3110.4	Well 3	Rep.	Town of Innisfil	170.1	Rep.	2009 WTRS	184.2
Water Supply	Municipal	00-P-1370	16	616284	4910121	65.5	70.1	Alcona	228.96	Well 1	Rep.	Golder	0.0	Rep.	2009 WTRS* Golder	53.4 0.0
Water Supply	Municipal	00-P-1370	17	616213	4910177	48.8	52.4	Alcona	249.12	Well 2	Rep.	Golder	0.0	Rep.	2009 WTRS* Golder	70.4 0.0
Water Supply	Municipal	00-P-1370	18	616317	4910201	35.0	37.5	Alcona	0	Well 3	Est.	Golder	0.0	Est.	Golder	0.0

* MOE records from the Water Taking Reporting System do not agree with local understanding.

AquaResource
A Division of Matrix Solutions Inc.

BARRIE TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

APPENDIX C: GROUNDWATER FLOW MODEL CONSTRUCTION AND CALIBRATION (COMPANION REPORT)

AquaResource
A Division of Matrix Solutions Inc.

CITY OF BARRIE
GROUNDWATER FLOW MODEL
CONSTRUCTION AND CALIBRATION
TECHNICAL MEMORANDUM

Report Prepared for:

LAKE SIMCOE REGION CONSERVATION AUTHORITY

Prepared by:

AQUARESOURCE
A Division of
MATRIX SOLUTIONS INC.

July 2013
Breslau, Ontario

DISCLAIMER

We certify that we supervised and carried out the work as described in this report. The report is based on and limited by circumstances and conditions referred to throughout the report and on information available at the time of the site investigation. AquaResource has exercised reasonable skill, care and diligence to assess the information acquired during the preparation of this report. AquaResource believes this information is accurate but cannot guarantee or warrant its accuracy or completeness. Information provided by others was believed to be accurate but cannot be guaranteed.

This report is prepared for the sole benefit of Lake Simcoe Region Conservation Authority, and is solely warranted for the purposes outlined in this report. Any uses which a third party makes of this report, or any reliance on decisions made based on it, are the responsibility of such third parties. AquaResource, a Division of Matrix Solutions Inc. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

AQUARESOURCE
A Division of
MATRIX SOLUTIONS INC.

Michelle Bester, M.Sc.
Water Resources Modelling Specialist

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1.0 INTRODUCTION

1.1 Overview

The Lake Simcoe Region Conservation Authority (LSRCA) has undertaken a Tier Three Water Budget and Local Area Risk Assessment for the City of Barrie, as recommended within the Tier Two Assessment (Golder and AquaResource 2010). The Barrie Creeks subwatershed (within the City of Barrie) was identified through the Tier Two Water Budget and Stress Assessment analysis as having a moderate to significant potential for stress; as such it qualifies for more rigorous Tier Three review.

Earlier studies in the area (Golder 2004; Golder 2009) focused on delineating wellhead protection areas for the municipalities within south Simcoe County. The characterization phase of this work provided the conceptual foundation for individual numerical models of each municipality as well as for subsequent studies and investigations. A key outcome was the characterization of the complex aquifer system into a refined hydrogeologic framework consisting of eight distinct hydrogeologic units and a groundwater flow model used to delineate wellhead protection areas (WHPAs) for the City of Barrie. This model was a 3D fully-saturated model with static recharge derived from water budget methods and provided a sound understanding of the local flow patterns surrounding the Barrie municipal wells. A regional numerical groundwater model was also developed for the Tier Two study (Golder and AquaResource 2010) in the NVCA, LSRCA and SSEA watersheds, which incorporated the City of Barrie. This model was built upon the combined conceptual models developed during the South Simcoe studies and provides the general regional context for groundwater flow around the City of Barrie. Both of the previous models were focused on regional, rather than local, flow systems and features.

As outlined in the Conceptual Understanding Memo (AquaResource et al. 2011a), the Barrie Study Area (Appendix C.1, Map 1.1) contains the urban well fields within the City of Barrie as the primary focus. The Study Area is slightly larger than the previous Barrie FEFLOW model from the South Simcoe Studies (Golder 2004), and encompasses the modelled capture zones of the well fields of interest, aligned with natural flow divides where possible, and includes portions of Lake Simcoe so that surface water interaction can be accounted for. The model is simulated in unsaturated mode so that the water table can be accurately approximated which is important in this particular Study Area because of the high variability in topography. The goal of the Tier Three assessment is to evaluate the quantitative reliability of the water supply system for the well fields within the Barrie Study Area and to identify potential threats to that reliability. The assessment is centered on a highly refined area surrounding the Barrie Municipal Wells.

1.2 Study Area

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 is currently based on groundwater; however, a surface water source, on the south shore of Kempenfelt Bay (Lake Simcoe) has recently (August 2011) been commissioned to service the southern pressure zones within the City of Barrie. The majority of the water supply wells lie within 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; 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 (Township of Springwater), and Innisfil Heights and Stroud (Town of Innisfil), given their proximity to the City of Barrie. This boundary encompasses the modelled capture zones of these well fields (as determined by the WHPA model, Golder 2004) and further extends to the natural surface water and groundwater subwatershed boundaries as determined by equipotential and surface water feature maps (see Conceptual Understanding Report, AquaResource et al. 2011a). The complete Study Area covers an area of 800 km^2 and occupies both the Nottawasaga River 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.

1.3 Project Goals and Objectives

The goal of the current phase of work was to develop and calibrate a three-dimensional numerical groundwater flow model that incorporates a refined hydrogeologic model to facilitate a better understanding of the three-dimensional groundwater flow system as part of a risk assessment analysis for a Tier Three Water Budget.

The calibrated groundwater model described in this document has been developed based on the conceptualization of the geology and hydrogeology throughout the region completed by Golder (2004, 2009) as summarized in the Conceptual Understanding Report (AquaResource et al. 2011a). The model was developed using the groundwater modelling code FEFLOW (DHI-WASY 2009) and is appropriate for many applications and uses in water management, including assessment of well capture zones, determination of groundwater under the direct influence of surface water, evaluation of aquifer interconnectivity and interference between supply wells, and calculation of surface to well or surface to aquifer advection times.

Given the local scale, the calibrated groundwater model presented in this document is sufficiently detailed to provide the basis for a Tier Three analysis which includes the following components:

1. Calculate a local water budget;

2. Analyze flow patterns, water supply and demand;

3. Assess risk and evaluate environmental impacts of pumping;

4. Map vulnerable areas; and

5. Perform uncertainty analysis to assess data and knowledge gaps for future planning including but not limited to:

   - Factors/formations influencing flow;
   - Influence and interaction with surface water features;
   - Understand key uncertainties that influence flow direction.

The groundwater flow model was developed jointly by AquaResource, Golder Associates and International Water Consultants. The team experience provides site specific knowledge and expertise of the hydrogeologic framework and advanced model expertise to provide a defendable approach to understanding the 3D groundwater flow in a local setting.

1.4 Scope and Approach

This document describes the groundwater model calibration. Section 2.0 provides a summary of the Hydrogeologic Framework defined within the Conceptual Understanding Report (AquaResource et al. 2010). Section 3.0 presents and discusses the model construction. The overall approach to the calibration is presented in Section 4.0 with emphasis on what constitutes a good calibration given the objectives described above, as well as an introduction to the observed data used in calibrating the model. Section 5.0 presents the calibration results and includes a discussion of the model calibration at the well field scale with emphasis on high quality data. Section 6.0 summarizes the limitations of the groundwater flow model and Section 7.0 presents conclusions.

2.0 HYDROGEOLOGIC FRAMEWORK UPDATE

The hydrostratigraphic layer structure was developed in an earlier phase of the project and builds upon previous studies throughout the area, many of which have been modelled in smaller, individual models throughout the Study Area. For additional information on the hydrostratigraphic model, refer to the Conceptual Understanding Report (AquaResource et al. 2011a).

The hydrostratigraphic units developed throughout the South Simcoe and Tier 2 studies consist of eight major overburden units. Of the overburden units, there are four main aquifers (A1-A4) and four main aquitards (C1-C4) that constitute the numerical model layers within those studies. Within the numerical model layer structure, the uppermost main aquifer was further subdivided throughout model calibration of those models, mostly in the upland regions of the current Study Area where thicknesses were in excess of 140 metres. Because of its importance to municipal water supply as well as its thickness within the City of Barrie, the main production aquifer, A3, was subdivided into four layers within those models to increase the vertical resolution. Furthermore, a confining layer (UC) over the uppermost aquifer, A1, was added to accommodate for stream bed conductance and to control excessive drainage in the highlands. It is important to note that the original numerical model in the South Simcoe studies was simulated in fully-saturated mode whereas the current modeling will simulate variably saturated conditions.

2.1 Conceptual Model Modifications

Upon inspection of the surface isopachs and cross-sections and analysis of a preliminary model, it was determined that the UC layer was too thin to be effective as a confining layer and did not correspond with key boreholes (including high quality Ontario Geologic Survey (OGS) boreholes; see Conceptual Understanding Report (AquaResource et al. 2012) in the model area. Conversely, the uppermost aquifer (A1) layer which hosts the predicted water table location as well as numerous private pumping wells was still very thick, despite the subdivision of this layer. The present model for the Tier Three analysis was simulated using unsaturated/saturated conditions which require an increased vertical resolution in order to properly solve for the water table elevations; therefore, the thickness of the A1 unit was too large for this purpose.

When pumping and monitoring wells are added to a FEFLOW model, the well screens are approximated to the closest model slice. In most cases, model layers are designed with careful attention to screen elevations, in addition to borehole geology, so that the well screen elevations are as representative of field conditions as possible. Errors can be then avoided when the vertical resolution of the layers is appropriate and coincide with screen elevations. This is particularly important within the deep production aquifer where risk analysis and safe drawdown levels will be estimated. However, when a layer is too thick under unsaturated or partially saturated conditions, a secondary problem can occur. Well screen elevations can be erroneously approximated as being completely within the unsaturated portion of the model, resulting in numerical instability and erroneous head solutions. Within the Study Area, wells that are screened in this uppermost aquifer are generally household wells that are shallow and do not penetrate the full thickness of the aquifer unit, therefore the model layer needs to have sufficient vertical resolution so that at least the bottom elevation of the well screen elevations is below the water table.

In the preliminary modelling performed to test the suitability of the conceptual model, hydraulic conductivities were applied to the A1 unit using a Bulk Conductivity method in which borehole geology is used to approximate the bulk hydraulic conductivity in the horizontal direction using the harmonic mean method. The spatial distribution of the bulk hydraulic conductivity revealed that although some strong trends appeared, the inclusion of the shallow, very low K-value conductivities resulted in a very non-Gaussian distribution, which indicates that the layer delineation is too broad and not representative of the natural system.

In summary, the layer structure of the upper two layers required refinement and improvement due to the following:

- The Upper UC layer did not reflect borehole geology
- The expected location of the water table is within the interpreted A1 sequence within the highlands of the model where it is the thickest. Extra refinement within this unit would be more appropriate.
- Pumping and monitoring wells which are added to the FEFLOW model will be applied on the closest model slice. Therefore, theoretically, a well that should be screened to a 12-metre depth in the thickest area of A1 may only have the choice of being placed at either 0.20 m (Top of A1) or 70 m (Middle of A1) depth
- Bulk hydraulic conductivity within the uppermost modelled aquifer was too vertically heterogeneous suggesting that some important confining areas of the sequence were not adequately represented.

Cross sections were created in key areas of the model to assess where the UC layer would best be approximated. These cross sections were also drawn through OGS boreholes to ensure the model layers were still true to these very high quality interpretations. In the highlands, the most efficient way to approximate the new Top of A1 surface was to subtract the Top of C1 from the 100m Digital Elevation Model (DEM) and divide in half, as the bottom of most of the shallow A1 wells screened within A1 is located around this elevation. This half-way point is supported with borehole geology. In the lowlands, it was determined that UC should not exist at all. In the case of a hydrogeological unit not existing in a numerical model layer, it is standard to apply a minimum model thickness of 0.10 m to maintain layer continuity. However, when the thickness of A1 was divided in half in these areas, the average thickness is approximately 25 cm; therefore, it was sufficient to place the bottom of the UC/Top of A1 unit directly halfway between the Top of C1 and the DEM for the entire model domain. Once this was completed, the cross sections showed a good match with boreholes within the upland regions. The majority of the boreholes remain completed within the aquifer unit and most borehole geology shows some confining layers within it in most places within the highlands. Within the lowlands, the change has little effect as the uppermost layers UC and A1 were already at minimum thickness. These modifications resulted in improved refinement near the predicted water table elevation, better borehole representation, and realistic elevations for pumping and monitoring well screen depth placements.

2.2 Conceptual Model Overview

Table 2.1 presents a summary of the hydrostratigraphic units in the Study Area, including a description of the hydrostratigraphic unit name, and the specific geologic units identified within the hydrostratigraphic unit.

TABLE 2.1 Hydrostratigraphic units within the Study Area

Model Layer	Unit Name	Unit Description
Layer 1	SrfG	Represents conductance in stream beds, mapped surficial geology. 0.10-3 m in thickness.
Layers 2, 3	UC	Represents confining layer over A1, mostly present in upland area such as the Oro Moraine, where missing then A1 properties used
Layer 4	A1	Uppermost aquifer, present in upland areas. Frequently exists as surficial and unconfined, stratigraphically equivalent to the Oak Ridges Moraine, generally is associated with coarse-grained glacial and interglacial sediments mapped as ice-contact stratified drift.
Layer 5	C1	Upper Aquitard
Layer 6	A2	Intermediate Aquifer, stratigraphically equivalent to interstadial units within the Northern Till. Within the lowland areas it is often the uppermost coarse-grained unit, commonly used for private water supplies, as well as some of the smaller municipal water supply wells (i.e. Innisfil)
Layer 7	C2	Intermediate Aquitard, providing protection to the municipal aquifer
Layer 8, 9, 10, 11	A3	Main municipal production aquifer, stratigraphically equivalent to the Thorncliffe deposits in the Upland regions. Represents the bulk of the Barrie-Borden channel aquifer.
Layer 12	C3	Lower Aquitard
Layer 13	A4	Lower aquifer, thin and sometimes combined with A3 in the Barrie City Core, where C3 is thin or absent
Layer 14	C4	Lower Aquitard, also represents weathered bedrock

This hydrostratigraphic structure provides the basis for the layer structure of the numerical model.

2.3 Hydrogeologic Unit Mapping

A set of surfaces for the tops of each of the hydrostratigraphic units applied as layers in the groundwater model were developed based on interpretations from Golder (2004, 2006, 2009). A 5-meter resolution Digital Elevation Model (DEM), the depth to bedrock dataset (Golder 2009), and regional water well database (WWIS) top of bedrock picks provided supplemental information. The developed surfaces are as follows:

1. Top of SrfG: represented with 5 meter DEM

2. Top of UC: calculated from DEM – 3 m, where this unit is present*
3. Middle of UC: calculated from ((DEM – Top of A1)/2), where this unit is present*
4. Top of A1/Bottom UC: calculated from ((DEM – Top of C1)/2), where this unit is present*
5. Top of C1/Bottom A1: representative elevation as determined by borehole interpretation**
6. Top of A2/Bottom C1: representative elevation as determined by borehole interpretation**
7. Top of C2/Bottom A2: representative elevation as determined by borehole interpretation**
8. Top of A3/Bottom C2: representative elevation as determined by borehole interpretation**
9. Top A3 - Sublayer: calculated from ((Top of A3 – (Top of A3-Top of C3)/4)
10. Top A3 - Sublayer: calculated from ((Top of A3 – (Top of A3-Top of C3)/2)
11. Top A3 - Sublayer: calculated from ((Top of C3 + (Top of A3-Top of C3)/4)
12. Top of C3/Bottom A3: representative elevation as determined by borehole interpretation**
13. Top of A4/Bottom C3: representative elevation as determined by borehole interpretation**
14. Top of C4/Bottom A4: representative elevation as determined by borehole interpretation**
15. Top of Bedrock/Bottom A4: representative elevation as determined by borehole interpretation**

*In the case of an absent unit, the surface was calculated to be 0.10 m below the upper surface so that a minimum layer thickness is maintained for numerical purposes.

**See Conceptual Understanding Report (AquaResource et al, 2010) for more details.

If the hydrogeologic units pinch out, numerical model layers decrease to a minimum thickness of 10 cm, to maintain layer continuity. GIS polygons are used to ensure that the model properties applied within these areas represent that of the next adjacent lower layer that has a thickness exceeding 10 cm (i.e. if C2 is absent, properties from A3 are used. If A3 is absent as well, C3 is used, etc.).

2.4 3-D Hydrogeologic Unit Model

Hydrostratigraphic picks were generated at the interpreted upper surface of each hydrostratigraphic layer (Table 2.1). The generated surfaces represent the top of hydrostratigraphic units. Continuous surfaces of picks were generated in Surfer 8.05 (Golden Software 2009) using a linear kriging algorithm to a 100 m resolution. Kriging was chosen as it a) is an exact interpolator that will retain defined values at specified points (i.e. picks), and b) incorporates anisotropy and underlying trends in an efficient manner.

The generated numerical model surfaces were restricted to the boundaries of the Study Area.

Surfaces were imported into Leapfrog Hydro 3-dimensional visualization (Leapfrog Hydro 2012) where a 3-D hydrogeologic block model was created to visually inspect the vertical and lateral distribution of model layers based on the generated surfaces.

3.0 GROUNDWATER FLOW MODEL

The preliminary groundwater flow model for the study site was developed using FEFLOW, a commercially available finite element groundwater modeling code developed by DHI-WASY (2009). The groundwater flow model is based on the hydrogeologic framework described in Section 2.0 and based on the surfaces of the 3-D Conceptual Model that define the hydrostratigraphic units.

FEFLOW was selected as the modelling code for use in this area because of its advanced capabilities that include the following:

- Ability to discretize the mesh around specific areas of interest such as pumping wells, or rivers, to more precisely simulate observed physical features and follow naturally complex boundary conditions such as the steep slopes of the Upland Areas;

- Efficiency of localized mesh discretization; requires far fewer calculation points to achieve the same level of precision as with finite difference grids (e.g., MODFLOW) which are forced to carry refinements to the model boundaries (allows simulation of shallow aquifer within the context of the regional model);

- Ability of the elements to conform to the pronounced vertical variation of aquifer/aquitard layers;

- Advanced boundary conditions to avoid potential impacts of non-physical boundary conditions on the simulation results; and

- Stable water table simulation that facilitates more accurate simulation of the shallow subsurface and decreases numerical issues.

Given these considerations, FEFLOW was selected for use in completing the groundwater modelling for the Study Area.

3.1 Modelling Process

The numerical modelling process for the Tier Three Assessment consisted of three stages:

3.1.1 Model Set Up

Groundwater flow is simulated by applying boundary conditions at the locations were water enters or leaves the groundwater flow system (e.g., recharge, discharge to streams, pumping wells) and is subjected to a variable hydraulic conductivity, storage, and porosity field. For the purpose of a Tier Three analysis, the FEFLOW model was built in unsaturated mode to allow the benefit of water table approximation.

Both the surface water model (MIKE SHE, AquaResource et al. 2011) and groundwater model were designed for the purpose of calibrating each model simultaneously by exchanging information between them. In both models, analogous layer structures were designed, identical pumping data and groundwater monitoring wells were used, and external groundwater boundary conditions were applied.

Upon construction of both models, a recharge distribution was supplied to the FEFLOW model from a preliminarily calibrated MIKE SHE model.

3.1.2 Steady-State Calibration.

During the steady-state calibration, the model input parameters and boundary conditions were adjusted to obtain a reasonable fit to the range of head and baseflow values. Throughout the FEFLOW calibration, feedback was supplied back to the MIKE SHE model via new groundwater parameters (i.e. adjusted conductivity), the MIKE SHE model was recalibrated to the new parameters and a new recharge distribution was created for input to FEFLOW. This iterative process was repeated until both models were considered to be calibrated.

3.1.3 Transient Calibration/Long Term Verification

Long-term model verification is another step in the model calibration process whereby the calibrated model output is compared to a different set of field observations than those observations used to calibrate the model. In this assessment, a transient simulation was undertaken to examine the model predicted and observed responses to municipal pumping within the City of Barrie. This step aimed to simulate the head response resulting from groundwater extraction from all well fields within the City of Barrie between 1997 and 2010. The model was set up with average monthly recharge (obtained from the results of the MIKE SHE model) and average monthly groundwater extraction from each of the City of Barrie municipal wells. The 13 year simulation was divided into a total of 165 monthly stress periods, and as noted above, the groundwater pumping and recharge were considered constant throughout each of the stress periods. These stress periods, along with their pumping rates, are presented within the Conceptual Understanding Report (AquaResource et al. 2011a).

Model input parameters from the steady-state calibration were used as initial conditions to simulate the transient conditions. Input parameters (hydraulic conductivity and storage estimates) were modified until a reasonable match was achieved between the model simulated and observed hydraulic head measurements to represent observed water level changes during the tests. Changes to input parameters made during the transient calibration were incorporated back into the steady-state model to ensure the same input parameters were present in the two models.

3.1.4 Sensitivity Analysis

An assessment of the sensitivity of the model input parameters was conducted to provide a basis for a discussion on the uncertainty associated with the modelling and the model results.

This section of the report outlines the groundwater model set up, the steady-state and transient model calibration. The application of the sensitivity analysis to quantify uncertainty in the risk assessment is discussed in the main report.

3.2 Model Domain

Three main aspects were considered during the delineation of the model domain and creation of the finite element mesh. First, domain boundaries must extend adequately away from areas where predictions are necessary so that these areas are not strongly influenced by the model boundaries. For this site, the model domain needed to be such that the present and possible future extents of the capture zones of the municipal wells are sufficiently distanced from the model boundary. The second consideration is to identify physically-based boundary conditions around the perimeter of the model. Therefore, the model boundary was extended to the natural boundaries of the groundwater flow system. This was accomplished by examining the potentiometric surfaces and water levels within the watershed, paying particular attention to watershed boundaries. Lastly, while balancing these first two considerations, the size of the domain must also be taken into account so that it can contain an appropriate level of resolution while still remaining computationally practical.

The resulting numerical model domain encompasses the City of Barrie as well as portions of the Townships of Essa, Oro, and Springwater (Map 1.1). The model domain was designed to encompass the entire Barrie Creek subwatershed as well as adjacent subwatersheds that may possibly contribute to interbasin flow. In addition, the model extends into Lake Simcoe to simulate recharge/discharge directly to and from groundwater. The model domain is approximately 14.5 km in width (west-east) and it extends approximately 13 km in length (north-south) covering an area of 800 km^2.

3.3 3-D Finite Element Mesh

An important consideration during the development of the model is that the finite elements be aligned with important features in the model including locations of all wells, streams, ponds, and the well field focus area. As a result, boundary conditions can be applied to their exact locations either for present or future applications. Additionally, the mesh can be discretely refined to a higher resolution along these features. This method of variable mesh refinement allows for a numerical mesh that is both efficient for calculations but also practical for capturing local detail where needed.

The Study Area boundary, as well as the boundary of Lake Simcoe within the Study Area and the boundary of the well field Focus Area, provide the basis for the initial mesh design. The study boundary topology was normalized to a resolution of approximately 100 m and the Lake Simcoe boundary topology was normalized to a resolution of approximately 50 m. Within the ambient regions of Study Area (i.e. areas without significant features), the average element length is approximately 200 m and within the ambient regions of the Well Field Focus Area, the average element length is approximately 100 m.

The 2-D model finite element mesh is presented in Map 3.1. The mesh was refined in areas where it was important to have an enhanced definition of groundwater flow and the potentiometric surface. Features that were incorporated into the mesh design included wells, streams and lakes. A total of 124 wells were included in the mesh design, including present and future pumping wells, and private wells. The well locations were refined to a resolution of 15 m. Prominent streams and ponds were also included in the mesh design. To avoid poor mesh geometries that can lead to numerical instability, these features were first simplified to 50 m segments outside of the Focus Area and 20 m within the Focus Area. The simplified river segments were then incorporated as line features within the mesh design so model nodes were exactly located along mapped streams. Ephemeral or channelized streams were included for future use; however, only perennial streams and ponds as determined by air photo analysis are currently represented explicitly within the model.

This 2-D mesh was extended into 3-D by the addition of the surfaces described in Section 2.0, resulting in a total of 2,968,644 elements and 1,604,160 nodes. Images of the final 3-D mesh are presented in Map 3.2. The inset on Map 3.2 shows an example of the mesh refinement surrounding the municipal wells.

3.4 Boundary Conditions

Boundary conditions represent the interaction between the numerical model domain and the surrounding areas outside the model domain. Boundary conditions included in the model are described below:

- *Specified Head boundary conditions* are assigned in a model where the head value at a particular location is known. Specified head boundary conditions are often used to simulate flow along the perimeter of a model or for the simulation of lakes, rivers, or other surface water bodies.

- *Specified Flux boundary conditions* are assigned to represent a known flux across a surface, into the model domain. These types of boundaries are often used to simulate recharge entering the model through the uppermost layer of the model. Wells are also special types of flux boundaries.

Map 3.3 illustrates the spatial distribution of boundary conditions assigned in the FEFLOW groundwater model. Sections 3.4.1 through 3.4.4 provide a discussion on the boundary conditions applied in the model.

3.4.1 External Regional Flow Boundary Conditions

As mentioned above, the model domain was delineated to correspond to natural groundwater flow boundaries (groundwater divides). To determine appropriate lateral boundary conditions for the model, water level contours were reviewed (AquaResource et al. 2011a). Where water level trends suggested that natural flow boundaries exist (groundwater divides), no-flow boundaries were applied. In other cases, where the deeper groundwater flow regime did not exhibit the same boundaries as the shallow regime, boundary conditions were required to allow in/outflow along these deep features. These boundary conditions were set at specified head according to measured water levels in the area and monitored throughout calibration to obtain the observed gradient across the boundary.

Since a larger watershed scale model was completed prior to the completion of this assessment, cross-boundary flows from the adjacent models from those models could be used for comparison purposes to the current model. This comparison is helpful because the watershed scale model contains hydrogeologic information beyond the boundary of the current model and observed water levels beyond this boundary were used for calibration of that model. This comparison showed compatibility between the two models, in both flow direction and magnitude.

Map 3.3 shows the location and type of boundaries applied on the perimeter of the model domain. Inflow and outflow to the model through lateral boundaries has been incorporated into the model for both the shallow and deep aquifer flow systems. In the shallow aquifer (A1), most of the model boundary cross cuts the equipotentials (Map 3.3), indicating that groundwater flow divides exist in the model at these locations. Initially, no lateral boundaries were applied to the shallow system. However, the initial phases of calibration and further inspection into observed water levels in the area showed that that the northeast boundary is in an area where flow may be entering into the model; therefore, a variable Type 1 boundary condition was interpolated and also shown in Map 3.3.

For the deep layers, the inflow or outflow has been estimated based on equipotentials within the A3 Unit (Map 3.3). Where there has been no external boundary condition applied, the boundary is considered no-flow. Water levels around the western boundary indicate that there is interbasin flow occurring under the Minesing Wetland where the deep discharge to the Wetland occurs slightly west of the model boundary.

3.4.2 Surface Water Boundary Conditions

Selected rivers and streams were simulated in the model using specified head boundary conditions. In addition, large lakes including Lake Simcoe were also simulated in the model. The application of boundary conditions in the model to simulate these features is discussed below.

3.4.2.1 *Rivers and Streams*

Groundwater discharge from overburden occurs along streams, wetlands, and ponds. These surface water features have potential to be impacted from anthropogenic activities, such as excessive groundwater pumping. Perennial surface water features are represented in the FEFLOW model using specified head or head dependent flux boundaries. Perennial streams and ponds were initially identified using the Strahler number (1), but confirmed and modified by air photo analysis and field observations and represented in the FEFLOW model (Map 3.3).

Specification of stream and river boundaries using specified head boundary conditions requires the application of a value for the river stage (elevation). The stage elevation was taken from water levels represented in the 5 m Digital Elevation Model (DEM). Prior to assigning river boundary conditions in the model, the stream network was inspected using a GIS software package to ensure the river stage specified in the model was decreasing in the downstream direction. The boundary conditions applied to the model are therefore referred to as "hydraulically-corrected". As well, the degree of conductance through the river/ lake bed with the underlying groundwater system is assigned by using a thin model layer under the water body and applying a hydraulic conductivity appropriate for the mapped surficial geology to ensure that discharge to the water body is realistic. The stream conductance applied at the base of all stream and river segments (in the first layer of the model, Layer SrfG as described in Section 2.0) was variable depending on the surficial geology that the rivers or stream passes through, the flow characteristics of the river (e.g., sinuous versus straight paths), as well as the mapped thermal regime. In general, streams that travel with relatively straight courses and were mapped to contain coldwater fish species (NVCA and DFO 2009; LSRCA 2010) were given a high conductance value. Those streams that meander significantly through clay plains and are reported to have mixed or warmwater thermal regimes (NVCA and DFO 2009; LSRCA 2010) were given a low streambed conductance. While this conductance value does not greatly impact the surface water/groundwater interaction in lower hydraulic conductivity sediments, it is designed to control the interaction between surface water and groundwater in areas where the streams are interpreted to cut through coarse grained sediments. This is adjusted throughout the model calibration as warranted based on observed data.

3.4.2.2 *Lakes and Wetlands*

Lake Simcoe (Kempenfelt Bay and Cooks Bay) was simulated in the model using specified boundary conditions applied in the upper overburden layers with a head elevation set to 218.8 masl. The available bathymetry of the Lake was incorporated into the model so that boundary conditions of the lakes could be set in the deeper layers that they exist within, and so that the locations where the hydrogeologic layers intersect the lake basin (i.e. where surface water/groundwater exchange occurs) is realistic.

There are a total of three lakes mapped within the Study Area that were large enough to be simulated in the groundwater flow model (Map 3.3). To accurately simulate the flow into and out of these elements, only large lakes that were verified through air photo analysis were simulated. The threshold of 0.02 km^2 was applied as the FEFLOW elements regionally are approximately 0.02 km^2. In some areas, smaller riparian-type water bodies that were connected to larger systems such as streams and larger lakes were included with those features as boundary conditions in the model. Table 3.1 below outlines the lakes that were simulated in the groundwater model. The remainder, smaller water bodies that were not included that may have groundwater discharge were included as calibration verification points.

Lakes are simulated in the groundwater model using specified head boundary conditions. The application of these boundary conditions assumes there is good hydraulic connection between the lake and the underlying groundwater system. As with the rivers and streams, the lake stage elevation was taken from the 10 m DEM.

TABLE 3.1 Lakes Simulated in the FEFLOW Model

Lake Name	Surface Area (km^2)	Stage Elevation (masl)
Lake Simcoe*	57.0	218.8
Little Lake	2.3	227.8
Hendrie Lake	0.1	188.6
* only includes portion within model boundary		

3.4.3 Recharge

Groundwater recharge refers to the amount of water that infiltrates through the unsaturated zone and ultimately reaches the water table. The rate of groundwater recharge is dependent on a number of factors including precipitation, land use and vegetation, surficial soil type (geology), physiography, and ground surface topography. Recharge is enhanced in areas where the ground surface is hummocky and water does not runoff to nearby creeks and rivers.

Recharge rates used in the groundwater model were obtained from the surface water model MIKE-SHE which is described within the Recharge Estimation Memo (AquaResource et al. 2011b). The recharge rates provided by MIKE SHE were modified slightly for the input to the groundwater model; for instance, negative recharge values (i.e. discharge conditions) were assigned a value of 0, and the unsuitably high recharge was capped to a maximum of 450 mm/yr. The total amount of recharge to the model (Map 3.4) is 455, 250 m^3/day, which represents an average recharge of 225 mm/year. Estimated recharge rates and distribution were adjusted locally in a pseudo-coupled approach during the calibration process of both the groundwater and surface water models to address discrepancies between observed and simulated data.

3.4.4 Pumping Wells

In FEFLOW, groundwater extraction wells are typically represented using the constant flux boundary condition using one-dimensional vertical line elements superimposed on the three-dimensional finite element mesh. As such, the entire pumping rate is applied to the bottom node of the line element; fluxes into the well from all nodes along the well screen (vertically) are computed based on the transmissivity associated with each calculation point. In this manner, flux contribution to a well from multiple stratigraphic layers is automatically calculated. This is particularly important for wells that penetrate multiple geological sequences.

As noted in Section 3.3 above, the mesh was refined around the pumping wells to more accurately simulate the groundwater flow patterns surrounding the wells and to reduce model instability caused by high-velocity flow. The wells that are simulated under steady state conditions, along with their average daily pumping rates, are presented in Appendix C2. A total of 124 pumping wells are represented, however some wells are standby wells with combined pumping rates with their system. The locations of all pumping wells represented in the model can be seen in both Maps 1.1 and 3.1, and a close up of the wells can be seen on Map 4.2. The reported or estimated pumping rates for 2008 were applied in the model as these are more accurate for examining existing water demands than using the maximum permitted rates for the purpose of calibration.

3.5 Model Properties

The primary hydrogeologic properties assigned within the FEFLOW model for simulation of steady-state (average annual) conditions includes the hydraulic conductivity, porosity and unsaturated zone pressure-saturation properties. Hydraulic conductivity is a property of sediment or rock that describes the relative ease with which water can move through pore spaces or fractures and can have a significant impact on the model calculated hydraulic head distribution. Porosity refers to the volume of void space per unit volume of geologic materials and is used in velocity calculations. Therefore, porosity estimates are only used for particle tracking calculations. Since this study requires transient simulations for the drought assessment, storage is also estimated.

3.5.1 Hydraulic Conductivity

Hydraulic conductivity is the primary variable that controls the calculated hydraulic head distribution throughout the model domain (based on boundary condition values). In developing a groundwater model, initial estimates of hydraulic conductivities are specified and refined through the calibration process to achieve an acceptable fit to observed data. Initial conductivity estimates are based on the conceptual understanding of the geologic/hydrostratigraphic units and their hydrogeologic properties. Where data from pumping tests is available, these data can help to constrain the conductivity estimates within particular geologic formations. When such data is not readily available, conductivity values are often estimated from literature values for materials with a similar lithological description, or from previous studies conducted in the area. In this study, a combination of site specific, measured hydraulic conductivity and lithology-estimated conductivity values are applied. It has been assumed that all model layers contain fresh water (low TDS and salinity).

The majority of hydraulic conductivity estimates within the Focus Area were extracted from the previous groundwater protection studies (Golder 2004, 2006) as well as more recent well field assessments. Outside of the Focus Area, lithology from boreholes was used to derive an initial conductivity estimate. Those estimates were interpolated in each of the interpreted hydrostratigraphic layers and generalized to produce hydraulic conductivity distributions. This method produces a heterogeneous distribution of hydraulic conductivities across the model layers where the heterogeneity represents spatial lithology changes. The hydraulic conductivity distribution within each unit was then demarcated into representative zones, called Kzones, and assigned an average conductivity value based on either the borehole lithology or measured values from hydraulic testing.

The initial conductivity distribution in the model ranged from $5x10^{-3}$ m/s for coarse-grained gravel deposits, to $1x10^{-7}$ m/s for fine-grained deposits. Average initial hydraulic conductivity estimates for each unit are presented in Table 3.2. These estimates are consistent with those used within the South Simcoe Studies (Golder 2004), and are refined through additional data collection associated with on-going studies and model calibration. It is important to note that these are non-weighted averages of the boreholes within each model layer; the average conductivity within the confining units may be offset by the high conductivities within the model layer, in areas where the predominant geological layer does not exist. The vertical hydraulic conductivity was set to be 1:10 of the horizontal.

TABLE 3.2 Initial Hydraulic Conductivity Estimates

Unit	Mean Hydraulic Conductivity (m/s)
UC	1.66E-06
A1	1.12E-04
C1	2.43E-07
A2	1.44E-04
C2	3.40E-07
A3	5.40E-03
C3	3.68E-07
A4	8.49E-05
C4	1.75E-07

3.5.2 Unsaturated Flow Parameters

In order to enhance the model's ability to represent groundwater flow on a site scale, saturated and unsaturated flows were calculated simultaneously using Richard's equation (Variably Saturated Mode). In this mode, the mesh and properties remain fixed and the parameters applied vary depending upon the saturation state within each element. Although this method requires specification of unsaturated zone parameters which are typically not well known, the purpose of unsaturated zone simulation is to represent the realistic position of the water table and not dynamic unsaturated responses. Therefore, simplified constitutive relations (e.g. material specific K-saturation relationships) were simulated for this model.

The most common way to simplify the relationship is to assume the function that relates the saturation and the relative hydraulic conductivity is linear which was completed for the Van Genuchten Modified relationship model. This simplification avoids some of the non-linearities within the unsaturated zone and allows an iterative solution of the water table position to be efficiently achieved (Vogel et. al. 2001; Beckers 1998; Huyakorn et al. 1986).

3.6 Transient Model Setup

Long-term model verification is another step in the model calibration process whereby the calibrated model output is compared to a different set of field observations than those observations used to calibrate the model. In this assessment, a transient simulation was undertaken to examine the model predicted and observed responses to municipal pumping within the Study Area. This step aimed to simulate the head response resulting from groundwater extraction from all well fields within the City of Barrie between 1997 and 2010. The model was set up with an average monthly recharge and average monthly groundwater extraction from each of the City of Barrie municipal wells. The 13 year simulation was divided into a total of 165 monthly stress periods, and as noted above, the groundwater pumping and recharge were considered constant throughout each of the stress periods. These stress periods, along with their pumping rates, are presented within the Conceptual Understanding Report.

3.6.1 Aquifer Storage

Groundwater storage is defined as the quantity of water released from an aquifer system due to a unit change in the water level. The size of the storage coefficient is dependent on whether the aquifer is unconfined or confined. In a confined aquifer, water derived from the storage is relative to the expansion of water as the aquifer is depressurized and the compression of the aquifer. In a confined aquifer, the load on top of an aquifer is supported by the solid rock skeleton and the hydraulic pressure exerted by water (the hydraulic pressure acts as a support mechanism). Because of these variables, the storage coefficient of most confined aquifers range from 10^{-5} to 10^{-3}. Conversely, in an unconfined aquifer setting, the predominant source of water is from gravity drainage and the expansion of water and compaction of rock is negligible. Thus, the storage coefficient is approximately the value of the specific yield and ranges from 0.1 to 0.3 (similar to the porosity). Note: steady-state and do not require the specification of storage parameters.

The initial storage coefficients within the model are shown in Table 3.3. However, within the focus area, storage was specified via zones based on pumping test analyses, where available and is shown in Table 3.4. Within the area of wells 17 and 18 (See Map.4.2 for well locations), storage was generally found to be within the 10^{-4} to 10^{-5} range (IWS 2001), confirming excellent aquifer conditions in this area. Within the vicinity of Well 6 (nonoperational well as of 2001), as well as Wells 9 and 13, storage was determined to be around 10^{-2}, suggesting semi-confined leaky artesian conditions (IWS 2001). Amongst the Lakeshore wells (Wells 11, 12, 14, and 15), confined artesian conditions were found with a storage coefficient of 10^{-4} with restricted flow or connection to the lake due to the confining layer (IWS 2001); however, earlier pumping tests for well 12 were at 1.6 x 10^{-3} and lower (IWS 1985).

TABLE 3.3 Regional Storage Coefficients

Geologic Description	Specific Storage (1/m)
Sand and Gravel	10^{-4}
Silt	10^{-5}
Clay	10^{-6}
Till	10^{-6}

TABLE 3.4 Well Field Storage Coefficients

	Well Name	Specific Storage (1/m)	Source
Pressure Zone 1 – Lakeshore Wells	12 (Centennial Park)	1×10^{-4}	IWS, 1985
	14 (Heritage Park)	1×10^{-4}	IWS, 1985
	15 (Centennial Park)	1×10^{-4}	IWS, 1985
	11 (Heritage Park)	1×10^{-4}	IWS, 1985
Pressure Zone 1 - Core	3A (Anne Street)	5×10^{-4}	IWS, 2011
	4 (Perry Street)	5×10^{-4}	IWS, 2011
	5 (John Street)	5 v 10^{-4}	IWS, 2011
	6 (Wood Street, non-operational since 2001)	10^{-2}	IWS, 2001
	7 (Tiffin Street)	$10^{-3} – 7 \times 10^{-3}$	IWS, 2011
	17 (Cross Street)	10^{-5}	IWS, 2009
	18 (Cross Street)	10^{-5}	IWS, 2009
Pressure Zone 2 - North	9 (Johnson Street)	2×10^{-1}	IWS, 2001
	13 (Johnson Street)	2×10^{-1}	IWS, 2001
	16 (Brownwood)	10^{-3} - 5×10^{-4}	IWS, 1995
Pressure Zone 2 - South	10 (Huronia Road, Decommissioned as of date)	10^{-4} - 10^{-5}	IWS, 1999

4.0 CALIBRATION APPROACH

Calibration is the process of adjusting the model representation of the physical system, by adjusting parameter value distributions and/or boundary conditions to minimize the difference between simulated and observed values for hydraulic head or groundwater discharge. A steady-state calibration implies long term average conditions are modelled. A transient calibration entails using temporal data over a discrete period of time to compare model response to changing conditions (i.e. pumping, recharge).

The approach for the model calibration includes these general steps:

1. Initial model simulation using estimated conductivity values, boundary conditions and a preliminary average annual recharge estimate obtained via surface water modelling,

2. Modification of model properties (such as hydraulic conductivity) and boundary conditions (such as interbasin flow) through scaling factors for broad regions to improve regional calibration,

3. Provide qualitative and quantitative feedback from the groundwater model to the surface water model (i.e. changes in model properties or boundary conditions)

4. Local refinement and review of model properties and boundary conditions, including revisions to the surface water model produced recharge estimate, to improve the local model calibration,

5. Evaluation of the model flows and calculated baseflows followed by refinement of boundaries and hydraulic conductivity values at streams and rivers to interaction with streams,

6. Additional identification of streams that are channelized, ephemeral or in an area known to have perched water table conditions. Update and refine to improve calibration,

7. Completion of transient simulations, local refinement.

During the model calibration process, the model input parameters are changed, the model is run, and the results are reviewed. The approach in this study was to initially focus on the ability of the model to represent regional flow conditions. This is done in steps 1 and 2 listed above by completing an initial model simulation and then adjusting the hydraulic conductivities in the model layers by a scaling factor. This will result in a model that is able to represent the regional flow system well, but locally additional refinement will be necessary, which is accomplished by steps 3-5. Step 6 will verify any outstanding questions regarding material properties, in particular, storage.

Typically, when calibrating a groundwater flow model, hydraulic conductivity and storage is specified for discrete hydrogeological units (i.e., aquifers and aquitards), where the value of the property would encompass many elements and one or more layers. However, as model layers are very heterogeneous, adjusting properties manually on an elemental basis would be impractical. To overcome this challenge, the model area was subdivided into regions or polygons with similar hydrogeological properties and assigned a uniform hydraulic conductivity value and a specific storage value. The values applied to these regions were modified through the calibration process. Locally, hydraulic conductivity and storage were adjusted as needed to satisfy calibration targets and additional zones were added as warranted. Throughout this process, checks are conducted with borehole lithologies from drill logs and background reports containing hydraulic test results, to maintain geological veracity.

4.1 Steady-State Calibration Datasets

The ability of the model to represent actual field conditions is judged based on the available observation data. Establishing an observation data set is essential to the development of a defensible groundwater model. Special considerations need to be applied to achieve a calibration dataset that is consistent with the chosen calibration pumping period and addresses the varying quality of observation data throughout the model area.

Observed water levels (hydraulic head data) and groundwater discharge estimates are often used as targets when calibrating steady-state groundwater models. The sections below outline the calibration targets used in the groundwater flow model and the approach taken in this study to calibrate the groundwater flow model.

4.1.1 Surface Water Data Set

In order to estimate groundwater discharge, streamflow records can be used to determine baseflow within the Study Area. It is assumed that baseflow is predominately groundwater discharge within the Study Area, and therefore baseflow estimates are appropriate calibration targets. This calibration measure is important because it helps to eliminate some of the non-uniqueness associated with a specific model calibration. Recognizing the uncertainty in estimated groundwater discharge rates, the calibration approach relies on an estimated range, as opposed to a single value. Calibration efforts focus on those areas where the difference between the observed and simulated conditions is highest. For those areas, model layer structure modifications as well as local hydraulic conductivity modifications can be used to improve the local calibration to baseflow.

Streamflow records within the 1980-2009 periods were used from 3 gauges operated by Water Survey of Canada (WSC). The distribution of these gauges is illustrated on Map 4.1. A baseflow separation exercise was performed on the continuous streamflow data to obtain estimates of baseflow. The baseflow separation routine used in this analysis is the Baseflow Separation Program, included with the Soil and Water Assessment Tool (SWAT) hydrologic model (See Section 5.1, AquaResource et al. 2011a). This routine employs a digital filtering technique meant to replicate by-hand hydrograph separation. This program, previously known as BFLOW, was found to be the most appropriate (Bellamy et al. 2003) and has been selected as the optimum baseflow 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 baseflow estimates. Recognizing the uncertainty in estimated groundwater discharge rates, the calibration approach utilized a range in baseflow estimates, as opposed to a single value.

4.1.2 Hydraulic Head Data Set

In calibrating a groundwater model, observed water levels are used for the entire Study Area, as long as those wells are reported to be of good reliability. Their locations, elevation and construction details should generally be known with a high level of confidence.

The goals for establishing a calibration data set for this model were as follows:

- Identify and use wells that have location and elevation reliabilities that are considered acceptable as a standard data set

- Identify and use groundwater level targets from wells that reflect the temporal calibration pumping conditions
- Identify and weigh 'High Quality' calibration targets
- Achieve a spatial distribution of calibration targets that adequately covers the entire model domain

After a dataset has been established, each calibration point will be assigned to the appropriate model layer based on the hydrostratigraphic unit across which the well is screened.

A total of 2260 well water levels (obtained from the MOE WWIS) distributed across the entire Study Area was used to calibrate the steady-state model. All data from those wells are considered to be of acceptable reliability (UTM reliability codes less than 5), and range from 1980-2010. Map 4.1 illustrates the boreholes within the Study Area. These static water level observations offer the significant benefit of having model calibration targets that extend across the entire model domain, however, there can be high uncertainty associated with the individual observations. These uncertainties arise from errors in the reported location of the wells and the measurement techniques used were not designed to provide reliable scientific information. As a result, the MOE water well records were used to calibrate the model and identify regional trends in observations however they were not considered to be accurate indicators of an exact water level at a discrete location in the present day.

4.1.3 High Quality Datasets

Equipotential Surface Review Wells

A subset of high quality water levels were also selected for calibration targets, as indicated in Map 4.1 and Map 4.2. This high quality dataset of observed water levels was extracted from a concurrent study conducted by Golder (2009) to more accurately map flow directions in the immediate vicinity of municipal production wells throughout South Simcoe County, and therefore were weighted higher than the remainder of the total water levels within the calibration process. Within the Golder studies, this well data was reviewed and deemed of higher quality when 1) the elevation and locations were verified with GPS/Land Survey and 2) the water levels were assessed or measured by a professional geoscientist. In most cases, this led to water levels measured or verified for the purpose of other groundwater studies being assigned as high quality.

City of Barrie Monitoring Well Network

Because this project focuses on local area risk, high quality wells within the Focus Area were given priority consideration throughout calibration of the model. These wells consist of regularly-monitored test or sentinel wells as well as municipal pumping wells and are shown on Map 4.2, as these wells have a time series of water levels, from which average values can be inferred.

4.1.4 Transient Calibration Dataset

An important component of calibration in the Tier Three review is the consideration of transient conditions. The transient calibration builds upon the insights gained in the steady-state calibration with the goal of refining model parameters local to the well field. Such refinement provides more reliable prediction of well sustainability (drawdown) and potential interference with other wells and/or surface water bodies. Calibration to transient hydraulic responses facilitates refinement of model storage parameters as well as hydraulic conductivity. The transient data provides an additional important constraint on the analysis and can greatly enhance the understanding of lateral and vertical aquifer interconnections.

The final stage in the calibration process was to run the groundwater model transiently between 1997 and 2010. The calibration targets include the high quality wells outlined in Section 4.1.3 above, and they are also illustrated on Map 4.2.

4.1.5 Calibration Measures

To ensure that the model reflects observed conditions, the simulated conditions are compared with observed conditions, including water levels, baseflows and known discharge areas. Qualitative assessment of predicted and observed water levels can provide an assessment of the model calibration; however a quantitative assessment is usually also helpful. Quantitative measures of calibration are based on residual values (the difference between simulated and observed water levels at a point) and include:

- Residual mean (average of all residuals)
- Absolute residual mean (average of the absolute value of all residuals)
- Root mean squared error (square root of the sum of the squares for all residuals)
- Normalized root mean squared error (root mean squared error divided by model water level range)

For this modelling effort, the normalized root mean squared (NRMS) error and the absolute residual mean (ARM) error are considered the most important. The NRMS is used to evaluate the overall calibration of the model, while the ARM is used to evaluate the calibration in more localized areas, such as within the vicinity of the plume. The distribution of residuals (error between model and observed heads) should also be considered. The distribution of residuals presented as a histogram can show if there is a bias in the calculated heads, with the goal of having a bell-shaped distribution of residuals. Cumulative probability plots can show similar effects, indicating whether or not the majority of the residuals approximate a normal distribution, suggesting that the residuals are distributed randomly.

Given the expected end uses and our ability to characterize the groundwater flow system within the Study Area, a well calibrated model should exhibit the following traits:

- Normal distribution of residuals (difference between measured and observed groundwater levels) with the greatest number of residuals very close to 0 m.

- Normalized root mean squared error less than 5% for groundwater level residuals. This is common calibration target used in groundwater models and indicates a good match between observed and calculated water levels.

- Mean absolute error for groundwater level residuals for the different well fields to be less than 5 to 10 m or within the range of annual groundwater fluctuations and measuring error for the different groundwater levels.

- Predicted equipotentials are similar to equipotential maps generated using monitored data with similar flow directions and gradients where high quality information is available.

- Discrepancies between model predicted and field estimated baseflows to be within a factor of two of each other.

- Transient hydrographs comparing both the observed temporal water levels and simulated temporal water levels to ensure response due to changes in pumping and/or recharge are reflected within the model.

5.0 CALIBRATION RESULTS

5.1 Quantitative Assessment

5.1.1 Calibration to Baseflow Estimates

Streamflow records within the 1980-2009 periods were used from 3 gauges operated by Water Survey of Canada (WSC). Recognizing the uncertainty in estimated groundwater discharge rates, the calibration approach utilized a range in baseflow estimates, as opposed to a single value. The high and low baseflow estimates from the baseflow separation analysis were used as a target range for model calibration, expressed as average annual baseflow estimates over the 1980-2009 period.

It is important to note that whereas baseflow separation routines may separate quick stream response from slow stream response, the association of baseflow to groundwater discharge is not absolute. Baseflow is the release of water from storage contained within the upstream drainage area that drains to a particular stream gauge. This water released from storage could originate in aquifers, and hence is termed groundwater discharge, but also could originate from wetlands or reservoirs. Other anthropogenic impacts such as sewage treatment plant discharges or water diversions may contribute a portion of baseflow as well. Recognizing this, as well as the effects of natural seasonal and climatic variability, there is a higher degree of uncertainty associated with baseflow calibration targets. Regardless, for this study it has been assumed that baseflow predominately represents groundwater discharge within the Study Area, and that baseflow estimates are appropriate calibration targets.

The match between observed and simulated baseflow is presented in Figure 5.1. Simulated baseflow from the steady-state groundwater-flow model is calculated by adding up the total groundwater discharge to stream boundary conditions for all calculation locations upstream of the observed location (i.e., stream gauge). The stations are listed from left to right in order of the relative groundwater discharge, with those on the left representing headwater streams and those on the right representing major river segments.

Care was taken to match simulated and observed discharge wherever possible. In general, the fit to observed flows along large stream reaches is considered good, the baseflows are within the same order of magnitude as the observed values. Predicted baseflows in Willow Creek are slightly underestimated, most likely due to uncertainty in the thick shallow aquifer system in the Upland regions to the east. It is not likely that the mismatch between observed and simulated baseflows is due to local numerical errors in the flows calculated with the groundwater flow model. Numerical errors within the code are minimal at the scale of baseflow under examination (and if they were present to a large degree, it would be more obvious in a stream of smaller flow volumes, such as Lovers Creek, rather than a large catchment such as Willow Creek). It is more likely that the mismatches are due to limitations of the present understanding of the groundwater flow system, in particular uncertainties in the representation of the water table within the upland regions of the Oro Moraine. Recognizing the uncertainty associated with the baseflow calibration target values, the overall match to observed baseflow is considered reasonable and this suggests that estimated recharge rates are of a reasonable magnitude.

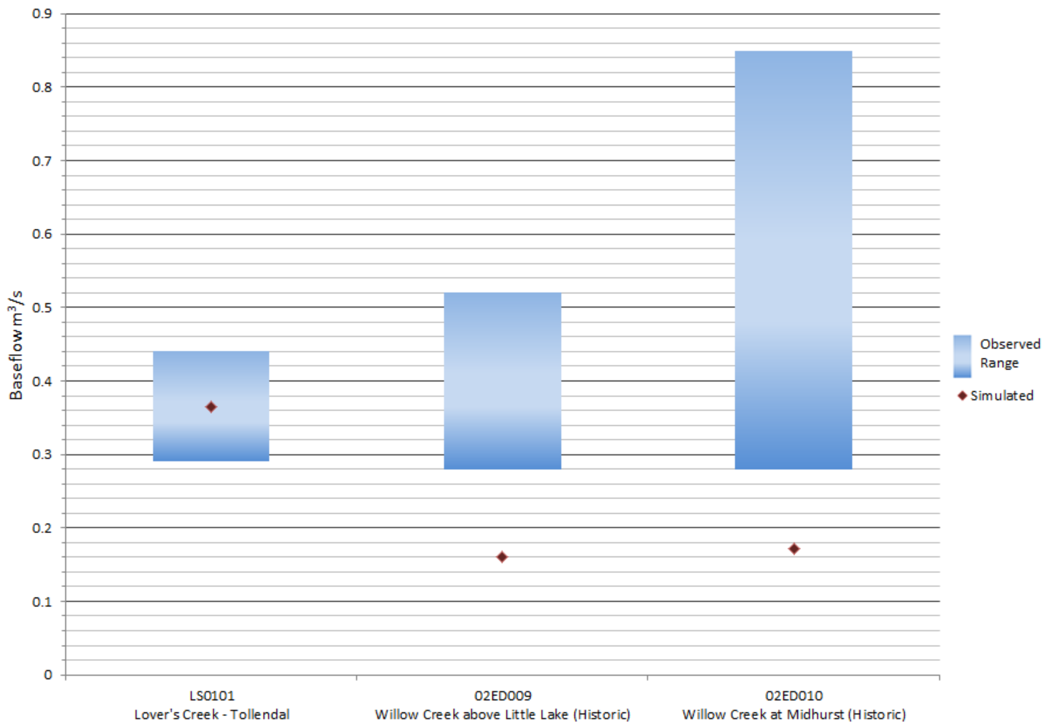

FIGURE 5.1 Comparison of Simulated and Observed Baseflow (m^3/s) for 1980-2010

5.1.2 Calibration to Hydraulic Heads

Figure 5.2 presents the scatter plot of observed and simulated hydraulic heads for the calibration target points. Good agreement between simulated and observed water levels was achieved. Although some small local trends can be seen, calculated water levels appear to be scattered randomly about the line of perfect fit. This distribution suggests that there is no large systematic bias in the model results. This regional match of observed and simulated water levels suggests that the numerical model represents the regional scale groundwater flow pattern to an acceptable degree. Calibration statistics for the hydraulic head calibration measures are further explained below.

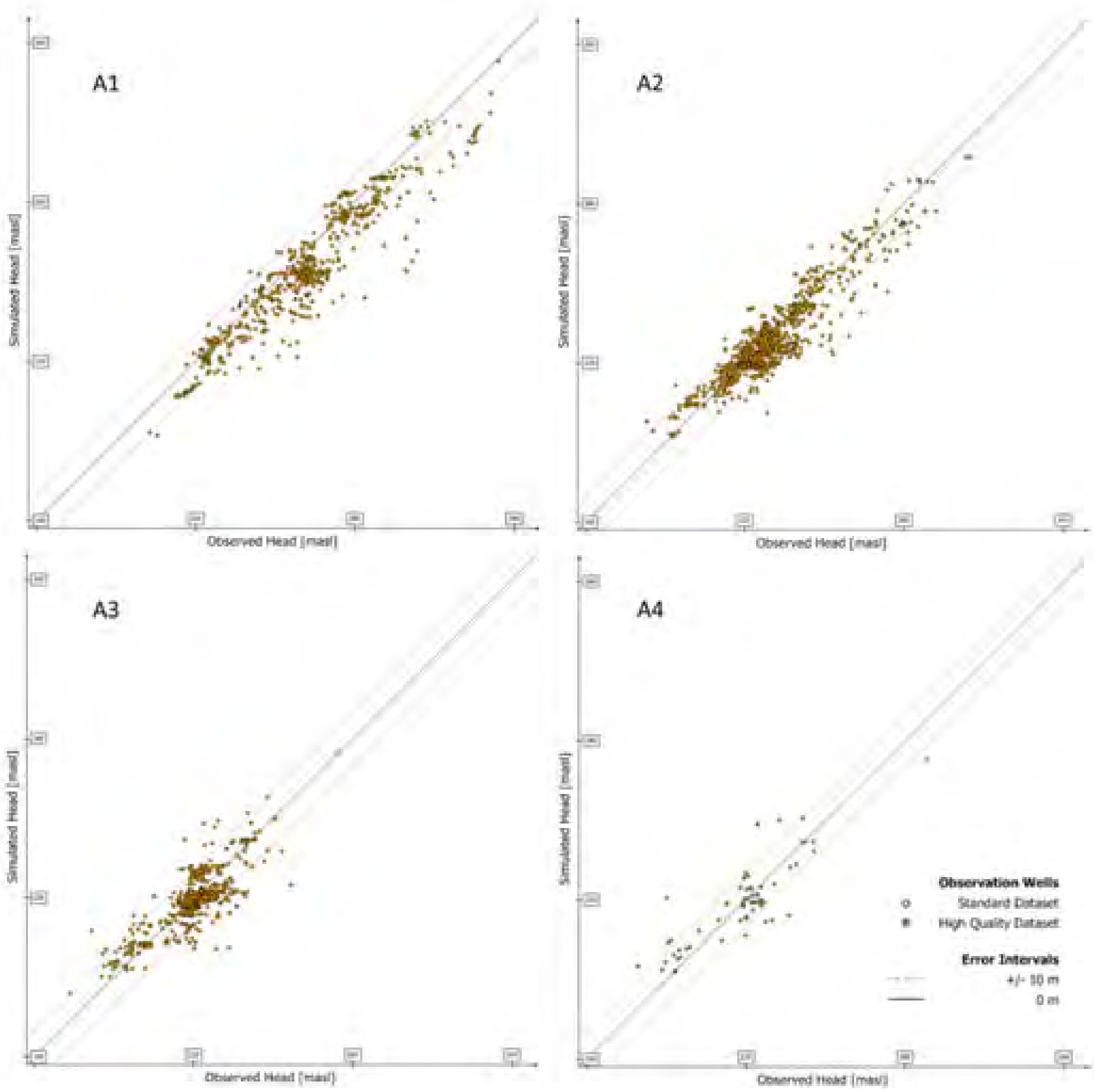

FIGURE 5.2 Scatter Plot of Calibration Residuals by Aquifer

Normalized root mean squared (NRMS) error = 3.6%. This percentage value allows the goodness-of-fit in one model to be compared to another, regardless of the scale of the model. This percentage value allows the goodness-of-fit in one model to be compared with another model, regardless of the scale. Typically, a model is considered representative with a 10% NRMS (Spitz and Moreno, 1996); however, the NRMS error is dependent on the range of observed water levels.

Root mean squared (RMS) error = 7.8 m. The RMS is similar to a standard deviation, providing a measure of the degree of scatter about the 1:1 best-fit line. The measure indicates that the majority statistical population of predicted water levels would fall within 7.8 m of the observed value. An error of ±5 m is generally accepted, in our experience, to be inherent in the use of water well record data, reflecting inaccuracies in well elevation and measurements. Additional error stems from the simplified representation of local flow conditions, particularly outside of the Focus Area (i.e. Alcona area) that were not a particular focus for the calibration efforts.

Mean Error = -2.2 m. The mean error is a measure of whether, on average, predicted water levels are higher or lower than those observed (ideally it should be close to 0). This statistic indicates that on average, the simulated water levels are low by 0.42 m, indicating that a good balance has been achieved between water levels higher and lower than simulated. This further indicates that the regional trends in water levels are well simulated.

Mean Absolute Error = 5.7 m. The mean absolute error is a measure of the average deviation between observed and simulated water levels. The mean absolute error of 5.3 m is less than the population statistic (RMS). An error of ±5 m is generally accepted to be inherent in the use of water well record data, reflecting inaccuracies in well elevation and measurements. Consequently the value achieved within this model is only marginally above the expected noise in the data.

As previously discussed, calibration efforts were focused on the Well Field Focus Area, and particular attention was paid to the high quality monitoring wells mentioned within Section 4.1.3. Within the Focus Area, the statistics described above show that the simulated groundwater flow levels are reasonably reflecting observed data. Considering only the high quality dataset, the calibration statistics are as follows: RMS = 4.1 m, ME = -1.8 m, and MAE = 3.5 m. The range and magnitude of error within the higher reliability wells is much smaller than with the standard data set which incorporates all observed data, including the high reliability wells.

Map 5.1 illustrates the spatial distribution of calibration residuals (simulated - observed hydraulic head) match between the observed and calculated hydraulic head measurements for all water level calibration targets. As this figure illustrates, the residual values are scattered about the simulated values. Where oppositely coloured symbols are next to one another, this reflects the uncertainty in the underlying data, whereas areas with local trends indicate that local conditions are not well represented. Within the Focus Area, trends have been removed through the steady state calibration. Small pockets of trends outside of the focus area remain and are generally located within the unsaturated, upland areas where the simulated water table is approximate, and perched water table systems are not represented within the model. Because of the thickness of the upper aquifer, it is difficult to achieve the level of vertical refinement (i.e., more layers) that is necessary for a more realistic approach to estimating the water table location within unsaturated flow modeling while remaining to be practical on a regional level for stress assessment purposes.

In the case where a perched water table was suspected, observed water levels were compared spatially with regards to one another in order to confirm the presence of the perched system. Data points that were confirmed to be within a perched system, either from local knowledge or because of stark contrasts between water elevation depths within the shallow system within a relatively small area, were included in Map 5.1 for visualization purposes, but were removed from the statistical calculations.

Within the Focus Area, care was taken to prioritize the City of Barrie monitoring network as a local calibration target. Because water levels from the WWIS system are taken from a discrete point in time which may not correspond with the pumping rates (2008), these targets were replaced with a range and a typical value for calibration purposes. These wells are considered a more reliable data source than the MOE static water levels and as such, the model calibration focused on fitting the model predicted heads within the range of observed values. The typical observed value, Do, was derived from the transient water level data which included 1997-2010. Water levels were taken, targeting the 2008-2009 range, where available, during pumping conditions. These values, as well as the simulated water levels for these wells, are shown (Do) in Table 5.1. This table represents a subset of high quality wells where water levels (static from time of drilling) from the WWIS dataset were updated with SCADA data.

TABLE 5.1 City of Barrie Monitoring Network and Pumping Wells - Water Levels

Well Name	Paired With	MOE	Depth to WL (m)			Ds Do (m)	Date Range/Comments
			Simulated (Ds)	Typical Obs. (Do)	Obs. Range		
TW9/59	Well 4	5700248	7.8	11.0	5.4-18.4	-5.7	2008-2009
TW1/60	Well 5	5700253	15.2	14.0	12.0-16.0	1.2	2008-2009
Well_5		5700271	15.5	15.9	11.9-17.9	-0.4	2008-2009
Well_6		5706146	12.8	10.8	6.8-16.8	2.0	2008-2009
Well_7		5709125	18.1	18.1	14.1-21.1	0.0	2008-2009
TW1/74	Well 10	5711576	24.4	27.2	25.2-32.2	-2.8	2008-2009, observed water levels range from 19 m to 27 m depth
Well_8		5711799	9.2	6.3	3.3-30.3	3.0	1991-2001 Non pumping used, no data after Jan 01
TW1/75	Well 9	5712119	39.1	34.0	29.0-34.0	5.1	1997-2004, No Data after Jan 03, Value picked from earlier years due to decreasing well quality
Well_9		5712496	39.7	39.3	29.3-40.3	0.4	1997-2007 Used, No data after April 2007
Well_10		5714078	26.5	33	23.0-55.0	0.5	2008
Well_12		5717393	3.7	6.8	1.8-21.8	-3.1	2008-2009, wide spread in data
TW1/81	Well 12	5717394	3.7	6.4	1.4-9.4	-2.7	2008-2009
TW1/83	Well 11	5718640	10.1	8.1	3.1-11.1	1.9	2008-2009, wide spread in data
Well_11		5719264	11.9	8.2	5.3-30.3	3.8	2008-2009, wide spread in data
TW3/88	Well 13	5723009	39.6	34.3	29.3-38.3	5.3	2008-2009
TW1/91	Well 3A	5728346	8.6	9.6	7.6-19.6	-1.0	2008-2009
Well_4		DHL0195	11.1	12.0	5.0-18.0	-0.8	2008-2009
Well_17		5737406	18.0	17.0	7.0-25.0	1.0	2008-2009
Well_18		5739442	17.0	16.5	12.5-24.5	0.5	2008-2009
Well_3A		5732108	11.6	19.8	7.8-39.8	-8.2	2008-2009
Well_16		5733545	31.3	26.6	17.6-31.6	4.6	2008-2009
Well_15		5728705	4.4	10.4	0.4-12.4	-6.0	2008-2009
Well_14		5727877	8.0	13.0	-2.0-23.0	-5.0	2008-2009
Well_13		5724686	40.1	44.3	26.3-45.3	-4.2	2009
TW2/60	Well 8	5700255	9.1	6.0	2.0-17.0	3.1	1997-2001 used but corresponds to replacement well TW4/72
TW2/66	Well 6	5700287	13.8	10.0	7.0-15.0	3.8	2008-2009
TW3/60	Well 7	5701702	18.0	16.0	13.0-19.0	2.0	2008-2009

Well Name	Paired With	MOE	Depth to WL (m)			Ds-Do	Date Range/Comments
TW3/81	Well 15	5717579	3.4	7.9	0.9-9.9	-4.5	2008-2009
TW3/90	Well 14	5727319	6.6	5.6	3.6-10.6	1.0	2008-2009
TW2/95	Well 16	5732632	30.6	25.6	18.6-28.6	5.0	2008-2009
TW1/02	Well 17 18	5736793	18.9	16.5	13.5-23.5	2.4	2008-2009
TW2/02	Well 17 18	5736794	17.4	17.0	15.0-22.0	0.4	2008-2009

The observed water levels were loosely compared to the typical measured value throughout the calibration. Overall, the comparison (Ds-Do) in Table 5.1 produced satisfactory results, such that the simulated water level was within the range of observed water levels. However, many of the wells had a wide range in observed water levels throughout the time period (1997-2010) due to changes in pumping conditions (including decreased pumping or non-pumping conditions). Therefore, it is also useful to compare the calculated water levels to the entire range. Figure 5.3 is a graph that illustrates the range in observed water levels within the high quality monitoring wells within the Study Area. As the figure illustrates, the model is predicting heads for most wells that lie within the range of the observed water levels or within an acceptable margin of error (1- 2 m), indicating the model is well calibrated to this dataset. A discrepancy of 1 to 2 m was considered acceptable because there may be discrepancies in the reference elevation (stick up, concrete pad, ground elevations) from which water levels are taken. One exception to the well matched simulated heads is Well 1/75. In this case, the well was decommissioned in 2003, while the steady state model uses 2009 pumping rates. Therefore, the observed hydrograph for Well 1/75 is not representative of current conditions.

Some monitoring wells exhibit a large range of observed water levels and this is due to their close proximity to the municipal pumping wells, which turn on and off at different times. Some pumping wells also exhibit a large range, in particular, wells 3A, 10, 11 and 14, all of which have experience some declining well performance and rehabilitation during the observed time range (1997-2010).

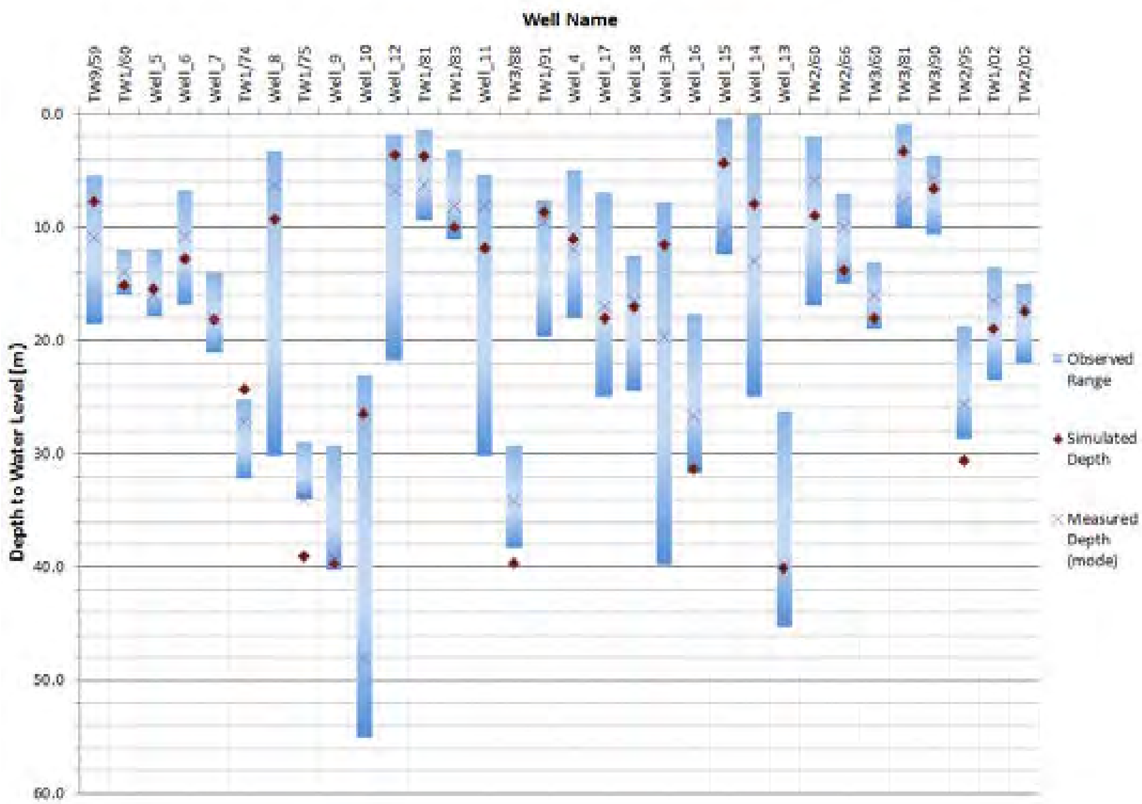

FIGURE 5.3 Calculated Vs. Observed Range of Head within the City of Barrie Monitoring Network

A cumulative probability distribution of the model results is show in Figure 5.4. The residuals approximate closely a straight line on the normal distribution plot. This confirms that the local mismatches between the observed data and the model are random, and that there is no systematic bias in the model results. Spitz and Moreno (1996) and Hill (1998) suggest that the residuals from a calibration should be normally distributed, with a mean of zero. This infers that the largest portion of the residuals plotted on a probability plot should approximate a straight line, with the residual corresponding to 50% close to zero (Neville pers. comm. 2011). The results from the model calibration satisfy this criterion.

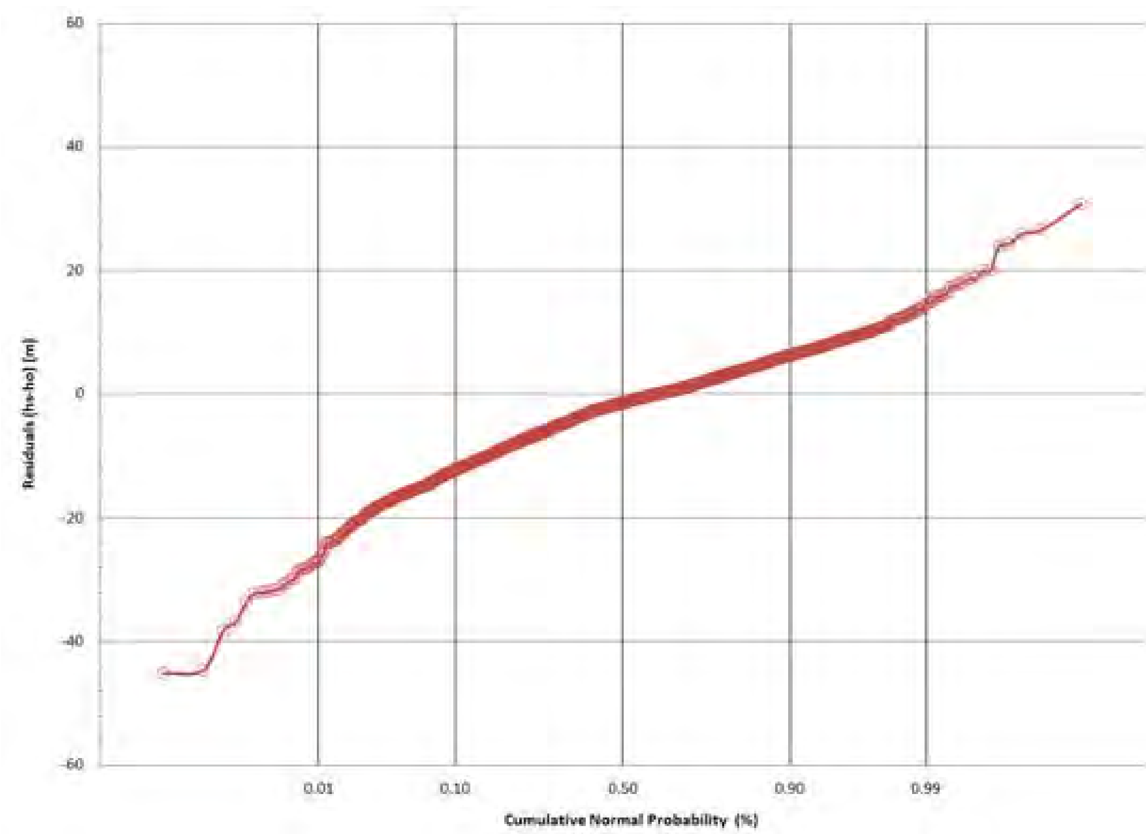

FIGURE 5.4 Cumulative Probability Distribution Plot

5.1.3 Transient Calibration Results

As noted above, the high quality monitoring wells within the City of Barrie were used to examine the model's ability to simulate the groundwater system's response to municipal pumping. Figures C.5.1 to C.5.13 in Appendix C3 illustrate the results of the long term (1997-2010) model simulation, in terms of relative drawdown. There is good agreement between the observed and model predicted heads for the majority of the wells examined in the calibration, particularly to the maximum water levels in the observation data. Some of the municipal wells have observed water level fluctuations that are greater than the water level fluctuations predicted by the model. This is attributed to the averaging of municipal pumping rates over the monthly stress periods; the average monthly pumping rates produce model predicted water levels that are dampened when compared to observed water levels. Additionally, this appears to be the case in wells known to have been rehabilitated throughout the calibration period, as these wells have a history of poor performance. In the case of poor well performance, minimum observed water levels cannot be reproduced within the model. Finally, when calibrating a model to two wells located very close together who exhibit different magnitudes of response, a compromise must be made to optimize the goodness of fit to the hydrographs of both wells.

City Core Wells (Wells 3A, 4, 5, 7, 17 and 18)

The model predicted (line) and observed drawdown levels (points) reported in monitoring well TW1/91 and Well 3A are presented on Figure C.5.1. The monitoring well lies 14 m south of Well 3A. While the observed water levels of the pumping well vary approximately 30 m over the period of analysis (1997-

2010), the observed water levels of the test wells vary approximately 8 m. The simulated drawdown shows an excellent match to the observed drawdown in the test wells, mimicking observed highs and lows. The pumping well, which has experienced some decline in performance (See Conceptual Understanding Report, Section 3.2.4), shows a good match between the simulated and observed drawdown; however, some well loss and extreme highs and lows are unaccounted for within the model.

The model predicted (line) and observed drawdown levels (points) reported in monitoring well TW9/59 and Well 4 are presented on Figure C.5.2. The monitoring well lies 40 m south of Well 4. Both the test well and the pumping well show a data spread of about 10 m. The simulated drawdown shows a good match to the observed drawdown in the test wells, mimicking observed highs and lows. The pumping well shows a reasonable match between the simulated and observed drawdown. The extreme high and low measurements are unaccounted for within the model; however, these points represent a very small population of the dataset.

The model predicted (line) and observed drawdown levels (points) reported in monitoring well TW1/60 and Well 5 are presented on Figure C.5.3. The monitoring well lies 10 m east of Well 5. Both the observed water levels and the well water levels vary approximately 10 m over the period of analysis (1997-2010). The simulated water levels show a similar response to pumping as the observed water levels in the test wells.

The model predicted (line) and observed drawdown levels (points) reported in monitoring well TW3/60 and Well 7 are presented on Figure C.5.4. The monitoring well lies 7 m southwest of Well 7. Similar to wells TW1/60 and Well 5, the observed drawdown of both wells varies approximately 10 m over the period of analysis (1997-2010). The simulated drawdown shows a similar response to pumping as the observed drawdown in the test wells.

The model predicted (line) and observed drawdown levels (points) in monitoring wells TW1/02, TW2/02, Well 17 and Well 18 are presented on Figure C.5.5a and C.5.5b. While the observed drawdown of both pumping wells varies approximately 10 m over the period of analysis (1997-2010), the observed drawdown of the test wells vary approximately 6 m. The simulated drawdown shows a good match to the observed drawdown in the test wells. The extreme high and low data points have not been well matched, but these represent a relatively small population of the actual data, which means they are discrete, very local responses unable to be accounted for by the model.

Well 6 (Figure C.5.6) was also simulated until its shutdown in 2001. The results show a good match with observed response to pumping as well as the shutdown in 2001.

Lakeshore Wells (Well 8, Wells 11/14, Well 12, and Well 15)

The model predicted (line) and observed drawdown levels (points) reported in monitoring well TW 1/83, TW3/90, Well 11 and Well 14 are presented on Figures C.5.8a and C.5.8b. TW1/83 is 3 m northeast of Well 11, and TW3/90 is 25 m southeast of Well 14. The observed drawdown of the pumping wells vary greatly, with a wide spread in data due to well loss, declining well performance (see Conceptual Understanding Report, Section 3.2.4), and very local drawdown. As a result, both wells have been rehabilitated several times, and Well 11 has been offline since 2009. As a result, calibration focused on the response of the test wells nearby. The drawdown trends in the observed water levels are represented quite well by the model.

The model predicted (line) and observed drawdown levels (points) reported in monitoring well TW1/81 and Well 12 are presented on Figure C.5.9. The monitoring well lies 7 m southwest of Well 12. While the observed drawdown of the pumping well vary approximately 20 m over the period of analysis (1997-2010), the observed drawdown of the test wells vary approximately 6 m. The simulated drawdown shows an excellent match to the observed responses in the test wells, mimicking observed highs and lows. In the pumping well, the high and low water levels have not been well matched.

The model predicted (line) and observed drawdown levels (points) reported in monitoring well TW3/81and Well 15 are presented on Figure C.5.10. The monitoring well lies 7 m southwest of Well 15. While the observed water levels of the pumping well vary approximately 20 m over the period of analysis (1997-2010), the observed water levels of the test wells vary approximately 10 m. The simulated drawdown shows a good match to the observed response in the test wells, mimicking general trends.

Well 8 (Figure C.5.11) was also simulated, and water levels were compared for both the pumping well and its paired monitoring well, TW2/60. The results show a well matched seasonal response until the wells were decommissioned in 2001; however, the minimum water levels have not been represented adequately within the model. Well 8 was decommissioned due to poor well operating conditions, it has been assumed that the poor match can be attributed to this.

Barrie South (Well 10)

Although Well 10 has been decommissioned, effort was made to also calibrate the model to its water levels throughout the time period. The model predicted (line) and observed drawdown levels (points) reported in monitoring well TW1/74 and Well 10 are presented on Figure C.5.12. The monitoring well lies14 m north of Well 10, and the water levels vary approximately 10 m over the period of analysis (1997-2010). The simulated drawdown shows an excellent match to the observed responses at TW1/74; however, the magnitude of the response is overestimated. Well 10 presents two distinct ranges for depths – with a wide range between them of approximately 20 m. The upper range was asserted to be appropriate for calibration, because of its correspondence to the water levels found in the monitoring well, TW1/74.

Barrie North (Wells 9/13 and Well 16)

The model predicted (line) and observed drawdown levels (points) reported in monitoring wells TW1/75, TW3/88, Well 9 and Well 13 are presented on Figure C.5.7. TW1/75 is approximately 10 m southwest of Well 9, and TW3/88 is approximately 10 m south of Well 13. The monitoring data for both pumping wells show two distinct groupings which appear to relate to pumping and non-pumping conditions. The model was calibrated to the water levels measured during pumping conditions, which also correlate to the trends and values of the water levels of the test wells, which are close by and screened within the same aquifer. The response trends in the observed drawdown are well represented within the model.

The model predicted (line) and observed drawdown levels (points) reported Well 16 is presented on Figure C.5.13. Well 16, which did not begin pumping until 2000, shows observed water levels with a range of 10 m. The model simulated water levels for both wells show a good match to the observed relative water level and there were excellent matches to observed lows.

5.2 Qualitative Assessment

The following sections outline the qualitative measures used to assess the model calibration. Models are non-unique and as such, field based parameter values are beneficial to assess the reasonableness of the input parameters. In addition, model-predicted water levels are compared and contrasted with the observed water level maps produced by contouring the water levels reported in the MOE water wells and the available higher quality data sets.

The following section outlines final model parameters within the municipal aquifer, as well as the model predicted water levels in the shallow (A1) and deep (A3) systems across the Study Area. These maps are compared and contrasted with the observed water level maps produced by contouring the water levels reported in the MOE water wells, as well as the City of Barrie high quality monitoring wells.

5.1 Model Input Parameters

Most of the wells are simulated in the model to be drawing from permeable sand, gravel and cobble units that lie within buried channel sediments. The hydraulic conductivity and transmissivity values of the sediment within the municipal aquifer material do not vary widely. Table 5.2 shows that the modelled transmissivity values are consistent with range of values determined from pumping tests referenced. Calibrated model conductivity in general was calibrated to be slightly higher than field based data; the small discrepancy comes from two sources. One, the model is calibrated on a zone basis, which applied an average K rather than a localized K. Second, model layers will always be more generalized than what is found in the field. Modelled Conductivity can be seen on Maps 5.2 to 5.5 for each aquifer unit.

Table 5.2: Modelled and Field-Based Bedrock Conductivity and Transmissivity Values

Name	Field Measured		Modelled	
	T (m^2/s)	K (m/s)	T (m^2/s)	K (m/s)
Well No. 3A	3.3E-02	1.45E-03	2.8E-02	1.60E-03
Well No. 4	1.4E-02	9.03E-04	1.8E-02	3.50E-03
Well No. 5	2.5E-02	6.60E-04	9.4E-03	1.60E-03
Well No. 7	3.9E-02	1.45E-03	4.0E-03	1.23E-03
Well No. 9	2.9E-02	3.94E-04	1.5E-02	1.63E-03
Well No. 11	1.4E-02	4.24E-04	1.7E-02	3.50E-03
Well No. 12	1.2E-02	3.01E-04	1.3E-03	1.60E-04
Well No. 13	3.0E-02	4.28E-04	1.8E-02	1.60E-03
Well No. 14	1.6E-02	5.63E-04	1.4E-03	1.61E-04
Well No. 15	2.1E-02	8.68E-04	9.3E-03	1.63E-03
Well No. 16	1.7E-02	7.75E-04	4.3E-03	5.02E-04
Well No. 17	2.9E-02	6.71E-04	8.2E-03	1.63E-03
Well No. 18	3.2E-02	7.35E-04	9.5E-03	1.63E-03

5.2.1 Simulated Shallow Aquifer (A1) Equipotential Contours

Map 5.6 illustrates the predicted water level contours produced in the steady state groundwater flow model. As illustrated on the figure, water table contours generally mimic the ground surface topography, and flow converges towards the higher order streams and wetlands. The groundwater elevation contours compare well with the observed water level contours illustrated on Map 4.3, in the Conceptual Understanding Report, in that flow gradients both in terms of direction and magnitude are similar, especially considering flow driven towards the Barrie city core. There are some local differences, the shape of the contour intervals within the simulated water levels are much smoother, indicating that there is local characterization that has not been captured, particularly in the highest areas of the Oro Moraine, and an area along Banks Creek south of Stroud.

The largest gradients (tightly spaced contours) are observed at regional discharge locations, which include the Nottawasaga River, the steep topography around Little Lake and along the flanks of upland regions. The lowest gradients are observed within the Minesing Wetland as well as in the flat regions within the centre of upland areas.

5.2.2 Simulated Deep Aquifer (A3) Equipotential Contours

Map 5.7 illustrates the deep aquifer water level elevation contours within the Study Area. The water level contours are similar to the shallow water levels however the deep water levels exhibit a more subdued expression. The water level contours converge within the bedrock valley associated with the modern day Nottawasaga River, and on regional groundwater discharge features such as Kempenfelt Bay. Flow is noted to be influenced by the Nottawasaga and the Minesing wetland complex where there is a hydraulic connection with the deeper system. As with the shallow system, although the simulated equipotentials reflect the same flow gradients as the observed equipotentials, some local features within the simulated results are absent.

5.2.3 Vertical Hydraulic Gradient

Map 5.8 illustrates the direction of the simulated vertical hydraulic gradient across the Study Area, calculated as the difference between the water table elevation surface and deep potentiometric surface. The map is shaded to show the upwards (blue) and downwards (green) gradients. Upwards gradients are predicted to exist along the Nottawasaga River and its tributaries and some wetland complexes; a reflection of groundwater discharge to those areas. The largest areas of groundwater discharge are in portions of the Minesing Swamp, consistent with the existing knowledge of the wetland, as well as Little Lake and Lake Simcoe. The highest downwards gradients are present along the crest of the Oro Moraine and along the flanks of the upland areas on either side of the Barrie city core where shallow overburden groundwater recharges the underlying aquifers.

5.2.4 Groundwater Discharge to Surface Water

Map 5.9 illustrates the location and magnitude of the simulated groundwater discharge zones along creeks and rivers incorporated within the groundwater flow model. On this figure, the darkest blue circles represent the river reaches with the largest groundwater discharge. Conversely, water shown in pink on the figure is simulated as recharging the groundwater system. These would be considered losing stream reaches. A comparison of the discharge mapping from the model with maps produced by the Fisheries Habitat Plan (NVCA and Fisheries and Oceans Canada 2009) and LSRCA (2010) shows that most coldwater and coolwater fishery stream reaches, both of which are known to be groundwater discharge areas, are well represented within the model. Some of the extreme upper reaches of the streams, particularly those close to or above the simulated water table, are not as well represented due to a lack of local refinement, especially in areas where the stream is thought to be fed by perched aquifer conditions. During the calibration process, stream segments that were simulated to be recharging the aquifer were compared to coldwater mapping and given a low conductance value, if warranted, such that the volume of water recharging along streams is minimal and does not negatively impact the overall water budget.

5.3 Overall Groundwater Model Calibration Assessment

The ability of the groundwater model to simulate the flow system in the Study Area was evaluated both qualitatively and quantitatively. Qualitatively, the simulated groundwater level contours and vertical hydraulic gradients are consistent with observed conditions. The elevations of regional wetlands were also overlain with model results to ensure modelled water levels were representative of these wetland elevations. Modelled stream discharge was compared to mapped coldwater regimes. Quantitatively, simulated hydraulic head and baseflow measurements closely match observed values within the acceptable statistical range, while reproducing observed flow directions and gradients. Regionally, the error based on the difference between observed and simulated water levels is minimized and there are no spatial trends in this error that are expected to impact predictions. Locally within the City, the simulated heads at most of the City's monitoring network were close to observed values and the model accurately predicts the flow system response to stresses due to pumping of the municipal aquifer. Model predicted groundwater levels over the 13 year period (1997-2010) are very similar to the measured hydraulic heads in monitoring wells over the same period within the city core suggest the model is well calibrated to transient conditions. And finally, simulated groundwater discharge rates agree favourably with a majority of the baseflow estimates.

The calibration was achieved using input parameter values that are within the expected range or measured range for the groundwater system in the area. Local knowledge of the Study Area was also beneficial in this regard, and helped guide the calibration effort. Overall, the calibration results show that the model is suitably calibrated for the Tier Three Assessment and that the Model can be used as a tool for prediction of groundwater flow directions and water quantity assessment.

6.0 GROUNDWATER FLOW MODEL LIMITATIONS

All models developed to represent natural systems are simplifications of the natural environment and the hydrologic processes within that environment. One can never understand all the complexities of the physical system to incorporate all details into a numerical context. In reality, most of the scientific approach involves representing physical conditions observed using approximations of larger-scale functionality; hydraulic conductivity is an example of this. This approximation does not negate the ability of scientists and practitioners to utilize numerical models as tools to help understand and manage natural systems; we do however need to recognize the limitations of such tools when interpreting model results.

Many elements of the groundwater modelling process using any modelling code are subject to uncertainty. Although the calibration process is performed in an attempt to provide a realistic representation of physical conditions and to reduce uncertainty, the model results and water budgets reflect the uncertainty in the model input parameters.

The following sections summarize some of the uncertainties associated with the modelling process and discuss some of the potential impacts of this uncertainty.

6.1 Scale

The groundwater flow model is designed to incorporate the key hydrogeologic features of the regional Study Area and localized features of the Focus Area around the City of Barrie well field. Thus the model has been designed to evaluate the flows through the system incorporating key identified features and characteristics as understood through the characterization process and through local experience. The implication is that features at a smaller scale may not be adequately represented outside of the Focus Area to support more local assessments and additional refinement and characterization is required to examine those areas. This is especially true for this Study Area, which contains several relatively small scale features such as sharp topographic changes, and numerous streams and wetlands.

6.2 Characterization Data

One uncertainty in groundwater models is the lack of high quality subsurface data. For this model, an attempt was made to reduce this uncertainly through the generation of hydraulic conductivity fields, based on the lithology recorded at individual boreholes and available aquifer testing data, combined with the development of a conceptual geologic model. However, very small scaled features within the shallow system of the upland areas are not well understood, as most hydrogeologic investigations within the Study Area focus on the deep aquifer system. This includes, but is not limited to, perched water table conditions. Properties within some of the confining aquitards are also not well known, and can only be inferred from borehole lithology or head differences across the layer, rather than hydraulic testing within that layer.

6.3 Calibration Data

The scale of the calibration effort is consistent with the scale of the model. The model was designed and calibrated to both regional-scale features that control groundwater flow at the subwatershed level, as well as local feature surrounding the municipal well fields. Accordingly, the calibration procedure implemented for this study grouped parameters spatially, and varied them in proportion to one another. During that procedure, calibration focused on spatial trends in observed water levels and discharge estimates. Calibration targets that included water levels reported in the MOE water well database and baseflow calibration targets, as discussed below:

- Water levels from MOE Water Well Records: In our experience, the expected range of uncertainty associated with water levels from water well records is on the order of 5 m. This is due to inaccurate water level measurements, inaccurate reference point elevations or measurements taken in poorly developed wells. This can include for example: variability of the water level relative to the time of measurement (i.e., seasonal or annual differences); measurement timing (i.e., levels may not have recovered to static conditions); measurement error or recording errors; well location errors; and measurement point elevation errors. Errors in elevations, either ground surface, screen information or water levels can also result in monitoring data being assigned erroneously to particular units. As a result, it is common to see scatter with this type of data, such that individual values have an associated degree of uncertainty, but the trends illustrated by multiple data points are expected to be realistic. Since natural fluctuations in groundwater levels are generally minor (~2 m or less where stress conditions are consistent), carefully measured water levels are considered to be more certain than most other calibration targets.

- Groundwater Discharge Estimates: Groundwater discharge is expected to be a component of the baseflow in most stream / river courses; the remainder of the baseflow is contributed from upstream wetland or other storage mechanisms. As the proportion of groundwater discharge to wetland discharge is rarely known, this is one source of uncertainty. Further, baseflow discharge is estimated using streamflow recession approaches which are empirical and interpretive. Further, baseflow estimates are generally determined from a limited time period of available streamflow record yet are assumed to be representative of an average “static” condition, although static baseflow conditions do not exist. The approximation from highly variable natural and seasonally fluctuating river conditions results in uncertainty such that calibration of groundwater discharge to baseflows is generally targeted to be within the range of observed baseflow estimates.

6.4 Limitations of the Modelling Approach

In addition to the characterization and calibration uncertainty, the numerical representation and simulation of groundwater flow systems also contains limitations. Model simulation uncertainty comes from both the approximate solution of the equations using the finite element method, as well as the limitations surrounding finite discretization and assumptions of steady-state.

- Galerkin Finite Element Solution: The Galerkin finite element method employed by FEFLOW solves the system of equations using an iterative solver that attempts to minimize the residuals globally; it is expected that some numerical error can exist internally within the model domain, although this is generally minor. Strict convergence criteria (i.e., 1e-3m) and water balance criteria (< 1% error) were applied to minimize residuals throughout the model.

- Finite Discretization: Practically, the solution of the equations is limited to calculation of groundwater head and flows at a finite number of points; the higher the number of points (smaller the elements), the more computer power and time needed. More precision is achieved when using a higher number of calculation points, particularly in areas of larger water level changes. With any scale of model, there is a balance between the level discretization (distance between calculation points) and the required computer power to efficiently run and calibrate the model (also financial budget). The practical limitation of discretization therefore presents some uncertainty in the water budget results. This limitation is especially important because it affects the majority of both the adjustable model parameters, as well as the trends in observed data, where many monitoring wells could be contained within one model element. In a model of this scale, balance needs to be struck between the level of detail needed, the data available, and the computational effort that is still needed to be practical for stress assessment purposes.

- Steady-State Solution: Similarly to the spatial discretization, the time discretization chosen for modelling affects the computer power and time (budget) required to calibrate and apply a numerical model. As a result, one simplifying assumption that is commonly made is that the groundwater flow system can be adequately represented using a steady-state simulation approach. Hydraulic stresses are often time-averaged and associated with water level targets averaged over the same temporal period. In addition, since groundwater systems respond at relatively slow rates (months, years, decades) particularly at the regional scale, a steady-state approximation is reasonable and provides general understanding. This assumption may however create differences between the simulated conditions and conditions observed in the field at any one particular time. For these reasons, transient simulations are conducted in an attempt to reduce uncertainty in hydraulic properties such as conductivity. However, this effort improves representation within the area local to the transient calibration wells (in this case, within the Focus Area) and outside of this region, uncertainty can still persist.

As noted above, there are a number of limitations in the numerical modelling process that lead to uncertainty in model predictions. The uncertainty due to the modelling process however, is considered to be relatively minor compared to the uncertainty in the physical characterization and calibration process. Overall, the discussed model limitations and uncertainty do not detract from using the numerical flow model developed for the stated objectives of the Tier Three Risk Assessment.

7.0 SUMMARY AND CONCLUSIONS

A FEFLOW groundwater flow model was developed for the Study Area. The model layers were developed from an established conceptual model that was based on deep borehole logs, and high quality logs reported in various hydrogeology studies completed within the Barrie area.

The model was calibrated using the recharge estimates provided by the calibrated Mike SHE surface water model. Both models were calibrated iteratively, so that they used the same information and could provide feedback from one model to the other. The model calibration focused on matching the range of observed water levels in 32 high quality monitoring wells, other high quality observation data that has been verified through other studies and to the static water levels reported in the MOE water well database. The model was also transiently calibrated to long term municipal pumping and observation data in the high quality monitoring data. The calibration results show that the model is well calibrated to current and historical conditions and is considered suitable for use in predictive scenarios. Knowledge of data gaps acquired through the model building and calibration process can be applied in an uncertainty assessment within the context of the predictive scenarios.

8.0 REFERENCES

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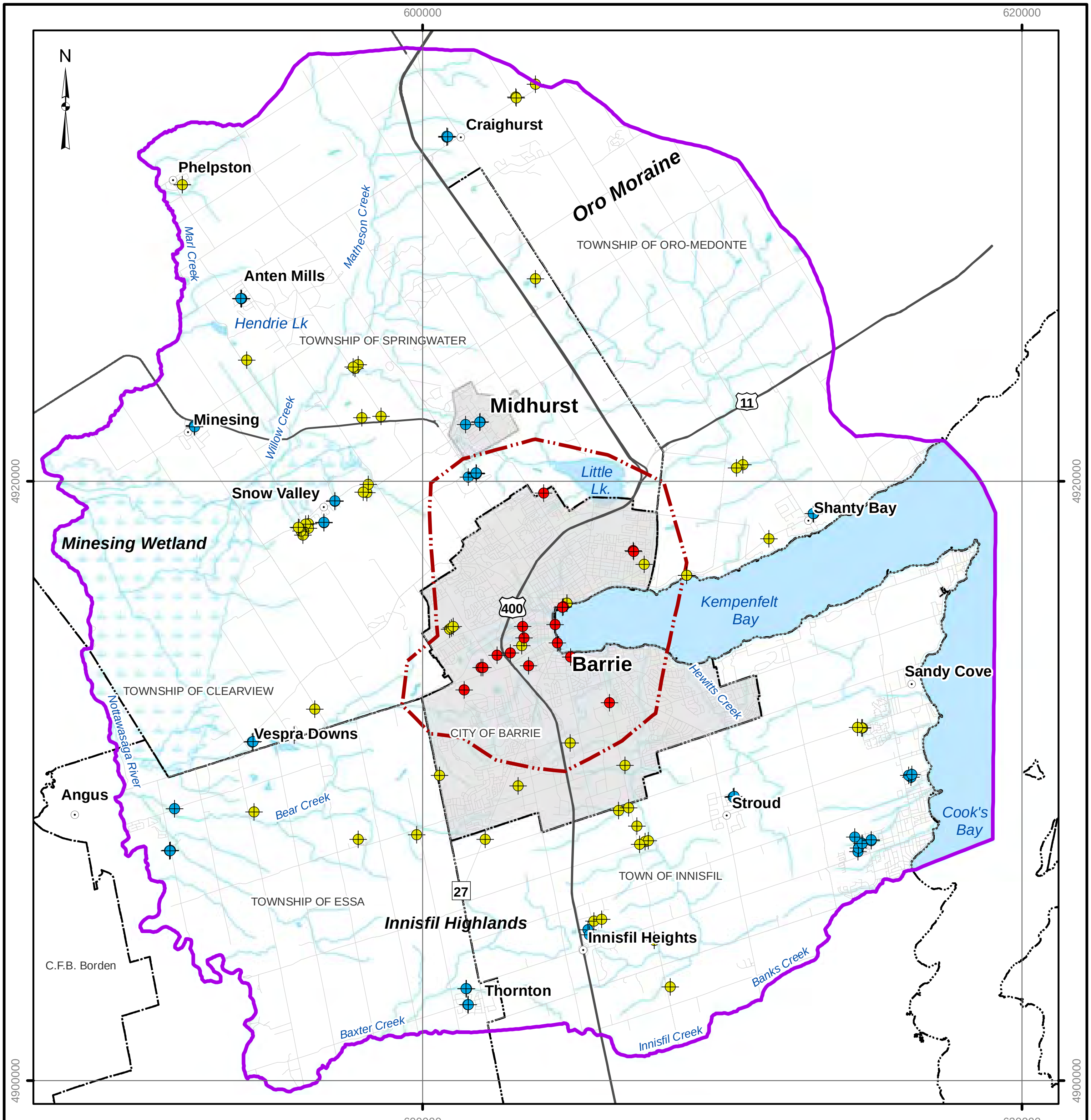
BARRIE TIER THREE WATER BUDGET AND

LOCAL AREA RISK ASSESSMENT

GROUNDWATER FLOW MODEL DEVELOPMENT

APPENDIX C1: MAPS



LEGEND

- Towns/Villages
- Barrie Municipal Wells
- Other Municipal Wells
- Private Permits
- Highways
- Roads
- River / Stream
- Open Water
- Barrie Tier 3 Boundary
- Focus Area
- Urban Centres
- Township Boundary

City of Barrie Tier 3 Water Budget and Local Area Risk Assessment Groundwater Flow Model

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Golder Associates

IWC International Water Consultants Ltd.

Map 1.1

Study Area

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: 12-Jun-2012; Created By: ccurry

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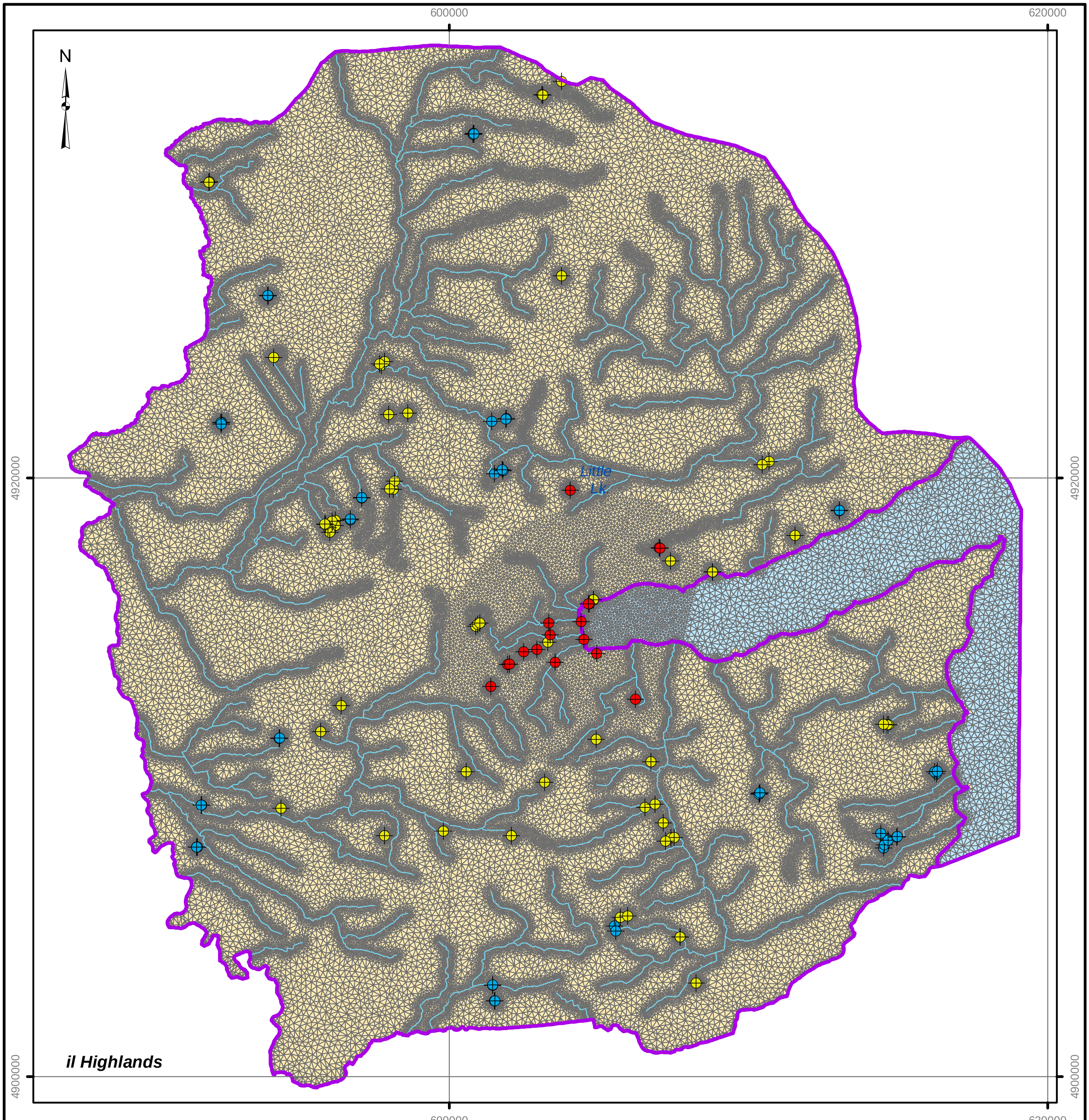
Kilometres



LEGEND

- Barrie Municipal Wells
- Other Municipal Wells
- Private Permits
- Barrie Tier 3 Boundary
- Finite Mesh
- Finite Mesh within Kempenfelt Bay

City of Barrie Tier 3 Water Budget and Local Area Risk Assessment Groundwater Flow Model

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IWC
International Water Consultants Ltd.

Map 3.1

2-D Finite Element Mesh

REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 18-Jun-2012; Created By: ccurry

Scale 1:180,000
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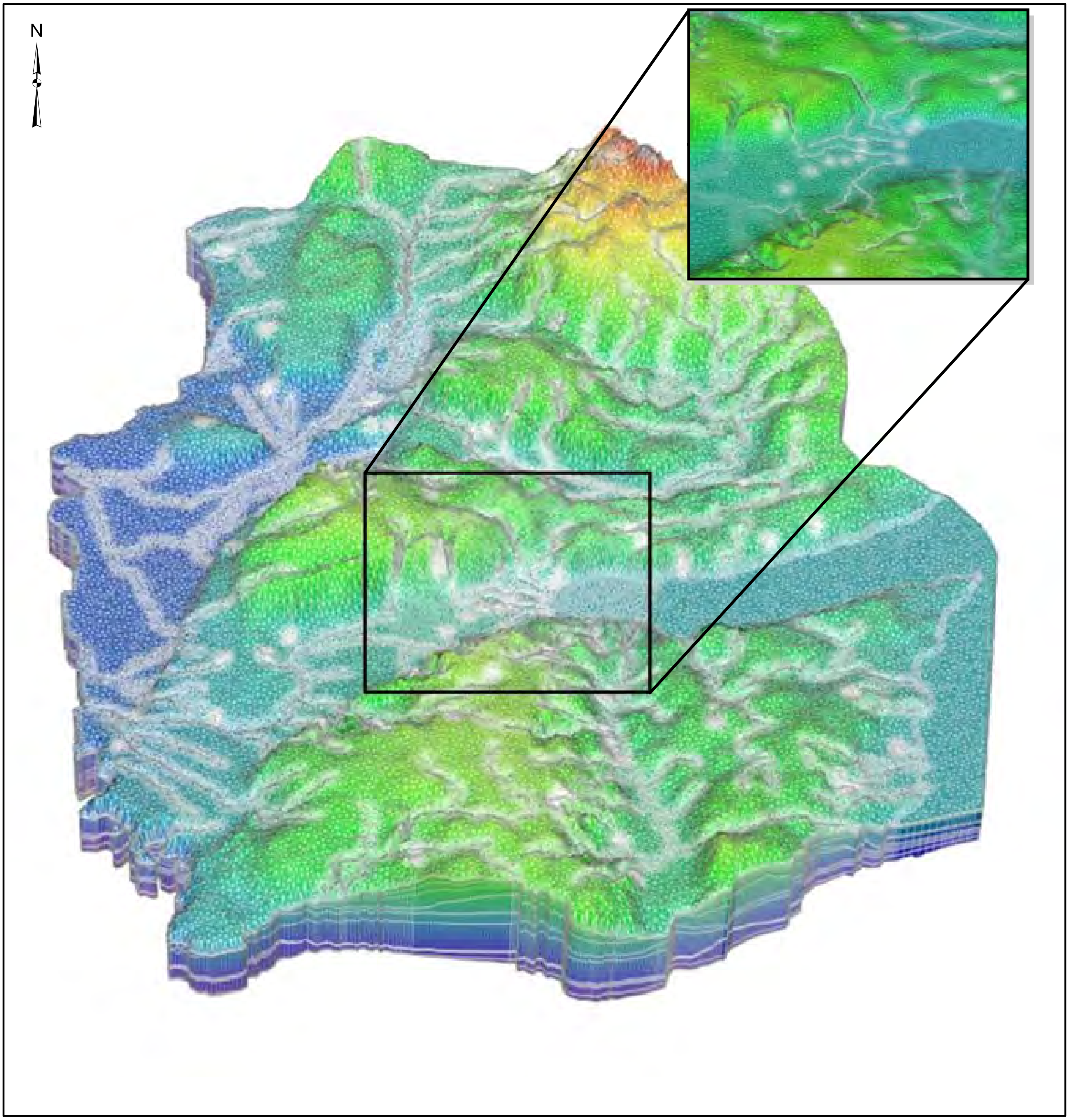
Kilometres



LEGEND

Elevation (masl)

- 400
- 370
- 340
- 310
- 280
- 250
- 220
- 190
- 160
- 130
- 100

City of Barrie Tier 3 Water Budget and Local Area Risk Assessment Groundwater Flow Model

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IWC
International Water Consultants Ltd.

Map 3.2

3-D Finite Mesh with Inset

REFERENCES
Base Data - NVCA, 2009
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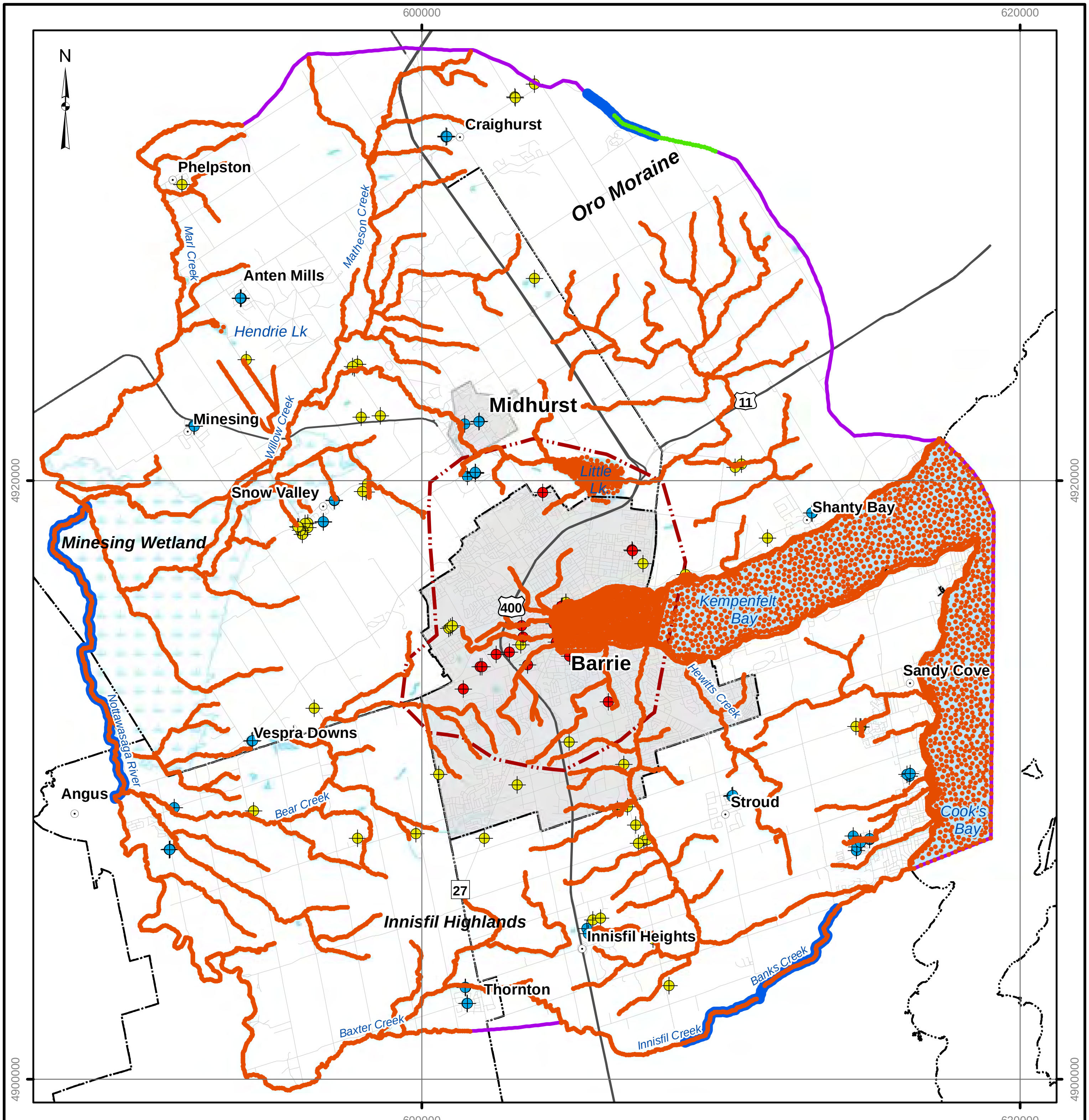
Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 12-Jun-2012; Created By: ccurry



LEGEND

- Towns/Villages
- Surface Water Boundary Conditions
- Shallow Boundary Conditions
- Deep Boundary Conditions
- Barrie Municipal Wells
- Other Municipal Wells
- Private Permits
- Highways
- River / Stream
- Open Water
- Barrie Tier 3 Boundary
- Focus Area
- Urban Centres
- Township Boundary

City of Barrie Tier 3 Water Budget and Local Area Risk Assessment Groundwater Flow Model

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Map 3.3

Boundary Conditions

REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
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Scale 1:180,000
2 0 2 4
Kilometres

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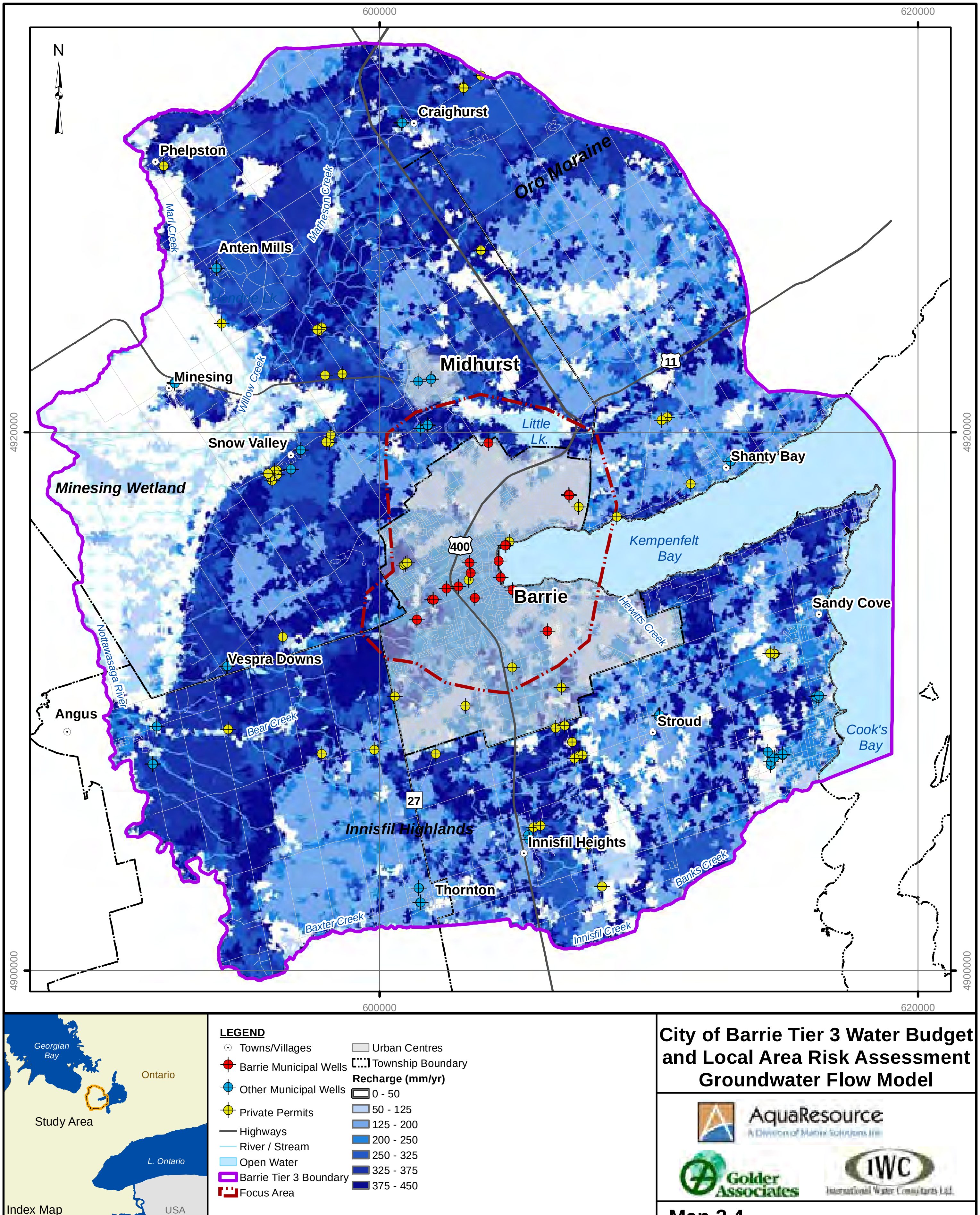
Project: 2010007 BarrieTier3



City of Barrie Tier 3 Water Budget and Local Area Risk Assessment Groundwater Flow Model

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Map 3.4

Recharge

REFERENCES
Base Data - NVCA, 2009
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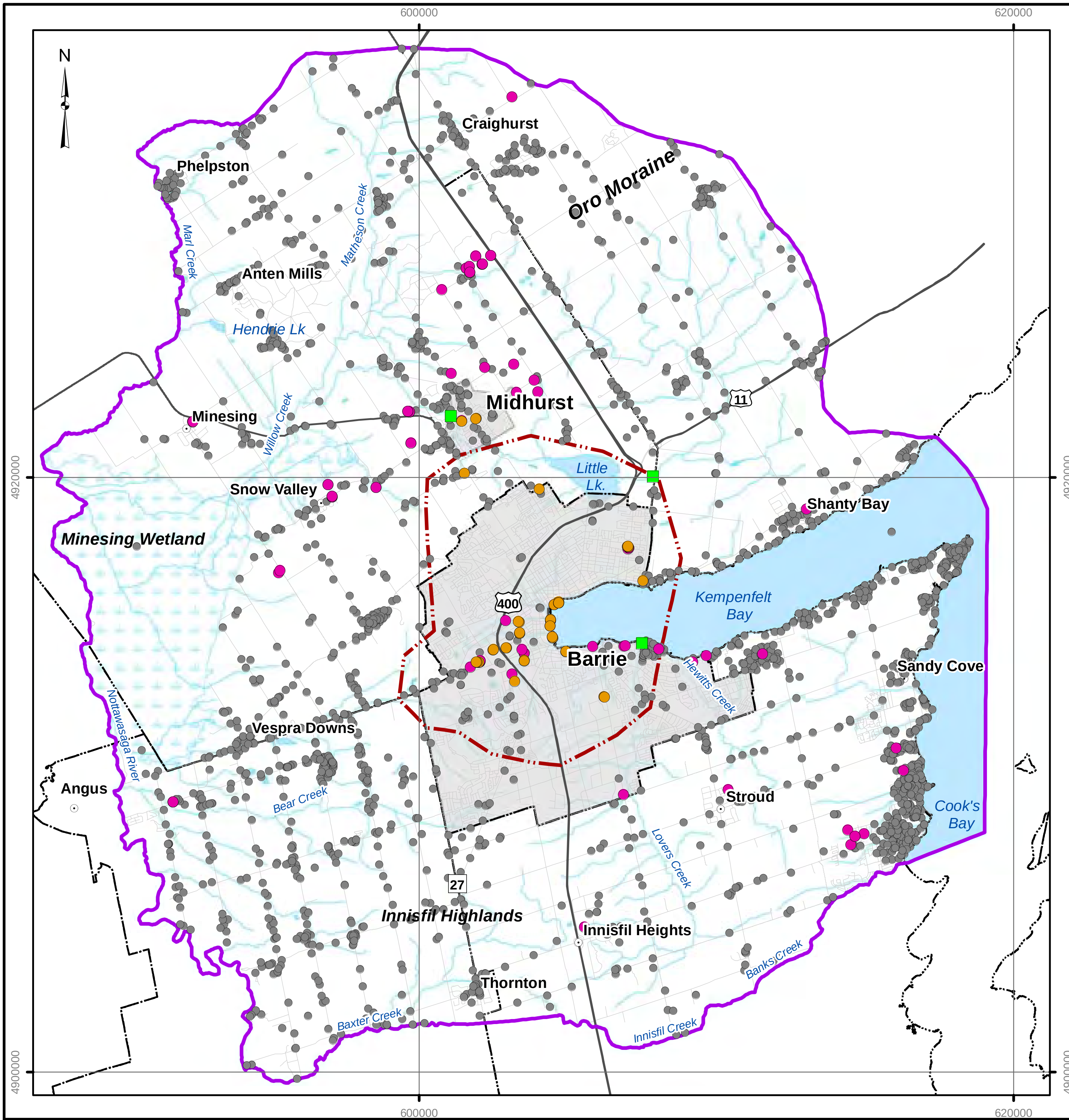

LEGEND

- Towns/Villages
- Standard Observation Wells
- High Quality Observation Wells
- City of Barrie Monitoring Network
- WSC Stream Gauges
- Highways
- River / Stream
- Open Water
- Barrie Tier 3 Boundary
- Focus Area
- Urban Centres
- Township Boundary

City of Barrie Tier 3 Water Budget and Local Area Risk Assessment Groundwater Flow Model

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Map 4.1

Stream Flow Gauges and Observation Datasets

REFERENCES
Base Data - NVCA, 2009
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Scale 1:180,000
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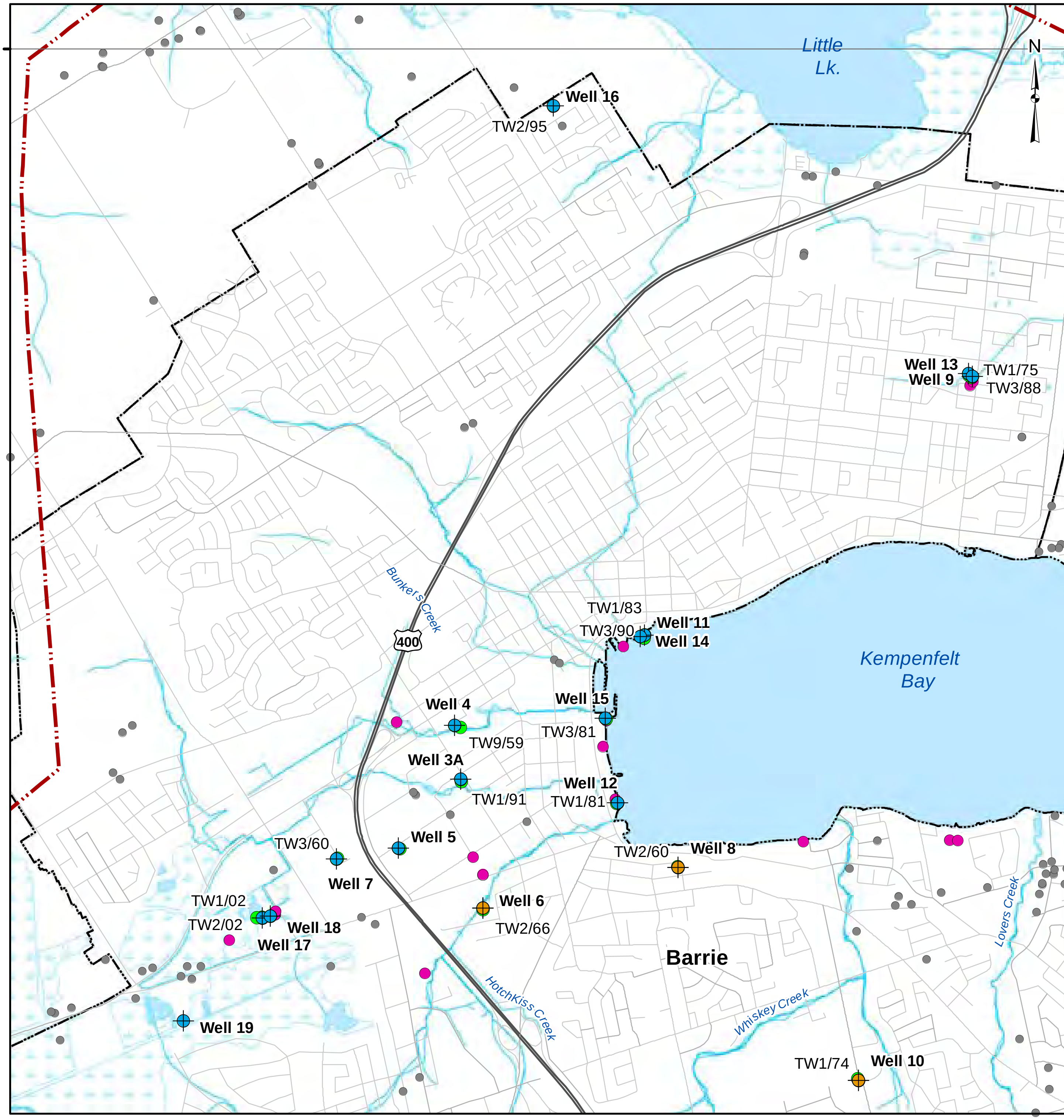
Kilometres



LEGEND

- Towns/Villages
- Standard Observation Wells
- High Quality Observation Wells
- Municipal Water Supply
- Decommisioned Municipal Pumping Wells
- Transient Calibration Wells
- Highways
- Roads
- River / Stream
- Open Water
- Wetlands
- Barrie Tier 3 Boundary
- Urban Centres
- Township Boundary
- Focus Area

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Scale 1:40,000
0.5 0 0.5 1
Kilometres

Map 4.2

City of Barrie Monitoring Network

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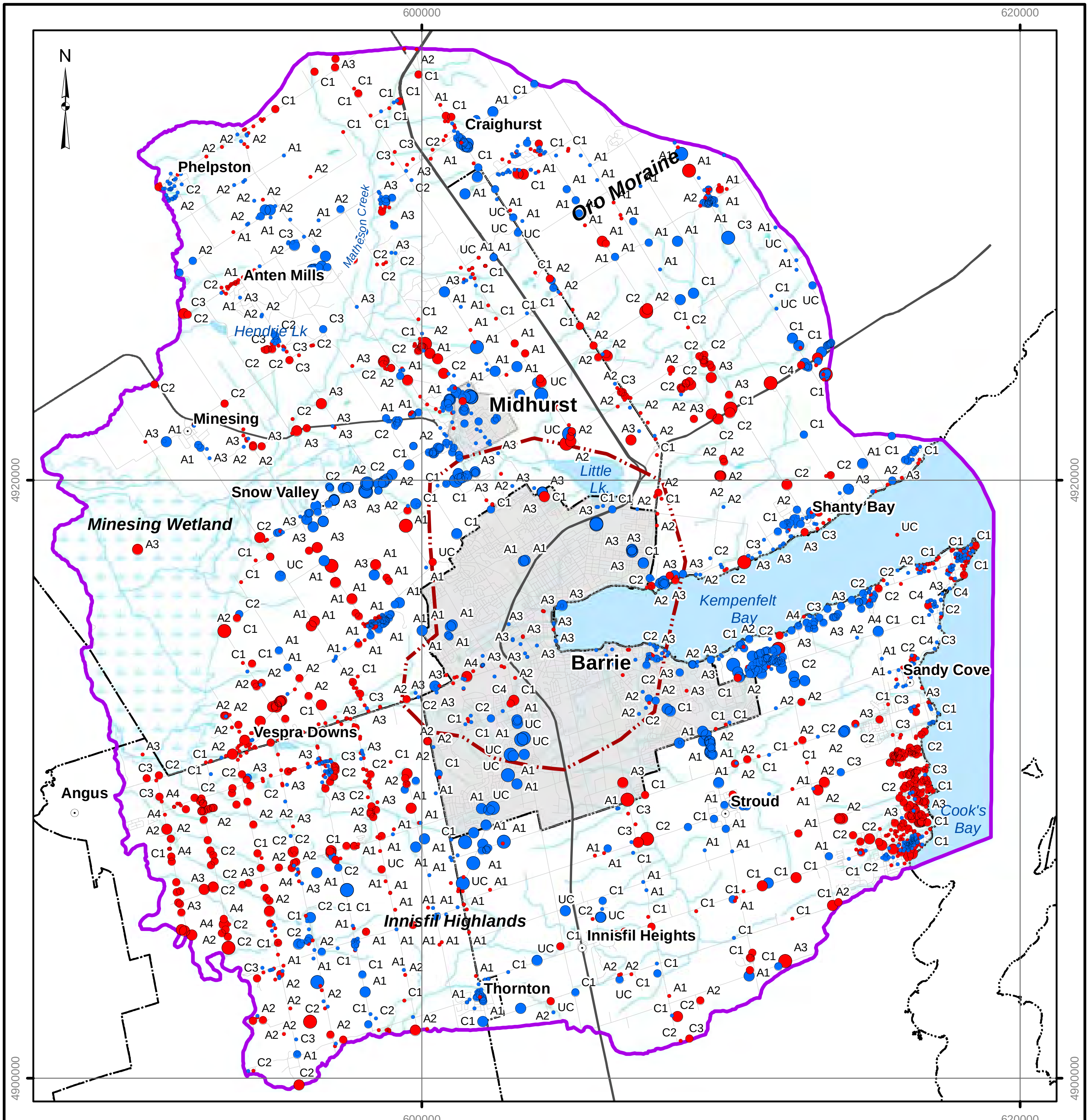
Project: 2010007 BarrieTier3



LEGEND

Calibration Residual (m)

- < -20 or > 20
- -20...-10 or 10...20
- -10...-5 or 5...10
- -5...5
- Lower than Observed Simulated Head
- Greater than Observed Simulated Head

- Towns/Villages
- Highways
- River / Stream
- Open Water
- Barrie Tier 3 Boundary
- Focus Area
- Urban Centres
- Township Boundary

City of Barrie Tier 3 Water Budget and Local Area Risk Assessment Groundwater Flow Model

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Map 5.1

Spatial Residuals

REFERENCES

Base Data - NVCA, 2009

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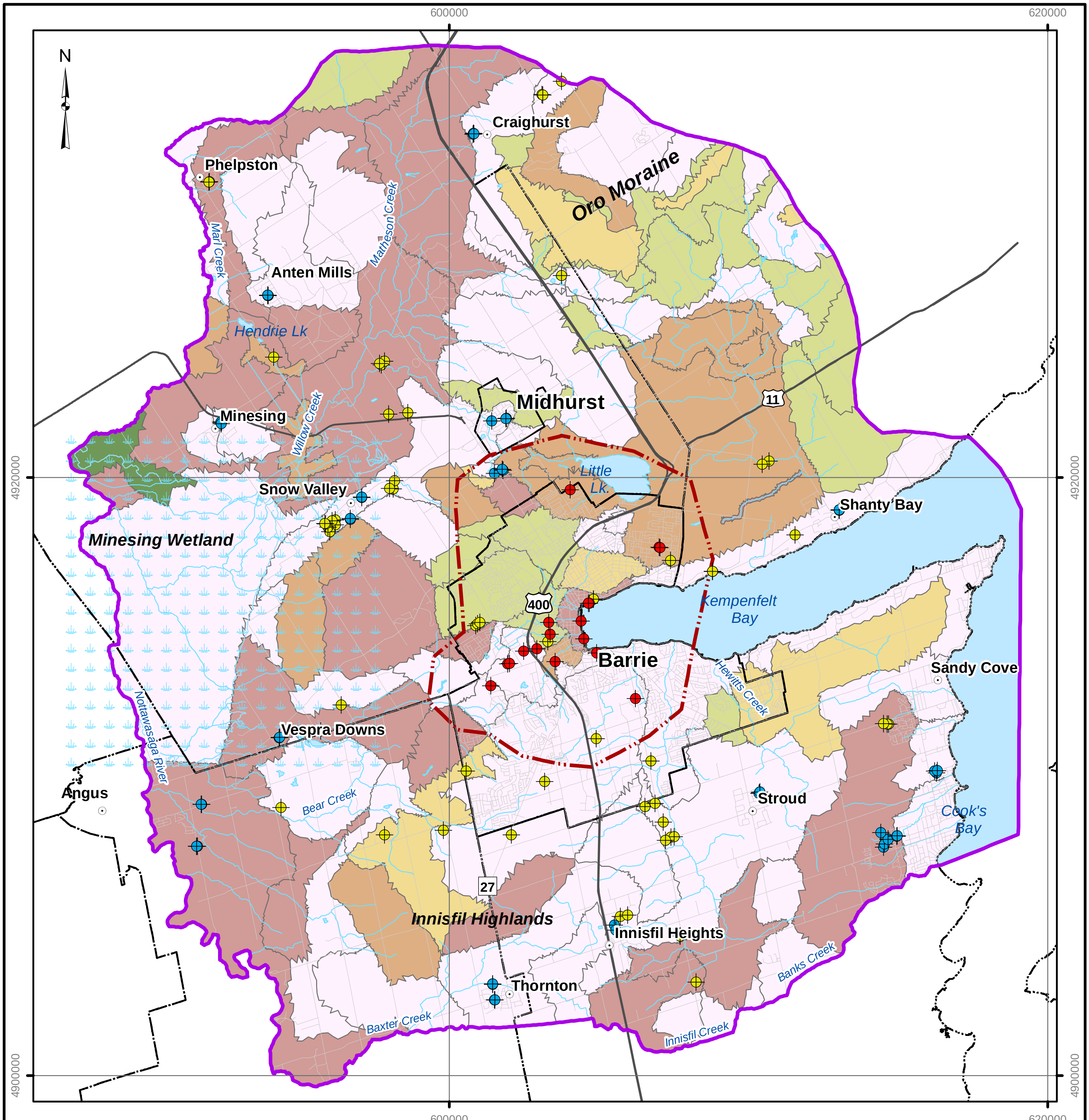
Scale 1:180,000

2 0 2 4

Kilometres



LEGEND

- Towns/Villages
- Barrie Municipal Wells
- Other Municipal Wells
- Private Permits
- Highways
- River / Stream
- Open Water
- Barrie Tier 3 Boundary
- Focus Area
- Urban Centres
- Township Boundary

Hydraulic Conductivity Distribution (m/day)

- < 1.00e-008
- 1.00e-008 - 1.00e-007
- 1.00e-007 - 1.00e-006
- 1.00e-006 - 1.00e-005
- 1.00e-005 - 1.00e-004
- > 1.00e-004

City of Barrie Tier 3 Water Budget and Local Area Risk Assessment Groundwater Flow Model

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Map 5.2
Hydraulic Conductivity Distribution (A1)

REFERENCES
Base Data - NVCA, 2009
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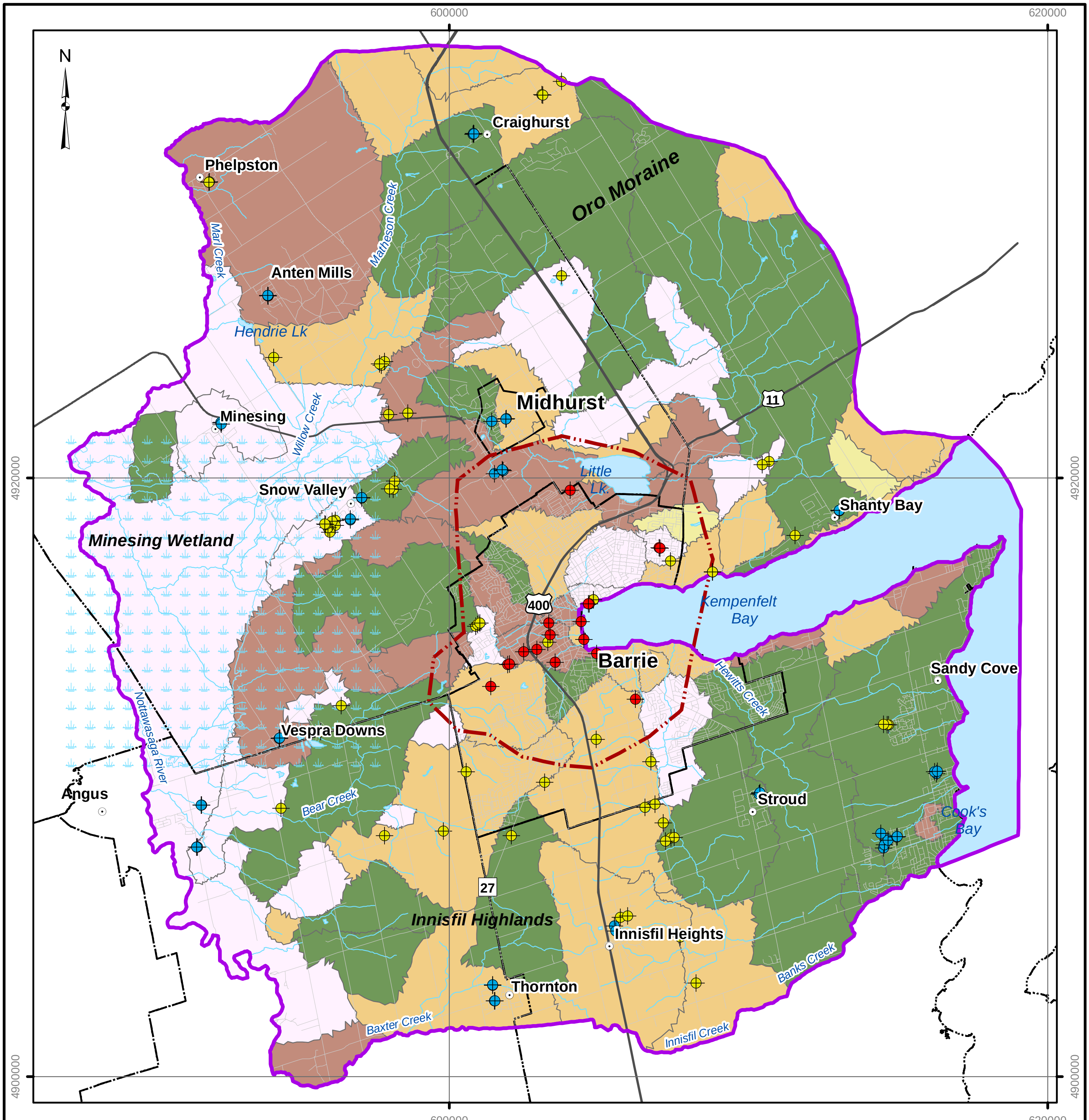
Map Version: 1; Map Date: 01-May-2013; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres



LEGEND

- Towns/Villages
- Barrie Municipal Wells
- Other Municipal Wells
- Private Permits
- Highways
- River / Stream
- Open Water
- Barrie Tier 3 Boundary
- Focus Area
- Urban Centres
- Township Boundary

Hydraulic Conductivity Distribution (m/day)

- < 1.00e-007
- 1.00e-007 - 1.00e-006
- 1.00e-006 - 1.00e-005
- 1.00e-005 - 1.00e-004
- > 1.00e-004

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Map 5.3
Hydraulic Conductivity Distribution (A2)

REFERENCES
Base Data - NVCA, 2009
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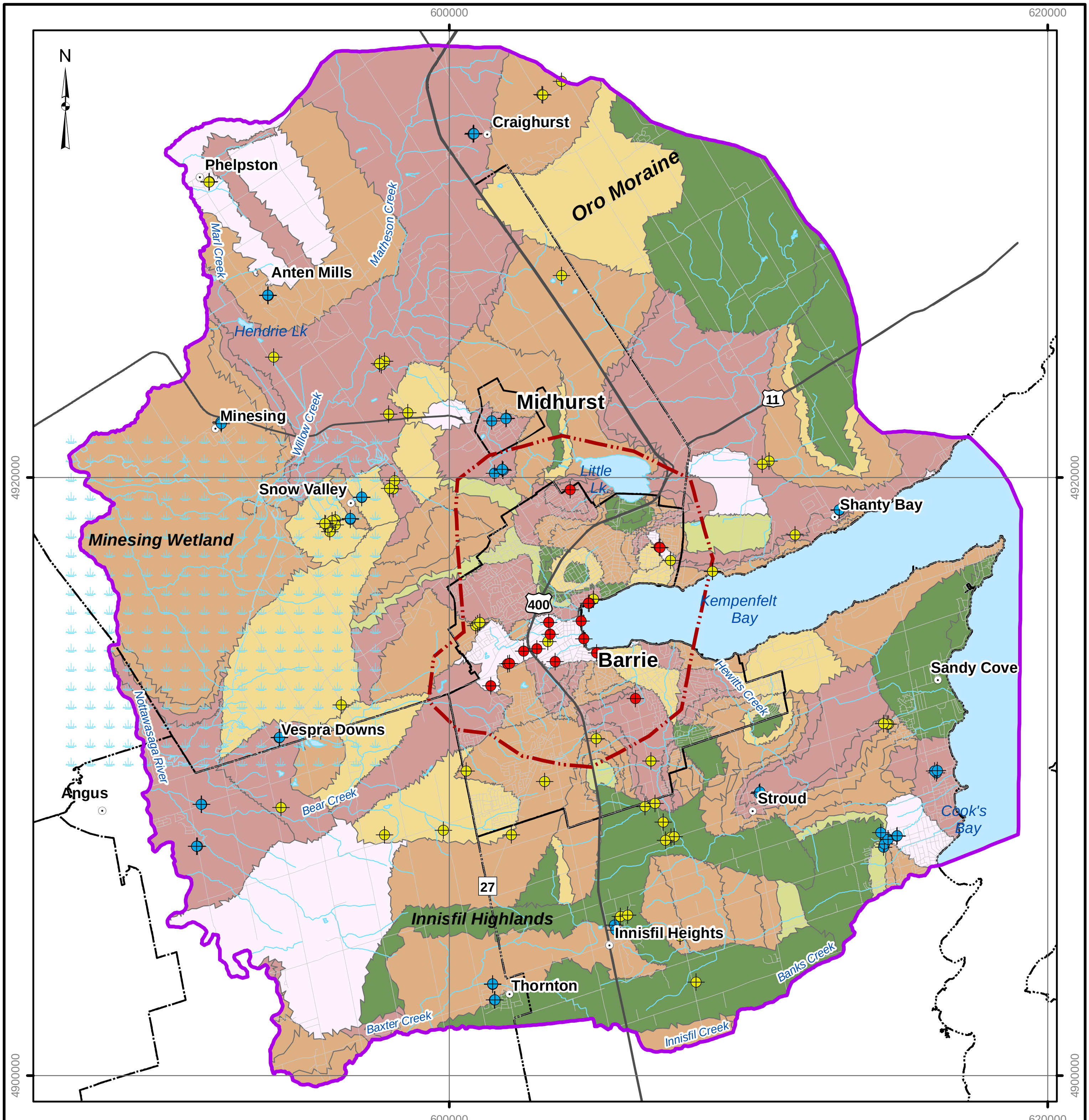
Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 01-May-2013; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres



LEGEND

- Towns/Villages
- Barrie Municipal Wells
- Other Municipal Wells
- Private Permits
- Highways
- River / Stream
- Open Water
- Barrie Tier 3 Boundary
- Focus Area
- Urban Centres
- Township Boundary

Hydraulic Conductivity Distribution (m/day)

- > 1.00e-007
- 1.00e-007 - 1.00e-006
- 1.00e-006 - 1.00e-005
- 1.00e-005 - 1.00e-004
- 1.00e-004 - 1.00e-003
- > 1.00e-003

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Map 5.4
Hydraulic Conductivity Distribution (A3)

REFERENCES
Base Data - NVCA, 2009
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Scale 1:180,000
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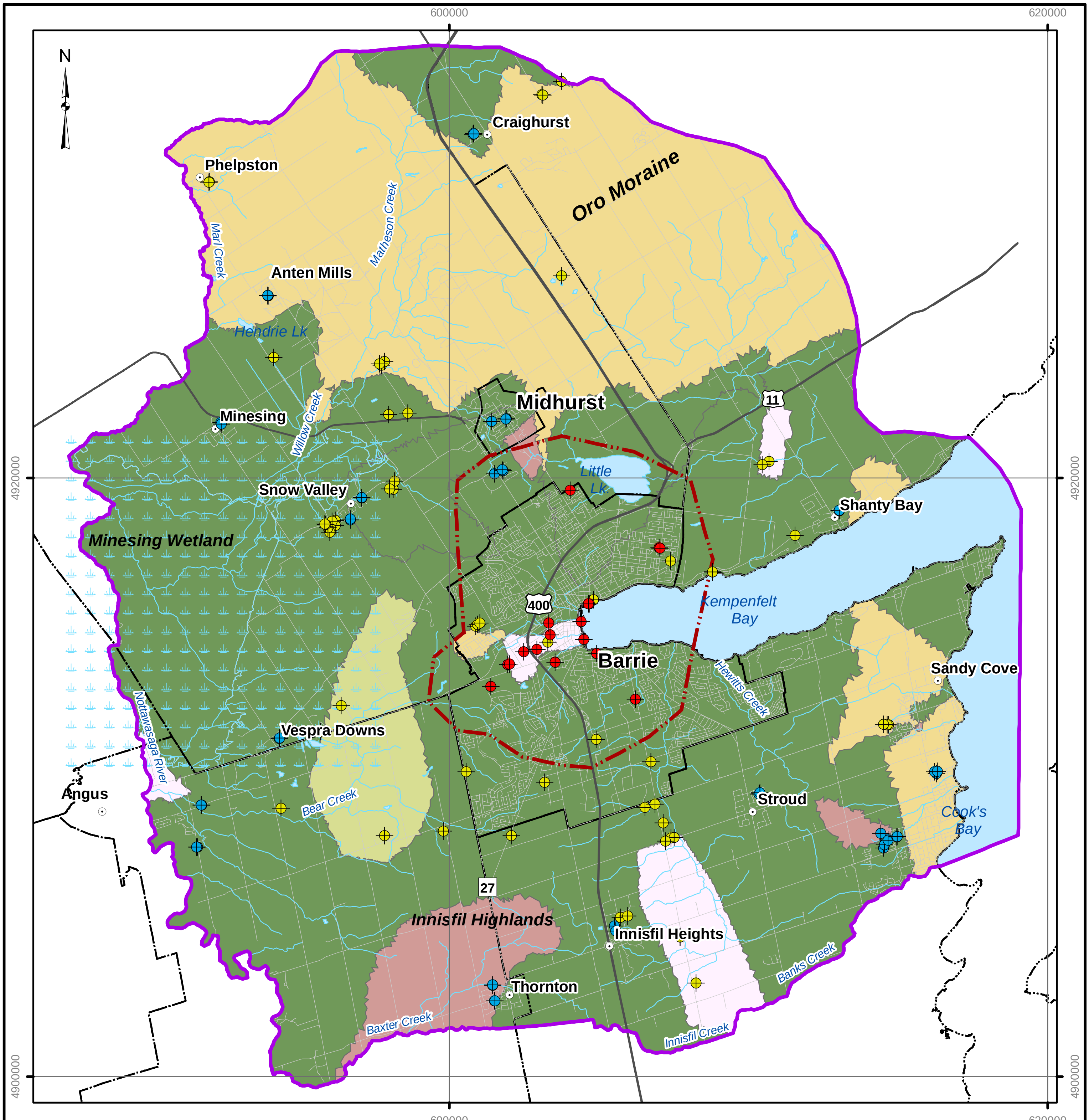
Kilometres



LEGEND

- Towns/Villages
- Barrie Municipal Wells
- Other Municipal Wells
- Private Permits
- Highways
- River / Stream
- Open Water
- Barrie Tier 3 Boundary
- Focus Area
- Urban Centres
- Township Boundary

Hydraulic Conductivity Distribution (m/day)

- < 1.00e-007
- 1.00e-007 - 1.00e-006
- 1.00e-006 - 1.00e-005
- 1.00e-005 - 1.00e-004
- 1.00e-004 - 1.00e-003
- > 1.00e-003

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Map 5.5

Hydraulic Conductivity Distribution (A4)

REFERENCES
Base Data - NVCA, 2009
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Map Version: 1; Map Date: 01-May-2013; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

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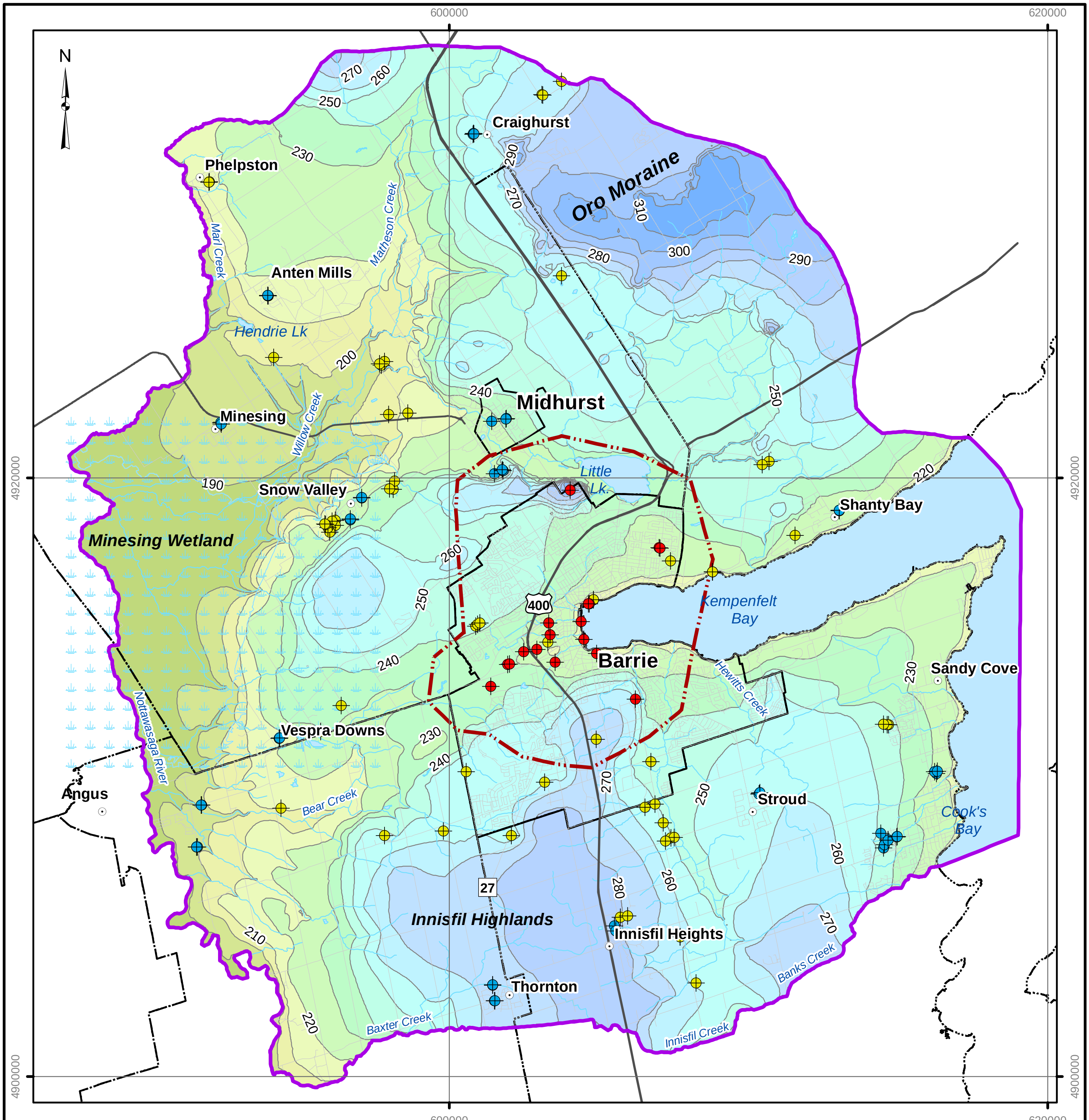
Project: 2010007 BarrieTier3



LEGEND

- Towns/Villages
- Barrie Municipal Wells
- Other Municipal Wells
- Private Permits
- Highways
- River / Stream
- Shallow Aquifer Equipotential Contours - 10m Intervals
- Open Water
- Barrie Tier 3 Boundary
- Focus Area
- Urban Centres
- Township Boundary

Shallow Aquifer Equipotential (m)

- < 180
- 180 - 190
- 190 - 200
- 200 - 210
- 210 - 220
- 220 - 230
- 230 - 240
- 240 - 250
- 250 - 260
- 260 - 270
- 270 - 280
- 280 - 290
- 290 - 300
- 300 - 310
- > 310

City of Barrie Tier 3 Water Budget and Local Area Risk Assessment Groundwater Flow Model

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Map 5.6
Simulated Shallow Aquifer (A1) Equipotential Contours

REFERENCES
Base Data - NVCA, 2009
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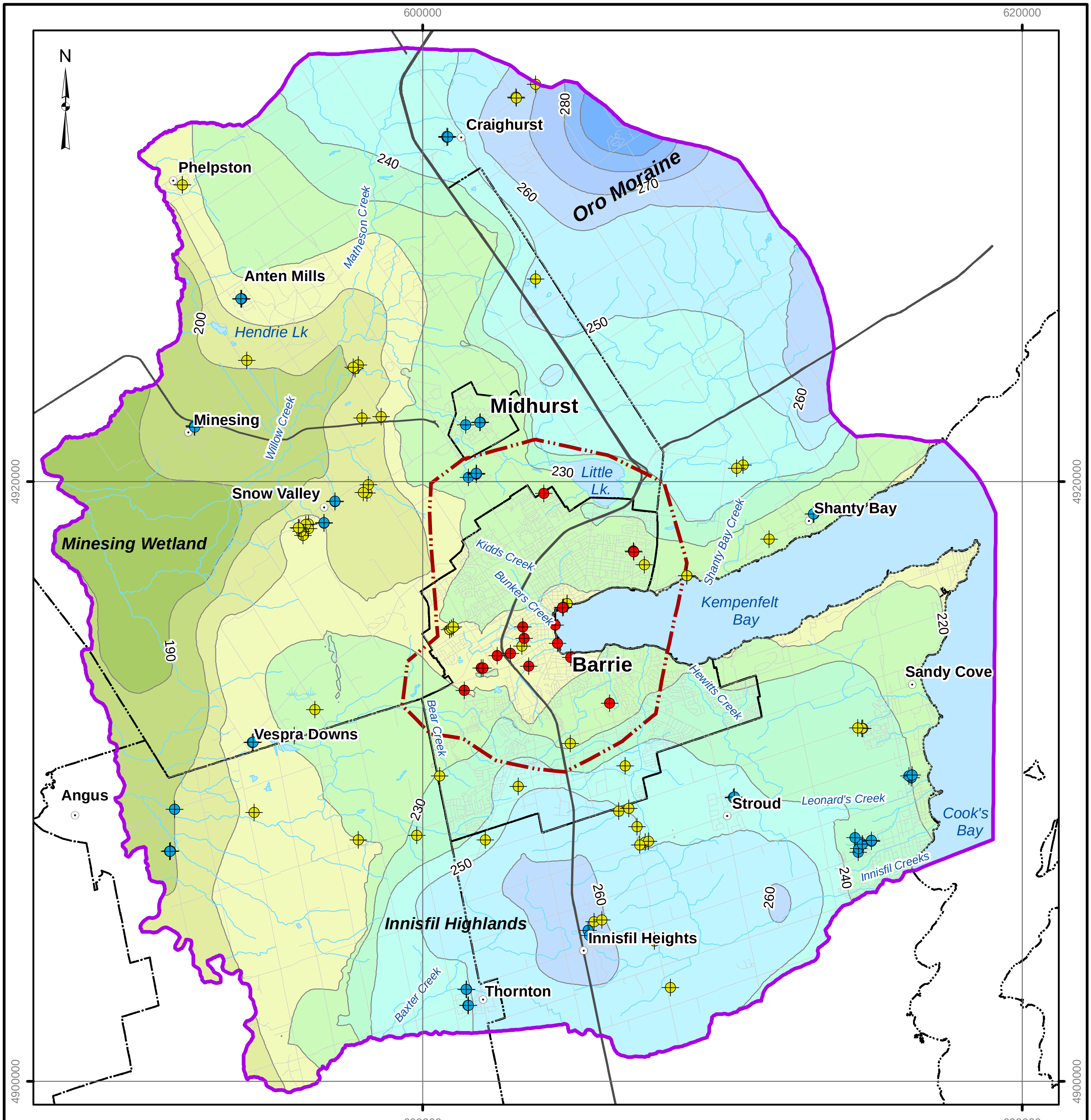
Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 24-Apr-2013; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres



LEGEND

- Towns/Villages
- Barrie Municipal Wells
- Other Municipal Wells
- Private Permits
- Highways
- River / Stream
- Shallow Aquifer Equipotential Contours - 10m Intervals
- Open Water
- Barrie Tier 3 Boundary
- Focus Area
- Urban Centres
- Township Boundary

Shallow Aquifer Equipotential (m)

- < 190
- 190 - 200
- 200 - 210
- 210 - 220
- 220 - 230
- 230 - 240
- 240 - 250
- 250 - 260
- 260 - 270
- 270 - 280
- 280 - 290
- > 290

City of Barrie Tier 3 Water Budget and Local Area Risk Assessment Groundwater Flow Model

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Map 5.7
Simulated Deep Aquifer (A3) Equipotential Contours

Scale 1:180,000

2 0 2 4

Kilometres

REFERENCES
Base Data - NVCA, 2009
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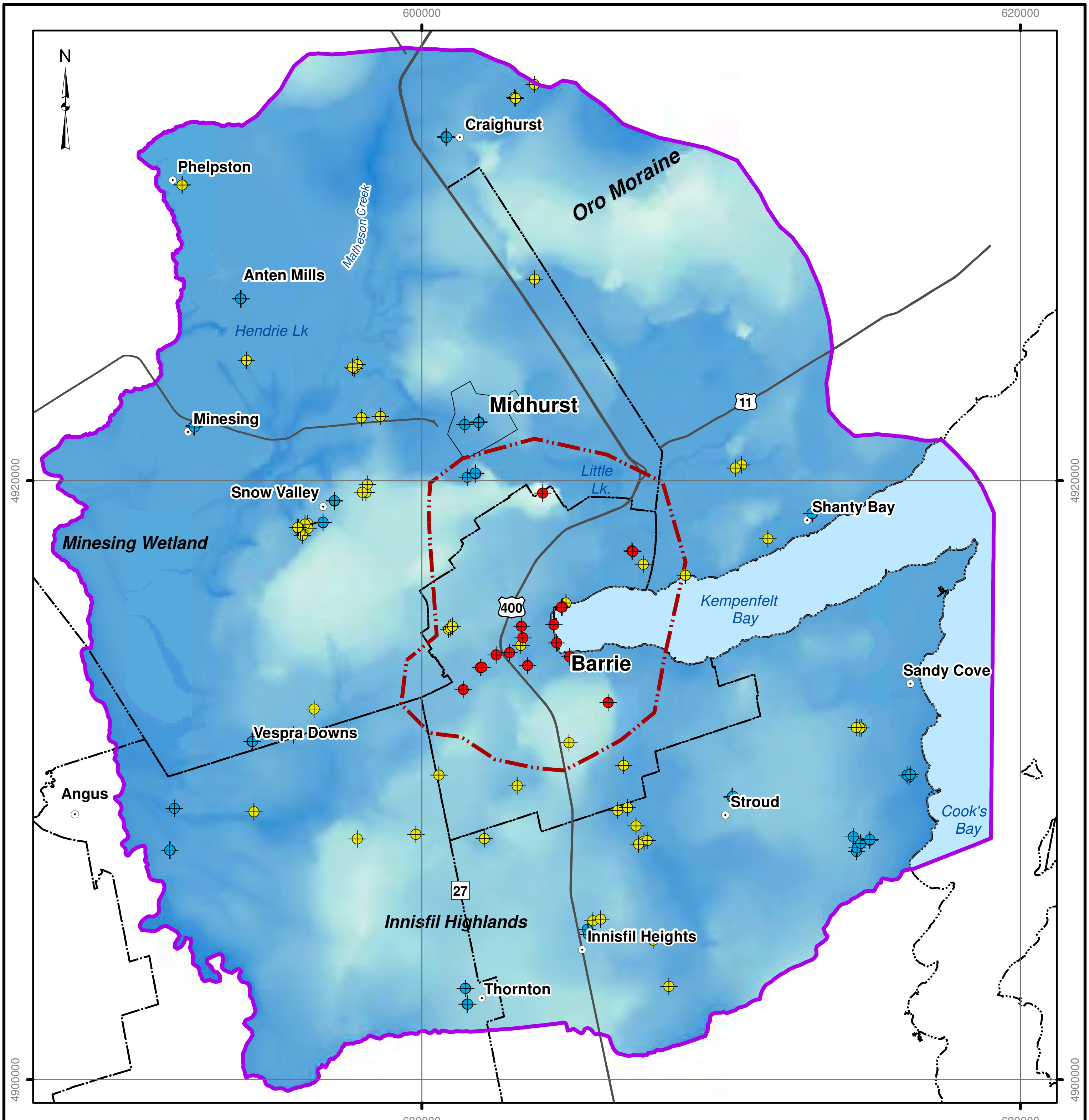
Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 24-Apr-2013; Created By: ccurry



LEGEND

- Towns/Villages
- Barrie Municipal Wells
- Other Municipal Wells
- Private Permits
- Highways
- River / Stream
- Open Water
- Barrie Tier 3 Boundary
- Focus Area
- Urban Centres
- Township Boundary

Vertical Hydraulic Gradient

Upward Flow

Downward Flow

City of Barrie Tier 3 Water Budget and Local Area Risk Assessment Groundwater Flow Model

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Map 5.8

Vertical Hydraulic Gradient

REFERENCES
Base Data - NVCA, 2009
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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 24-Apr-2013; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

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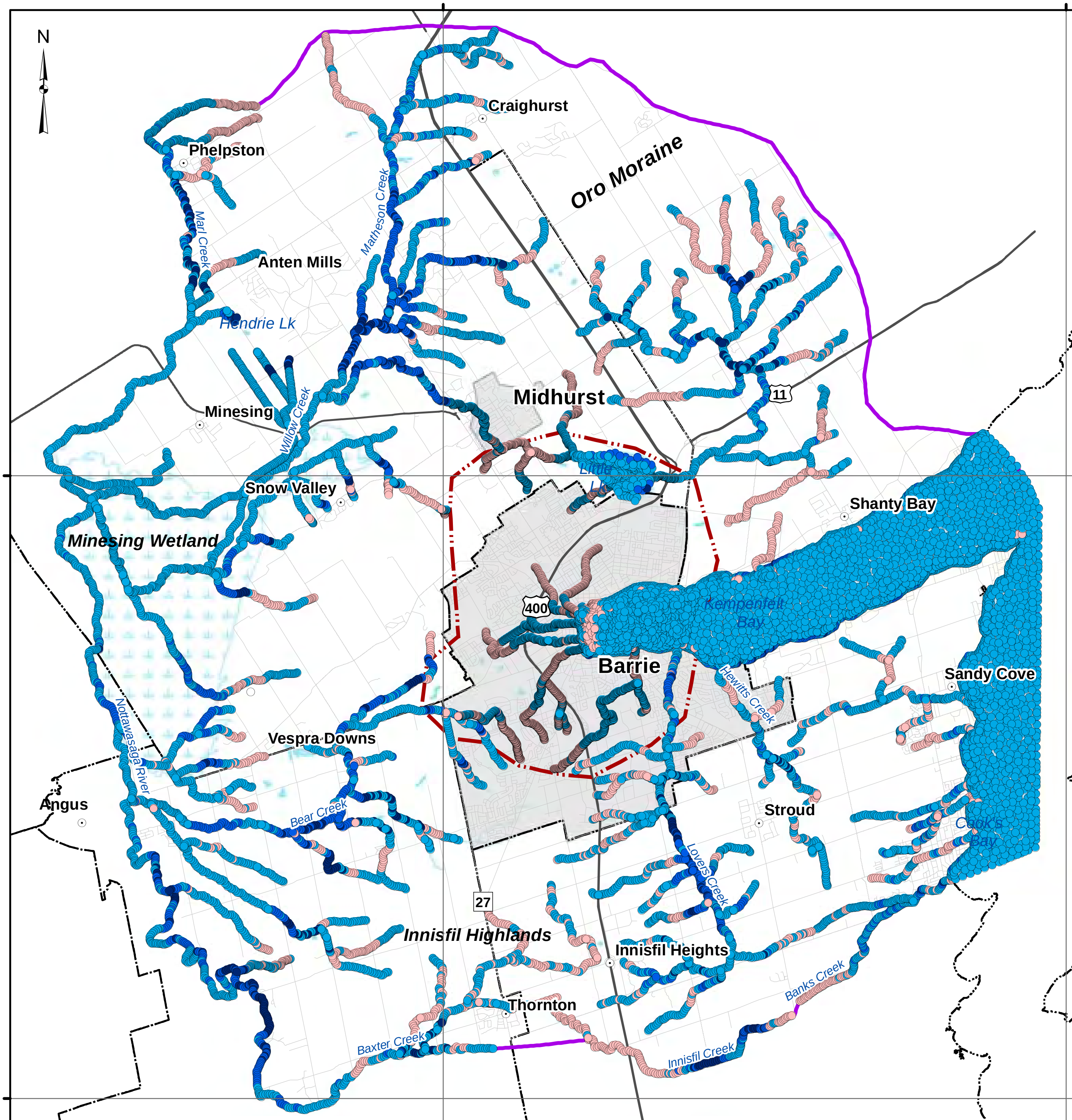
Project: 2010007 BarrieTier3



LEGEND

River Discharge (m^3/day)
- > 300
- 300 to 100
- 100 to 0
- < 0
- Towns/Villages
- Highways
- River / Stream
- Open Water
- Barrie Tier 3 Boundary
- Focus Area
- Urban Centres
- Township Boundary

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Map 5.9

Groundwater Discharge to Surface Water

REFERENCES
Base Data - NVCA, 2009
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Map Version: 1; Map Date: 24-Apr-2013; Created By: ccurry

Scale 1:180,000
2 0 2 4
Kilometres

T:\2010007 BarrieTier3\GIS\ArcView\MXDs\WaterBudget_GroundwaterFlowModel\Fig5.9_GW_Discharge_SW.mxd

Project: 2010007 BarrieTier3

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BARRIE TIER THREE WATER BUDGET AND

LOCAL AREA RISK ASSESSMENT

GROUNDWATER FLOW MODEL DEVELOPMENT

APPENDIX C2: MODELLED PUMPING WELLS

				Screened Interval (depth)		2008 Pumping Rate				
wellID	Permit Number	Easting	Northing	Top (m)	Bottom (m)	m3/day	Municipality	Major Category	Specific Purpose	Well Name
2	00-P-1210	602081	4908050	0.2	3.0	5.3	Innisfil	Agricultural	Other - Agricultural	Dugout Pond
69	03-P-1069	596398	4912393	0.1	3.0	161.4	Springwater	Agricultural	Field and Pasture Crops	Dugout Pond
27	0040-733RE2	603756	4933236	81.7	86.9	339.0	Oro-Medonte	Commercial	Golf Course Irrigation	Irrigation Well
28	0040-733RE2	603101	4932804	2.0	10.6	138.8	Oro-Medonte	Commercial	Golf Course Irrigation	Irrigation Pond
29	0040-733RE2	603126	4932775	66.1	67.1	1.3	Oro-Medonte	Commercial	Golf Course Irrigation	Clubhouse Well
81	0386-7AMLUY	598132	4919616	62.5	68.9	1145.6	Springwater	Commercial	Golf Course Irrigation	Well 1-4/93
82	0386-7AMLUY	598177	4919891	48.2	57.6	687.4	Springwater	Commercial	Golf Course Irrigation	Well 2-1/93
83	0386-7AMLUY	598008	4919625	48.2	57.6	753.3	Springwater	Commercial	Golf Course Irrigation	Irrigation Pond
239	3124-6J5T9M	594132	4924022	0.7	41.7	129.9	Springwater	Commercial	Golf Course Irrigation	Pump House
255	3474-759GY9	610681	4920539	45.4	47.9	9.9	Oro-Medonte	Commercial	Golf Course Irrigation	Heritage Well
256	3474-759GY9	610464	4920431	0.3	3.0	42.3	Oro-Medonte	Commercial	Golf Course Irrigation	Heritage Pond
316	4755-73RHNU	606539	4908998	13.7	15.2	3.0	Innisfil	Commercial	Golf Course Irrigation	Clubhouse Well
317	4755-73RHNU	606872	4909093	0.8	6.6	26.8	Innisfil	Commercial	Golf Course Irrigation	Dugout Pond
340	5372-6SYPRA	603184	4909825	62.5	71.6	39.2	Barrie	Commercial	Mall / Business	Well 1/06
343	5447-6QWR7W	594380	4908956	0.0	5.4	102.3	Essa	Commercial	Golf Course Irrigation	Irrigation Pond
355	5813-6U2S3J	607415	4907971	0.2	4.0	62.2	Innisfil	Commercial	Golf Course Irrigation	Irrigation Pond
358	5813-6U2S3J	607151	4908478	36.6	40.2	3.0	Innisfil	Commercial	Golf Course Irrigation	Well 1
404	6824-68XPUW	606744	4910509	0.0	3.0	50.2	Innisfil	Commercial	Golf Course Irrigation	Main Irrigation Pond
405	6845-6D7NUT	596189	4918575	0.0	3.0	347.8	Springwater	Commercial	Snowmaking	Pond Winter
406	6845-6D7NUT	596190	4918418	0.0	3.0	32.0	Springwater	Commercial	Snowmaking	Pond 1 Winter
407	6845-6D7NUT	596004	4918188	0.0	3.0	26.8	Springwater	Commercial	Snowmaking	Pond 2 Winter
408	6845-6D7NUT	595945	4918328	0.0	3.0	31.8	Springwater	Commercial	Snowmaking	Pond 3 Winter
409	6845-6D7NUT	596095	4918554	0.0	3.0	143.5	Springwater	Commercial	Snowmaking	Pond Summer
410	6845-6D7NUT	595878	4918441	0.0	3.0	322.8	Springwater	Commercial	Snowmaking	Pond Summer

Table A.3.1: Modelled Private Permits

				Screened Interval (depth)		2008 Pumping Rate				
wellID	Permit Number	Easting	Northing	Top (m)	Bottom (m)	m3/day	Municipality	Major Category	Specific Purpose	Well Name
423	7455-6QPLB5	599800	4908200	0.0	3.0	65.9	Essa	Commercial	Golf Course Irrigation	Dugout Pond
432	7542-6P8M92	600566	4910182	43.9	48.5	112.9	Barrie	Commercial	Golf Course Irrigation	Well 1/94
468	8141-7BYRP2	607723	4904671	22.6	25.0	200.0	Innisfil	Commercial	Bottled Water	Well 2
469	8141-7BYRP2	607723	4904671	22.6	25.0	200.0	Innisfil	Commercial	Bottled Water	Well 3
483	8531-6ASQXU	608252	4903121	62.8	65.8	248.6	Innisfil	Commercial	Bottled Water	Well 1
272	4105-7EENGW	603760	4926740	0.0	0.4	19.7	Springwater	Industrial	Aggregate Washing	Source Pond
373	6313-5Z4NC5	603300	4914507	47.9	52.7	180.8	Barrie	Industrial	Cooling Water	Private Well
333	5353-5W4LB8	598611	4922161	23.2	27.7	119.5	Springwater	Recreational	Other - Recreational	Artesian Well
334	5353-5W4LB8	597977	4922110	23.2	27.7	126.5	Springwater	Recreational	Other - Recreational	Pond
135	1315-6W3QAS	600889	4915049	88.2	112.4	163.6	Barrie	Remediation	Groundwater	Well 1
136	1315-6W3QAS	600950	4915097	19.8	35.1	308.3	Barrie	Remediation	Groundwater	Well 2
137	1315-6W3QAS	601019	4915147	23.5	35.7	172.3	Barrie	Remediation	Groundwater	Well 3
494	87-P-3008	614679	4911754	74.4	78.0	371.3	Innisfil	Water Supply	Communal	Well 1
495	87-P-3008	614638	4911757	73.5	77.1	371.3	Innisfil	Water Supply	Communal	Well 2
496	87-P-3008	614512	4911771	43.6	49.7	371.3	Innisfil	Water Supply	Communal	Well 3
54	02-P-1193	597842	4908046	101.8	122.1	5.8	Essa	Water Supply	Communal	Well 1
151	1586-62FLP2	611554	4918074	59.2	70.7	16.2	Oro-Medonte	Water Supply	Communal	O'Brien House Well
260	3772-6EQGSY	597740	4923757	73.1	73.2	3.8	Springwater	Water Supply	Campgrounds	Well 1
261	3772-6EQGSY	597843	4923884	73.1	73.2	6.7	Springwater	Water Supply	Campgrounds	Well 3
262	3772-6EQGSY	597678	4923800	26.5	33.2	4.6	Springwater	Water Supply	Campgrounds	Well 4
377	6334-72JP7N	591987	4929882	36.6	40.2	109.4	Springwater	Water Supply	Communal	Well 1
378	6334-72JP7N	591979	4929876	36.3	39.3	131.0	Springwater	Water Supply	Communal	Well 2
570	96-P-5022	595712	4911521	56.7	57.9	12.2	Springwater	Water Supply	Campgrounds	Well
411	6845-6D7NUT	595848	4918451	0.0	3.0	914.7	Springwater	Commercial	Snowmaking	Berry Hill Pond

Table A.3.1: Modelled Private Permits

					Screened Interval (depth)		2008 Pumping Rate			
wellID	Permit Number	Moe Number	Easting	Northing	Top (m)	Bottom (m)	m3/day	Municipality	System	Well Name
225	2828-7GDPJ2	5732108	603373	4914759	96.0	107.0	2378.6	Barrie	Barrie	Well 3A
226	2828-7GDPJ2	5724686	607015	4917670	80.2	97.2	1995.2	Barrie	Barrie	Well 13
227	2828-7GDPJ2	DHL0195	603330	4915148	50.0	56.1	1695.0	Barrie	Barrie	Well 4
228	2828-7GDPJ2	5700271	602927	4914267	88.4	106.7	2893.7	Barrie	Barrie	Well 5
229	2828-7GDPJ2	5709125	602484	4914189	85.3	100.6	4756.1	Barrie	Barrie	Well 7
230	2828-7GDPJ2	5712496	607042	4917649	77.1	93.0	3457.0	Barrie	Barrie	Well 9
231	2828-7GDPJ2	5714078	606225	4912601	85.6	93.3	2124.0	Barrie	Barrie	Well 10
232	2828-7GDPJ2	5719264	604690	4915794	47.2	61.3	3248.7	Barrie	Barrie	Well 11
233	2828-7GDPJ2	5717393	604499	4914593	73.8	88.7	2124.0	Barrie	Barrie	Well 12
234	2828-7GDPJ2	5727877	604660	4915782	39.6	61.0	1634.9	Barrie	Barrie	Well 14
235	2828-7GDPJ2	5728705	604411	4915199	45.7	51.2	2124.0	Barrie	Barrie	Well 15
236	2828-7GDPJ2	5733545	604037	4919591	61.3	73.5	4778.8	Barrie	Barrie	Well 16
237	2828-7GDPJ2	5737406	601953	4913766	86.2	104.9	3166.4	Barrie	Barrie	Well 17
238	2828-7GDPJ2	5739442	602010	4913778	87.5	106.1	3217.3	Barrie	Barrie	Well 18
307	4624-6HKPJW	5728783	600803	4931465	24.4	27.4	0.1	Oro-Medonte	Craighurst	Well 1
308	4624-6HKPJW	5728784	600807	4931504	24.1	25.9	11.5	Oro-Medonte	Craighurst	Well 2
309	4624-6HKPJW	5728785	600830	4931482	29.0	30.8	20.7	Oro-Medonte	Craighurst	Well 3
397	6733-6GDQYK	5710801	592395	4921852	29.6	34.7	119.0	Springwater	Minesing	Well 2
398	6733-6GDQYK	5724869	592369	4921832	30.5	35.1	119.0	Springwater	Minesing	Well 3
399	6733-6GDQYK	5729291	592390	4921798	34.4	38.1	137.0	Springwater	Minesing	Well 4
418	7274-6K8R94	5723177	601508	4902530	48.5	51.5	106.7	Essa	Glen Avenue	Well 1
419	7274-6K8R94	5730575	601528	4902528	46.6	49.7	121.6	Essa	Glen Avenue	Well 2
420	7274-6K8R94	5706712	601457	4903056	27.4	31.1	82.1	Essa	Thornton Estates	TW1-69
421	7274-6K8R94	5706711	601446	4903058	25.9	29.0	59.8	Essa	Thornton Estates	Tw2-69
426	7511-5MLRGP	5712365	593955	4926082	64.9	68.0	138.0	Springwater	Anten Mills	Well 1

Table A.3.2: Modelled Municipal Permits

					Screened Interval (depth)		2008 Pumping Rate			
wellID	Permit Number	Moe Number	Easting	Northing	Top (m)	Bottom (m)	m3/day	Municipality	System	Well Name
426	7511-5MLRGP	5712365	593955	4926082	64.9	68.0	138.0	Springwater	Anten Mills	Well 1
427	7511-5MLRGP	5710898	593940	4926072	65.2	68.3	120.0	Springwater	Anten Mills	Well 2
428	7511-5MLRGP	5737379	593932	4926084	59.1	66.8	283.0	Springwater	Anten Mills	Well 3
429	7520-6LJTGX	5712374	613036	4918913	54.0	58.5	42.7	Oro-Medonte	Shanty Bay	Well 1
430	7520-6LJTGX	5716548	613042	4918902	40.8	45.4	48.8	Oro-Medonte	Shanty Bay	Well 2
431	7520-6LJTGX	DHL0193	613027	4918911	58.5	65.8	54.9	Oro-Medonte	Shanty Bay	Well 3
435	7650-6CFRPK	5738227	596698	4918601	62.5	72.5	175.5	Springwater	Snow Valley	Well 3
436	7650-6CFRPK	5739425	596700	4918617	62.8	72.5	0.5	Springwater	Snow Valley	Well 4
437	7650-6CFRPK	5723284	597076	4919325	59.4	65.5	53.2	Springwater	Snow Valley	Well 1
438	7650-6CFRPK	5724900	597075	4919340	61.0	67.1	53.8	Springwater	Snow Valley	Well 2
472	8306-7JYPWU	5711853	605518	4905031	68.3	77.4	170.1	Innisfil	Innisfil Heights	Well 2
473	8306-7JYPWU	5727320	605560	4904863	61.3	68.9	170.1	Innisfil	Innisfil Heights	Well 3
13	00-P-1368	5708340	610360	4909456	105.8	110.3	165.6	Innisfil	Stroud	Well 1
14	00-P-1368	5711982	610356	4909438	102.1	107.0	165.6	Innisfil	Stroud	Well 2 Standby
15	00-P-1368	5720924	610386	4909474	103.9	109.7	165.6	Innisfil	Stroud	Well 3
86	0421-7B4TCZ	DHL0215	591722	4909066	46.6	54.0	305.8	Essa	Centre Street	Well 1 (McGeorge)
87	0421-7B4TCZ	DHL0022	591721	4909070	46.3	53.6	283.2	Essa	Centre Street	Well 2 (McGeorge)
96	0507-6B9S5G	5711983	601910	4921975	73.2	77.7	129.2	Springwater	Idlewood	Well 2
97	0507-6B9S5G	5718775	601894	4921956	70.7	78.6	436.7	Springwater	Idlewood	Well 3
98	0507-6B9S5G	DHL0194	601427	4921884	69.8	75.9	209.6	Springwater	Greenpine	Well 4
99	0507-6B9S5G	5725264	601513	4920127	79.2	83.5	304.2	Springwater	Carson Road	Well 5
106	0621-62MR3A	5729945	594314	4911296	58.2	64.3	38.9	Springwater	Vespra Downs	Well 1-93
107	0621-62MR3A	5728338	594336	4911308	57.6	60.7	0.3	Springwater	Vespra Downs	Well 1-91
201	2372-75VHJ5	5728243	601784	4920238	68.6	73.2	11.1	Springwater	Paddy Dunn's Circle	Del Trend Well 1
202	2372-75VHJ5	5728671	601795	4920244	64.0	68.6	17.7	Springwater	Paddy Dunn's Circle	Del Trend Well 2
203	2372-75VHJ5	5733452	601776	4920263	61.3	71.3	75.7	Springwater	Paddy Dunn's Circle	Del Trend Well 3

Table A.3.2: Modelled Municipal Permits

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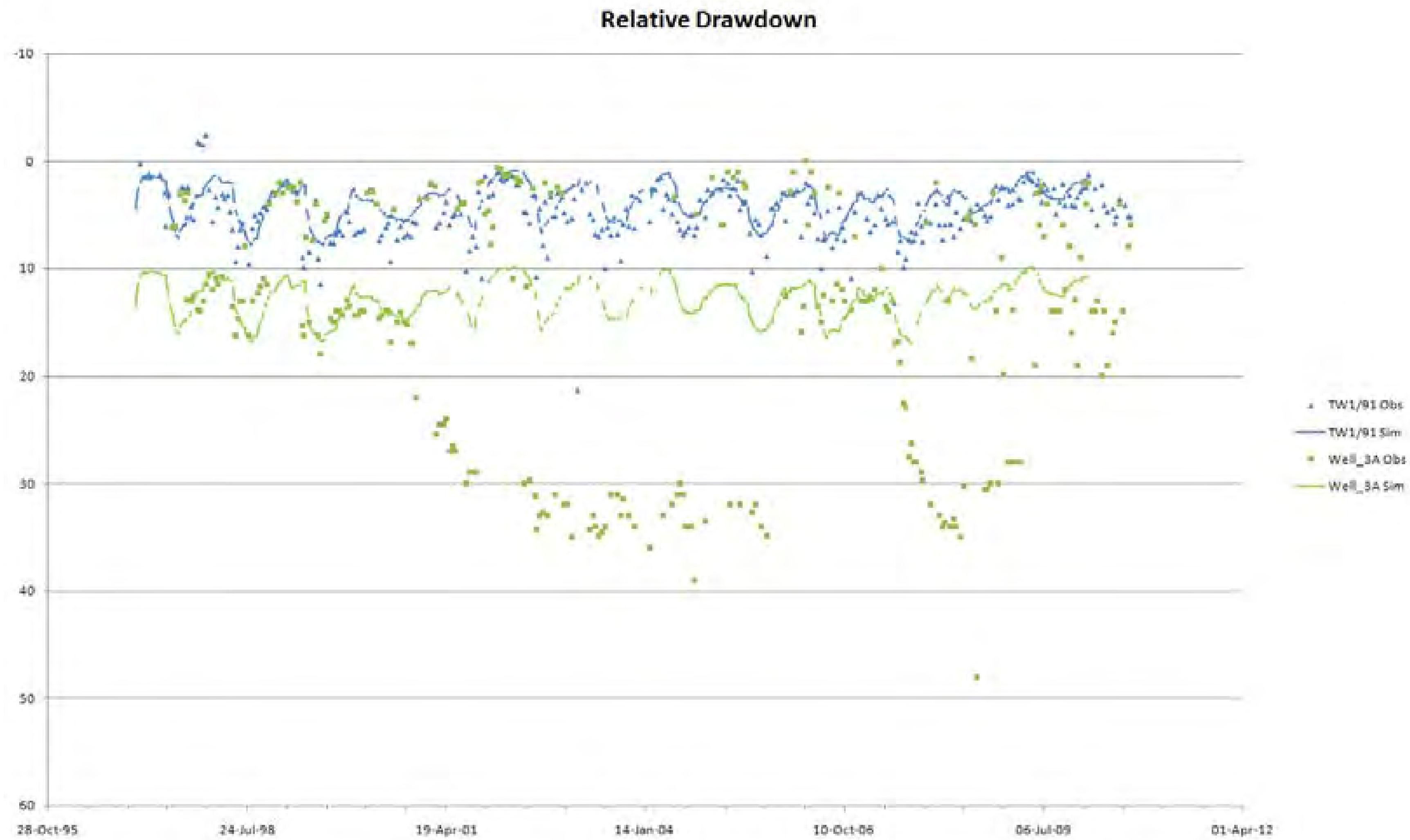
BARRIE TIER THREE WATER BUDGET AND

LOCAL AREA RISK ASSESSMENT

GROUNDWATER FLOW MODEL DEVELOPMENT

APPENDIX C3: TRANSIENT MODEL RESULTS BY MONITORING WELL



City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Figure C.5.1: Transient Groundwater Model Calibration Results (Well 3A)

AquaResource Inc.
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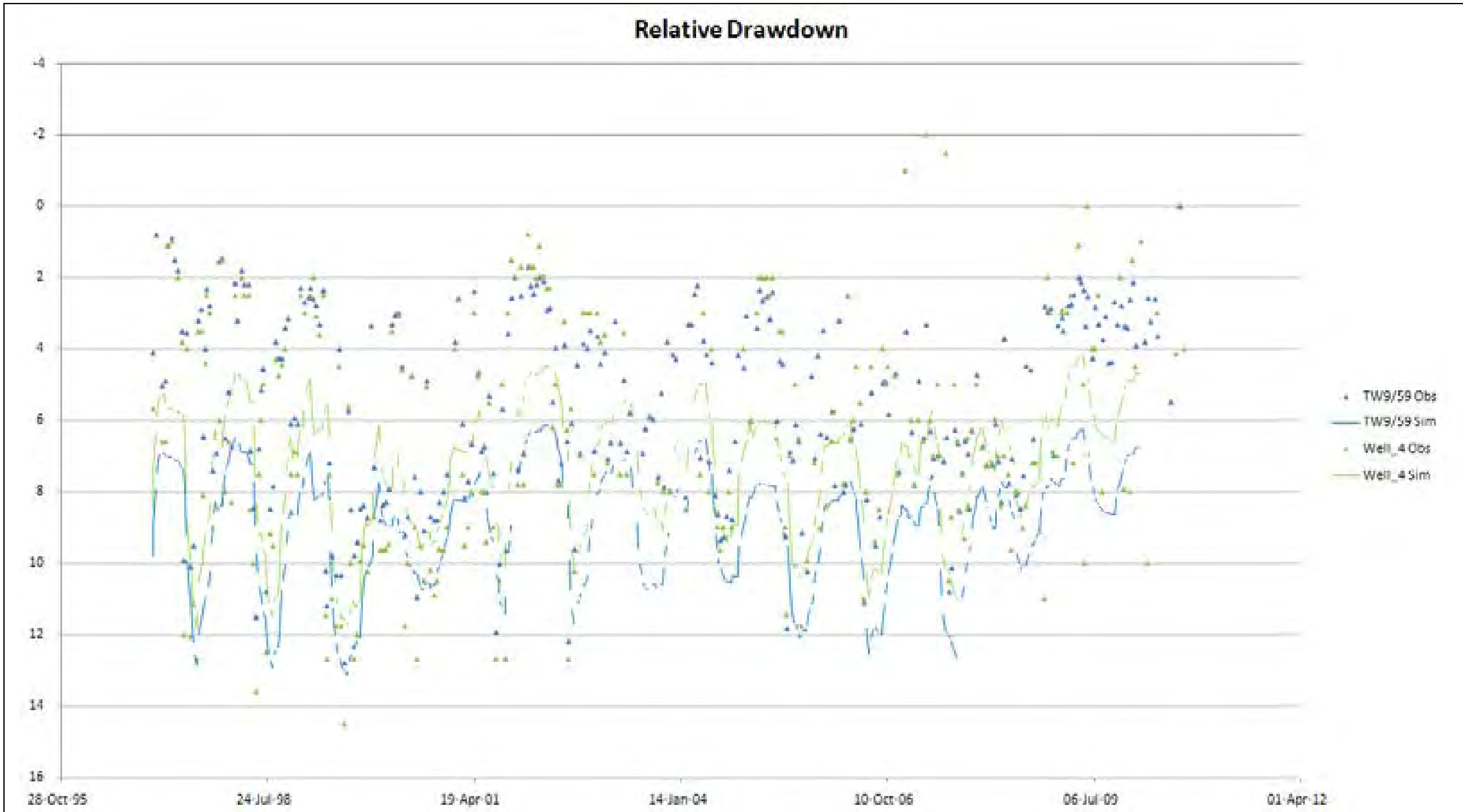
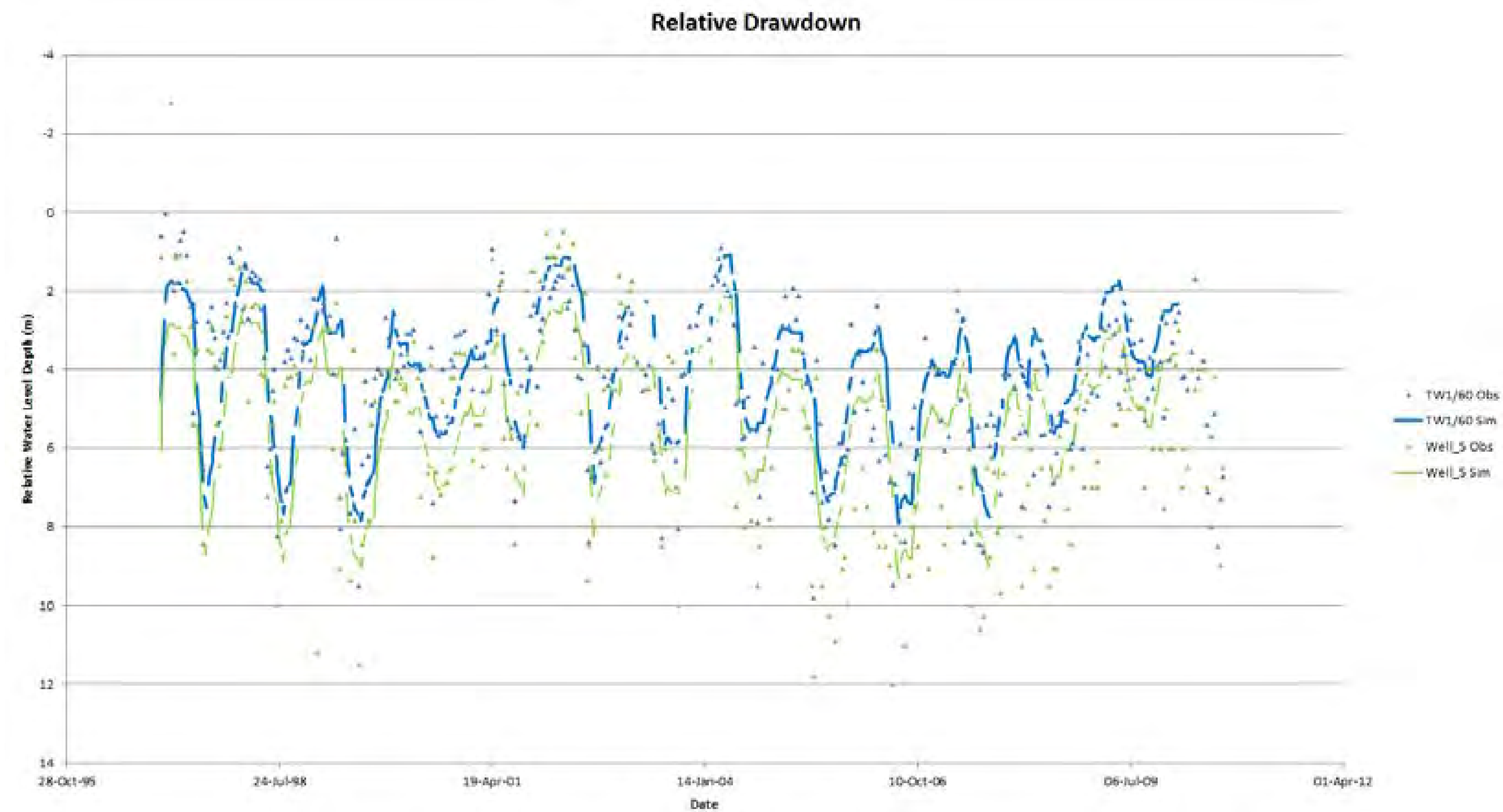
Golder Associates
IWC



City of Barrie Tier Three Water Budget and Local Area Risk Assessment	Figure C.5.2: Transient Groundwater Model Calibration Results (Well 4)	AquaResource Inc. Integrity · Technology · Solutions; Golder Associates; IWC



City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Figure C.5.3: Transient Groundwater Model Calibration Results (Well 5)

AquaResource Inc.
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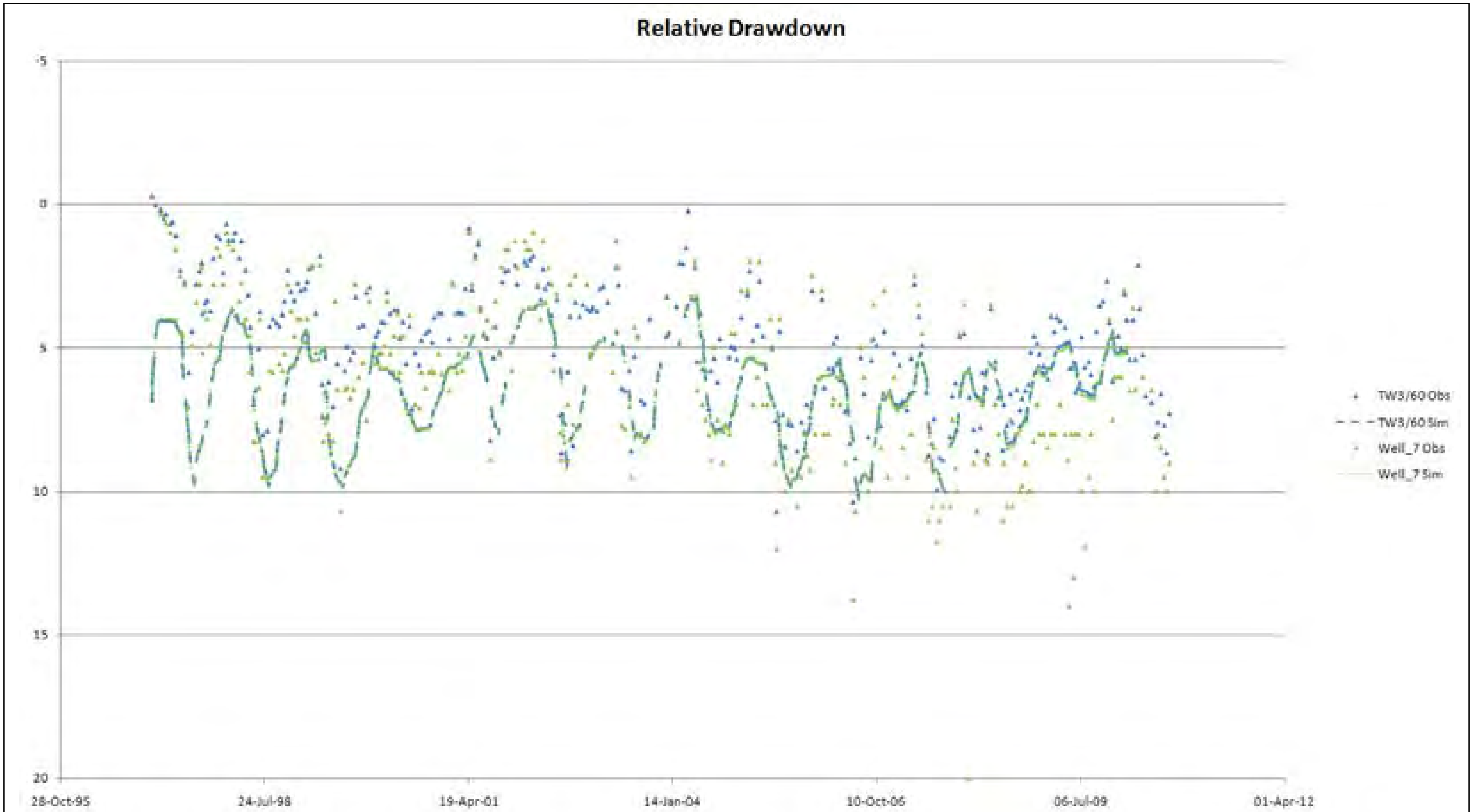
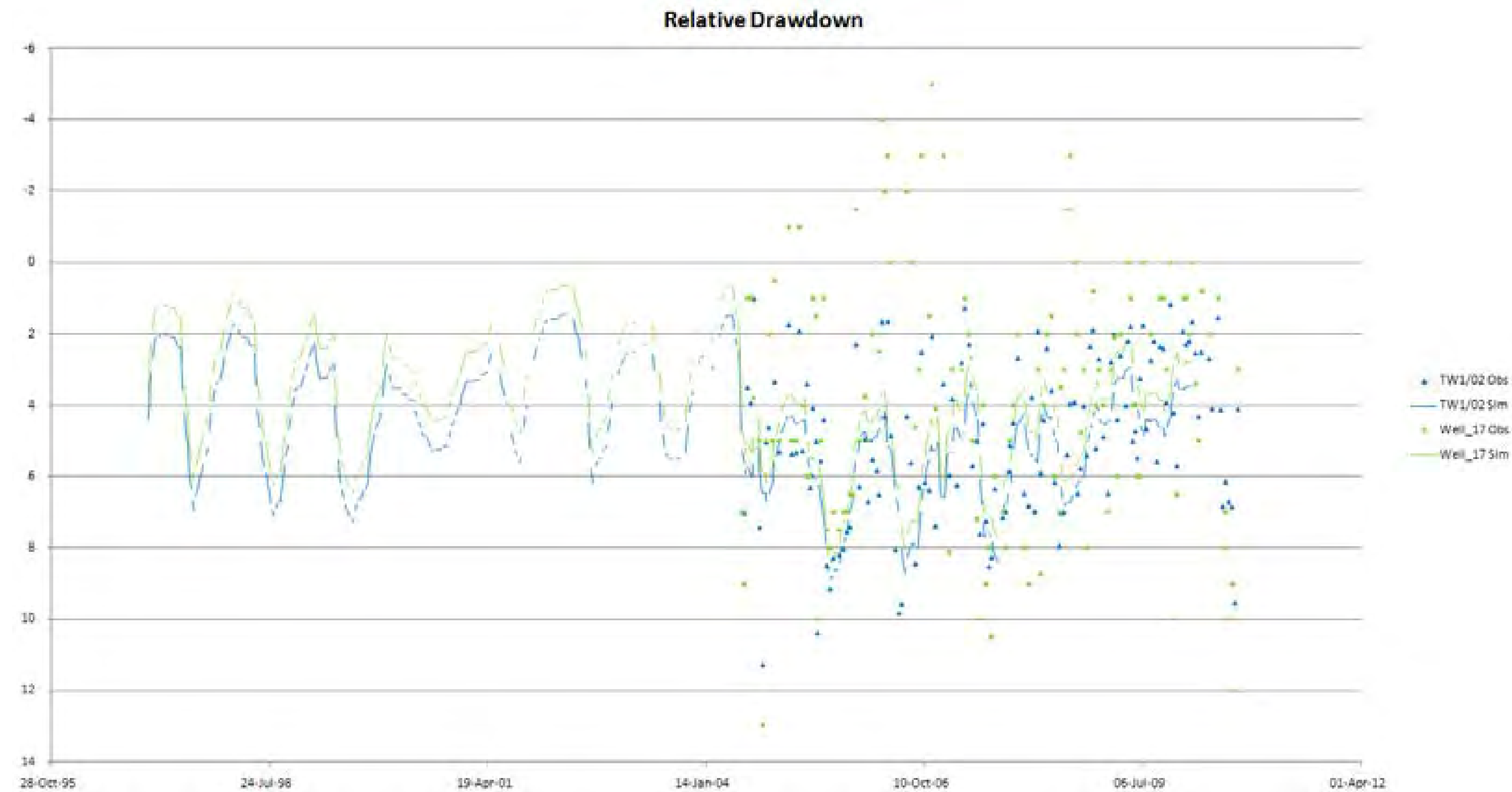
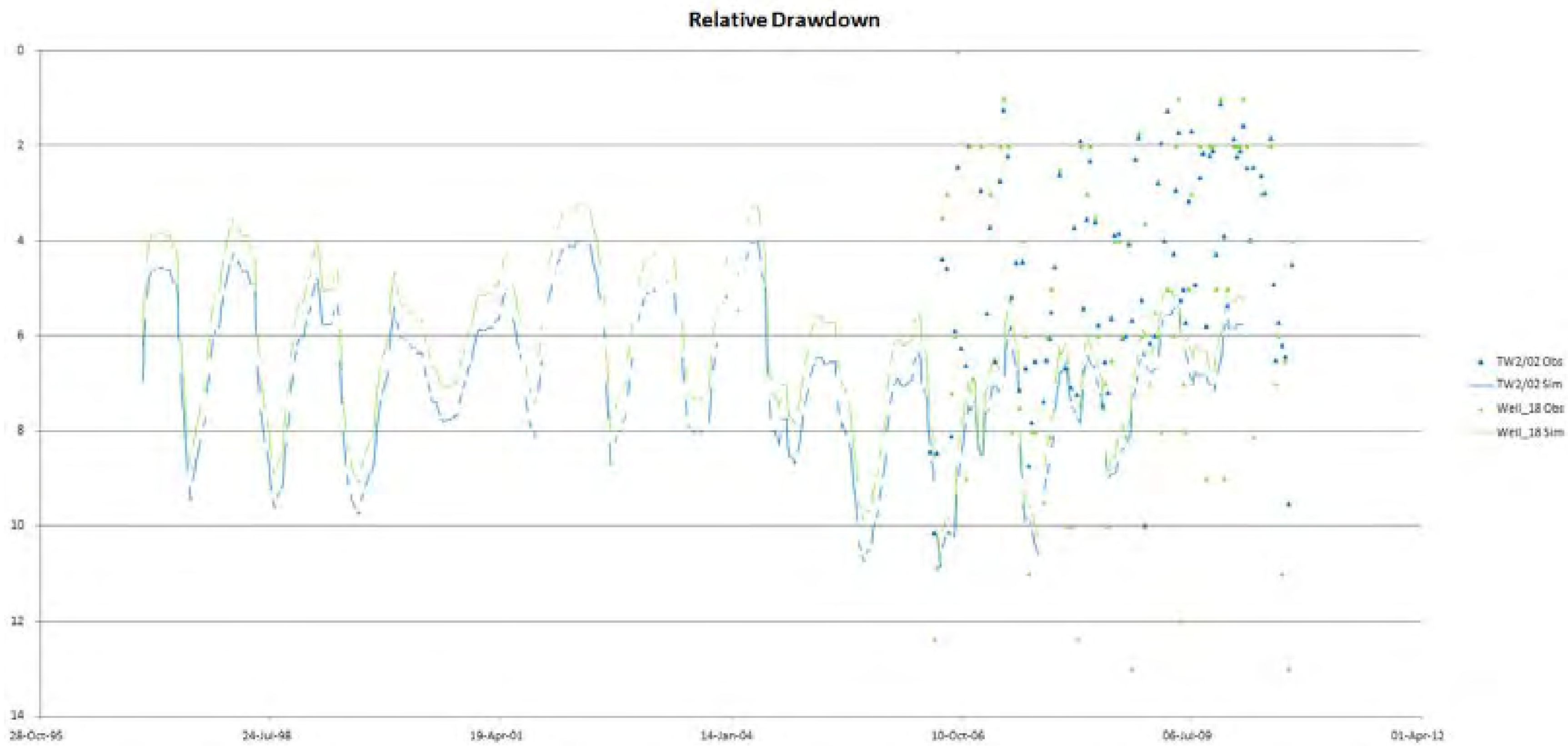
Golder Associates
IWC



City of Barrie Tier Three Water Budget and Local Area Risk Assessment	Figure C.5.4: Transient Groundwater Model Calibration Results (Well 7)	AquaResource Inc. Integrity · Technology · Solutions; Golder Associates; IWC



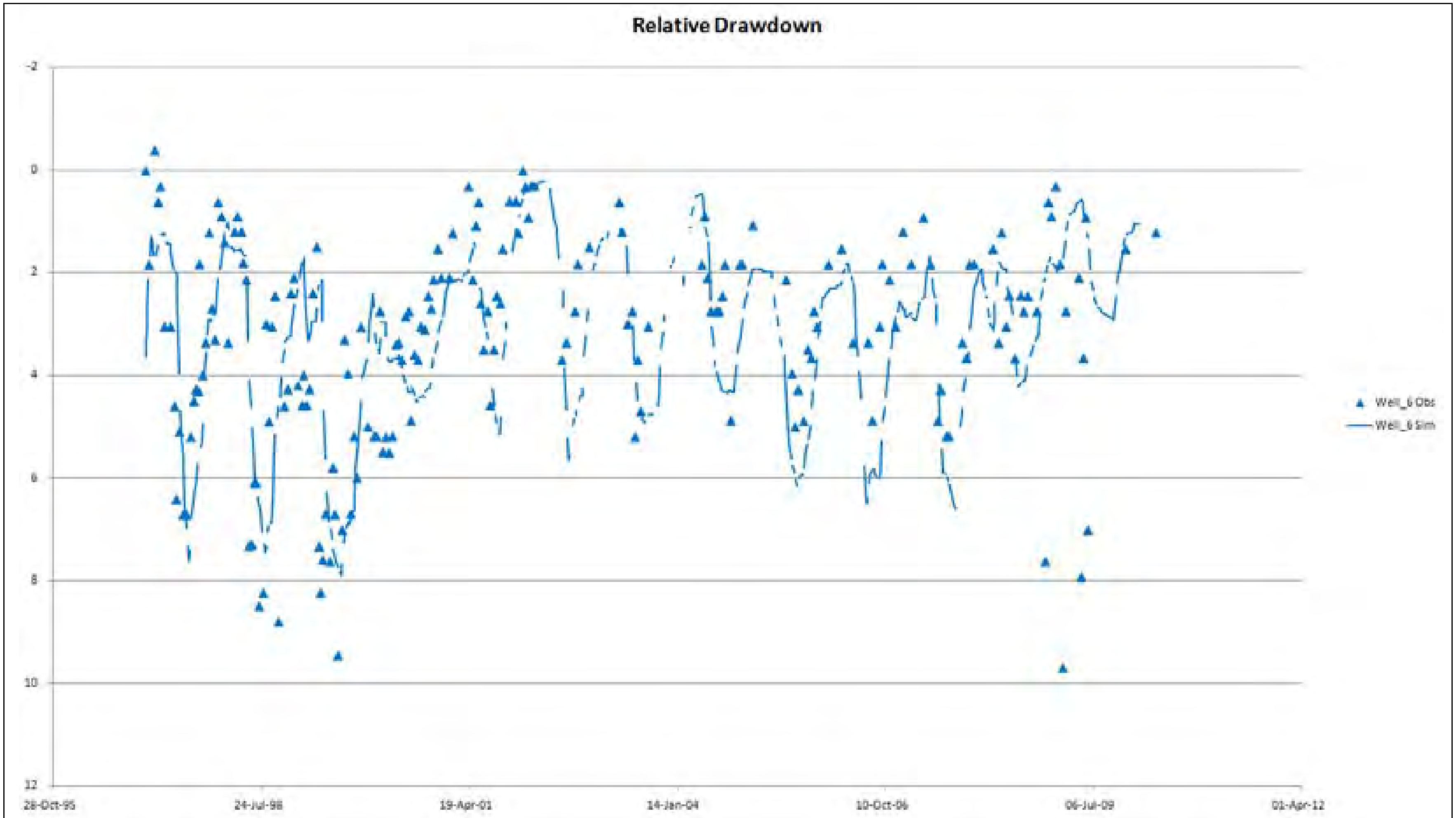
City of Barrie Tier Three Water Budget and Local Area Risk Assessment	Figure C.5.5a: Transient Groundwater Model Calibration Results (Well 17)	AquaResource Inc. Integrity · Technology · Solutions Golder Associates IWC



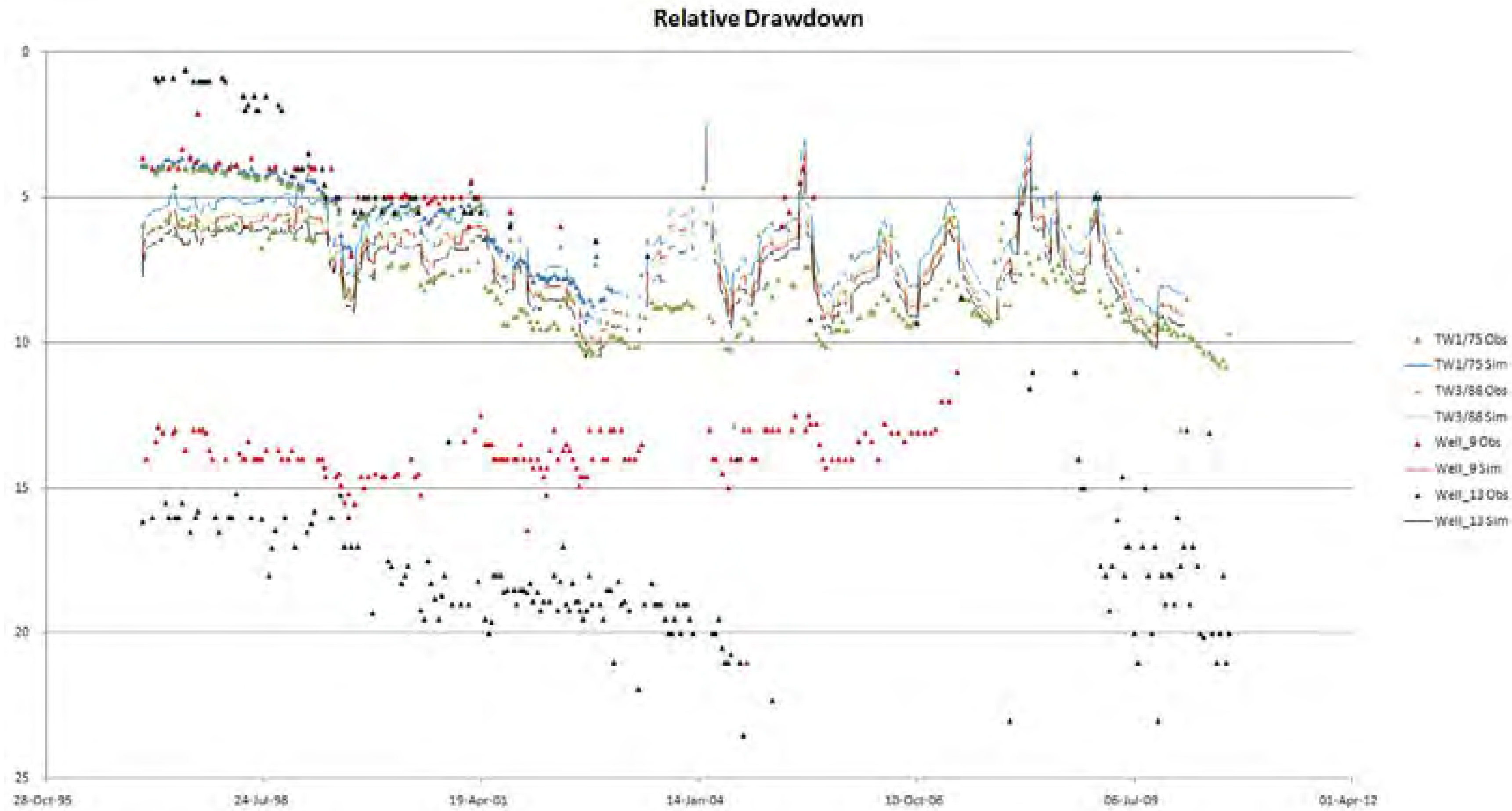
City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Figure C.5.5b: Transient Groundwater Model Calibration Results (Well 18)

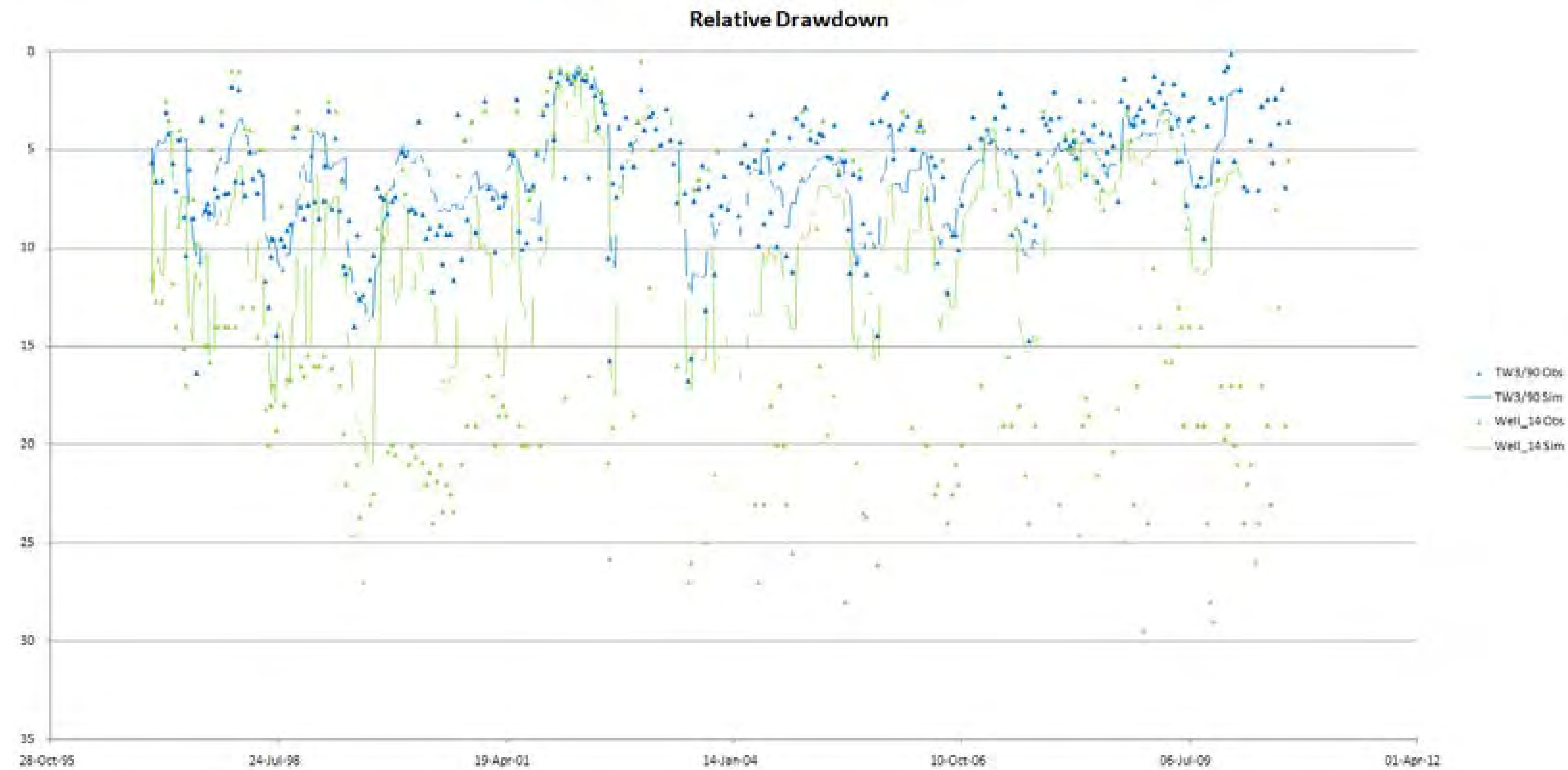
AquaResource Inc.
Integrity · Technology · Solutions
Golder Associates
IWC



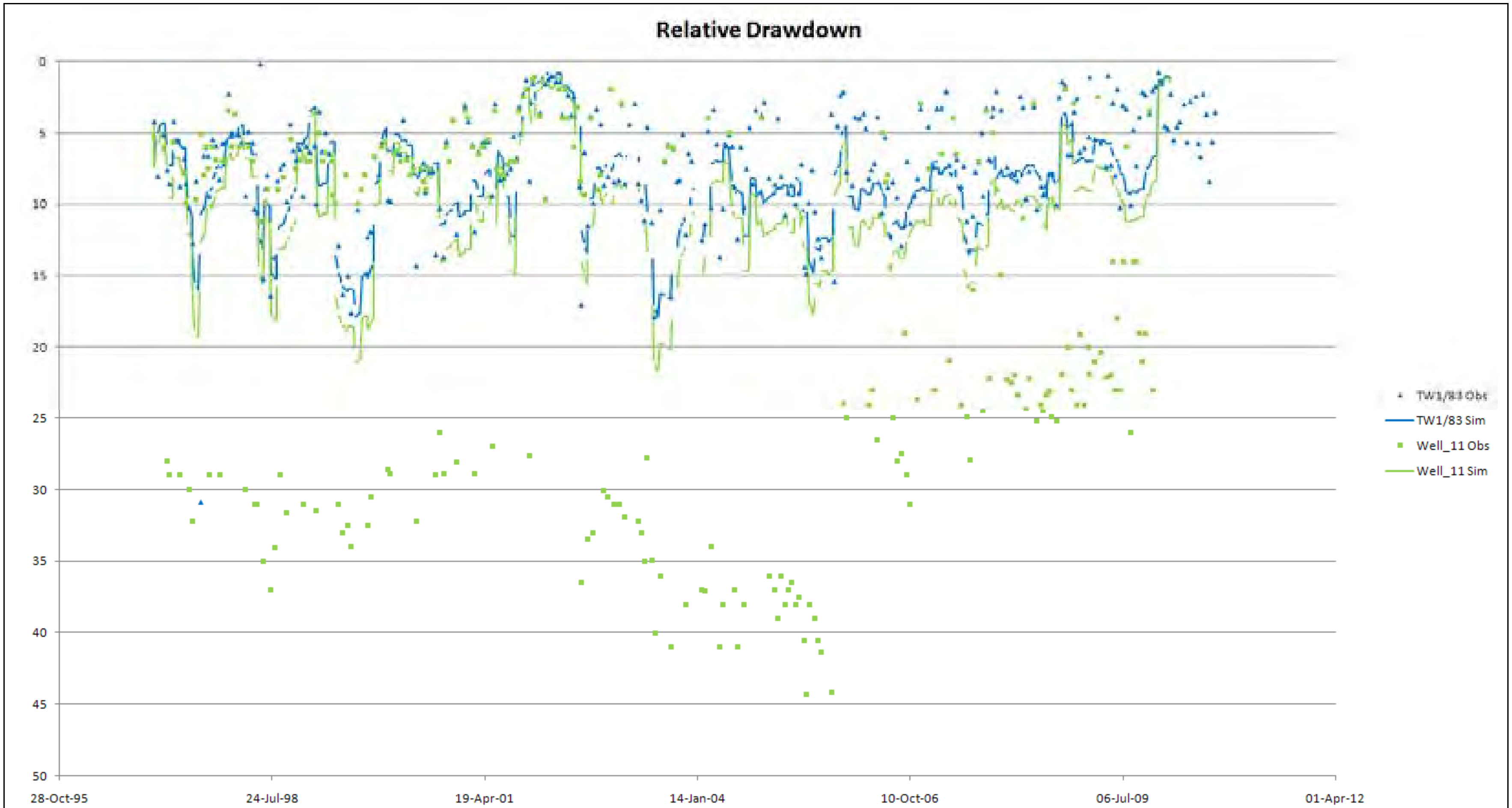
City of Barrie Tier Three Water Budget and Local Area Risk Assessment	Figure C.5.6: Transient Groundwater Model Calibration Results (Well 6)	AquaResource Inc. Integrity · Technology · Solutions; Golder Associates; IWC



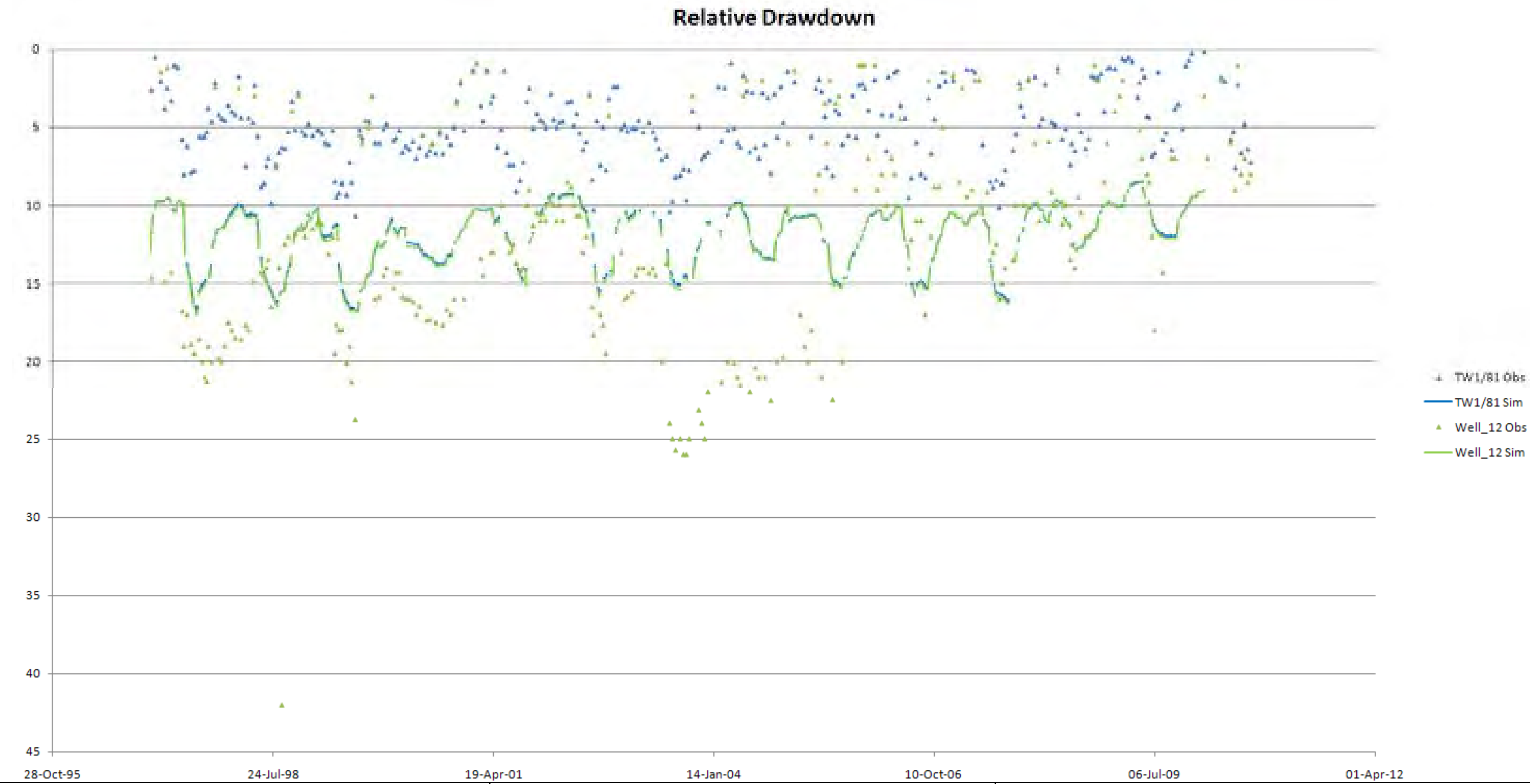
City of Barrie Tier Three Water Budget and Local Area Risk Assessment	Figure C.5.7: Transient Groundwater Model Calibration Results (Wells 9 and 13)	AquaResource Inc. Integrity · Technology · Solutions Golder Associates IWC



City of Barrie Tier Three Water Budget and Local Area Risk Assessment	Figure C.5.8a: Transient Groundwater Model Calibration Results (Well 14)	AquaResource Inc. Integrity · Technology · Solutions Golder Associates IWC



City of Barrie Tier Three Water Budget and Local Area Risk Assessment	Figure C.5.8b: Transient Groundwater Model Calibration Results (Well 11)	AquaResource Inc. Integrity · Technology · Solutions; Golder Associates; IWC



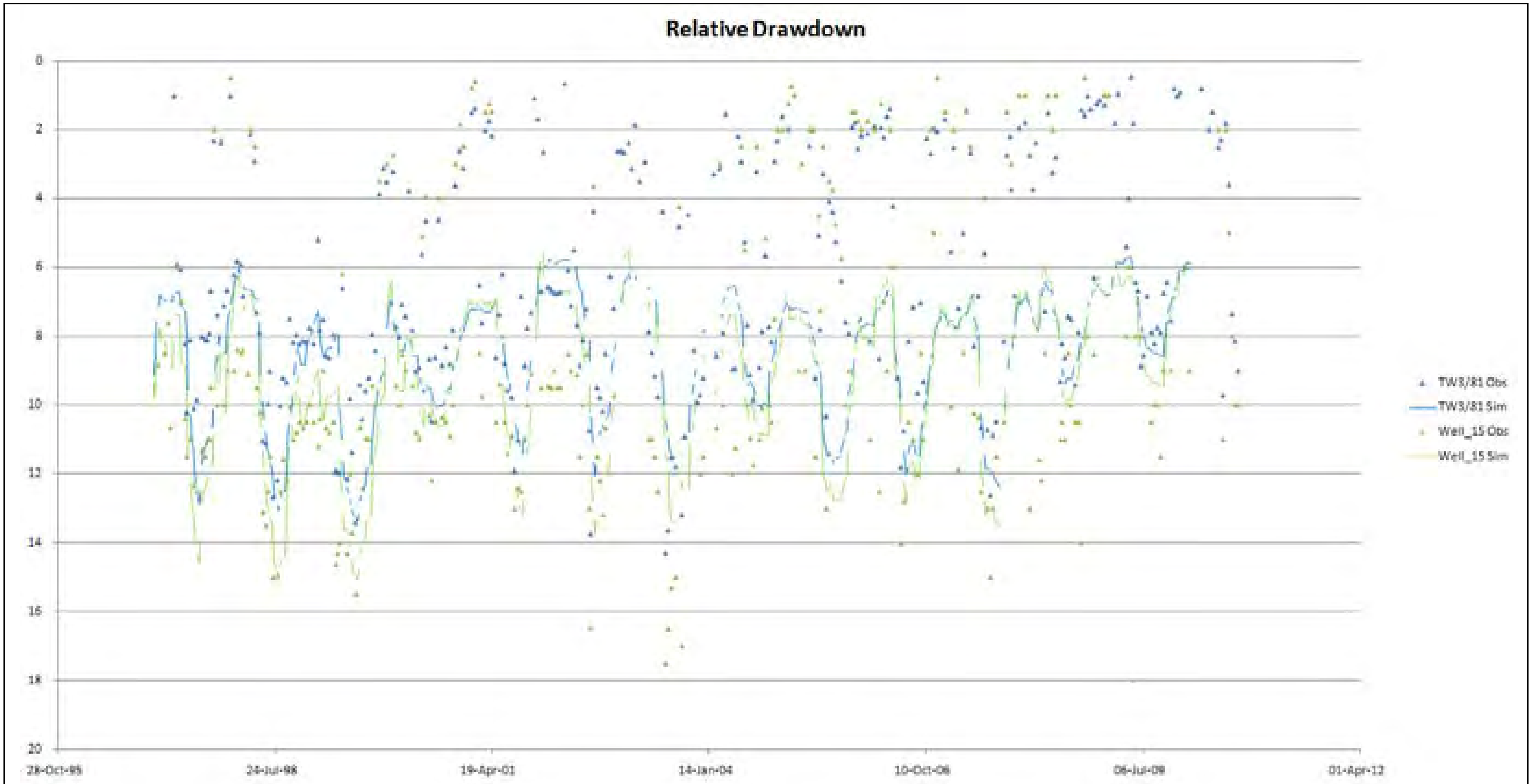
City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Figure C.5.9: Transient Groundwater Model Calibration Results (Well 12)

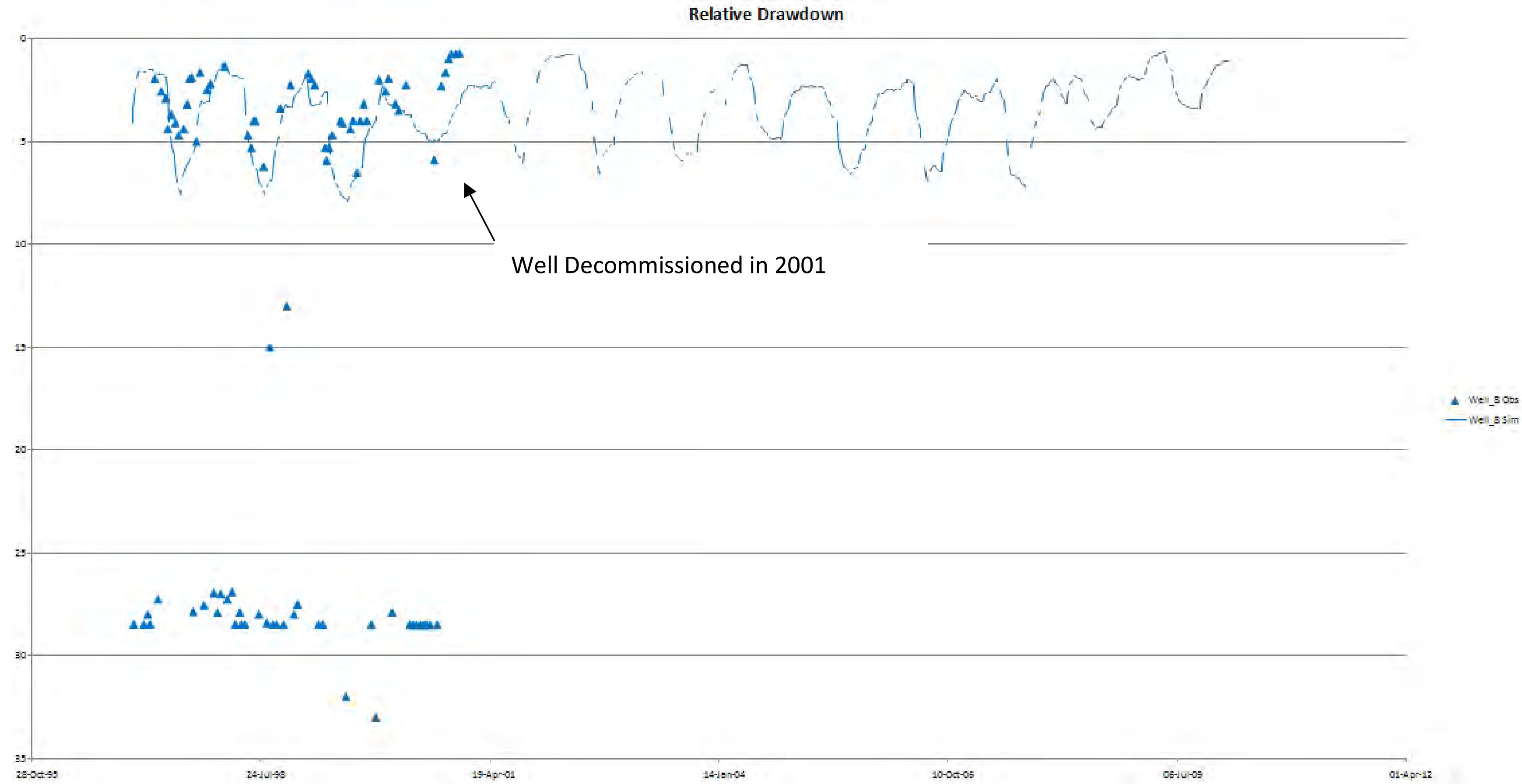
AquaResource Inc. Integrity · Technology · Solutions

Golder Associates

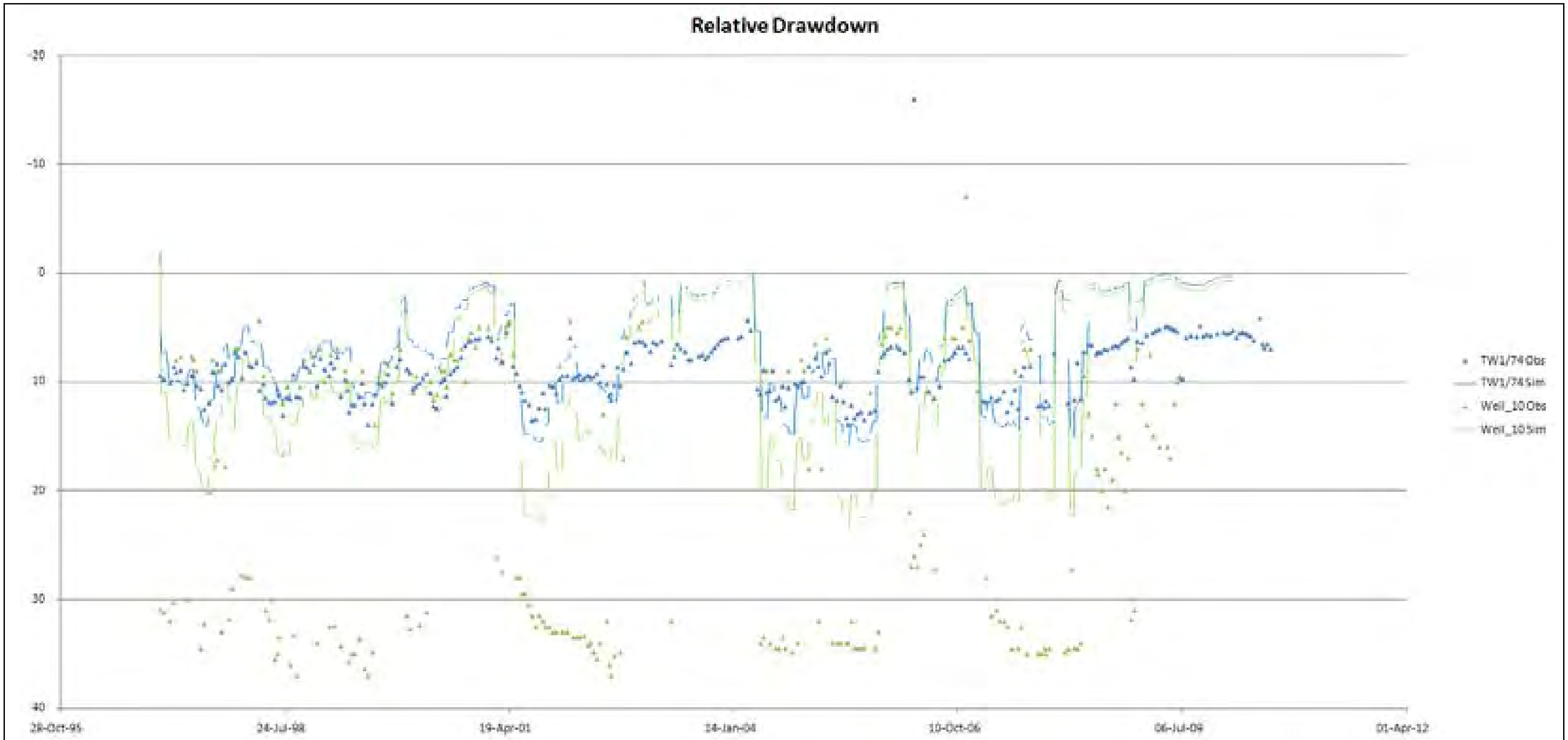
IWC



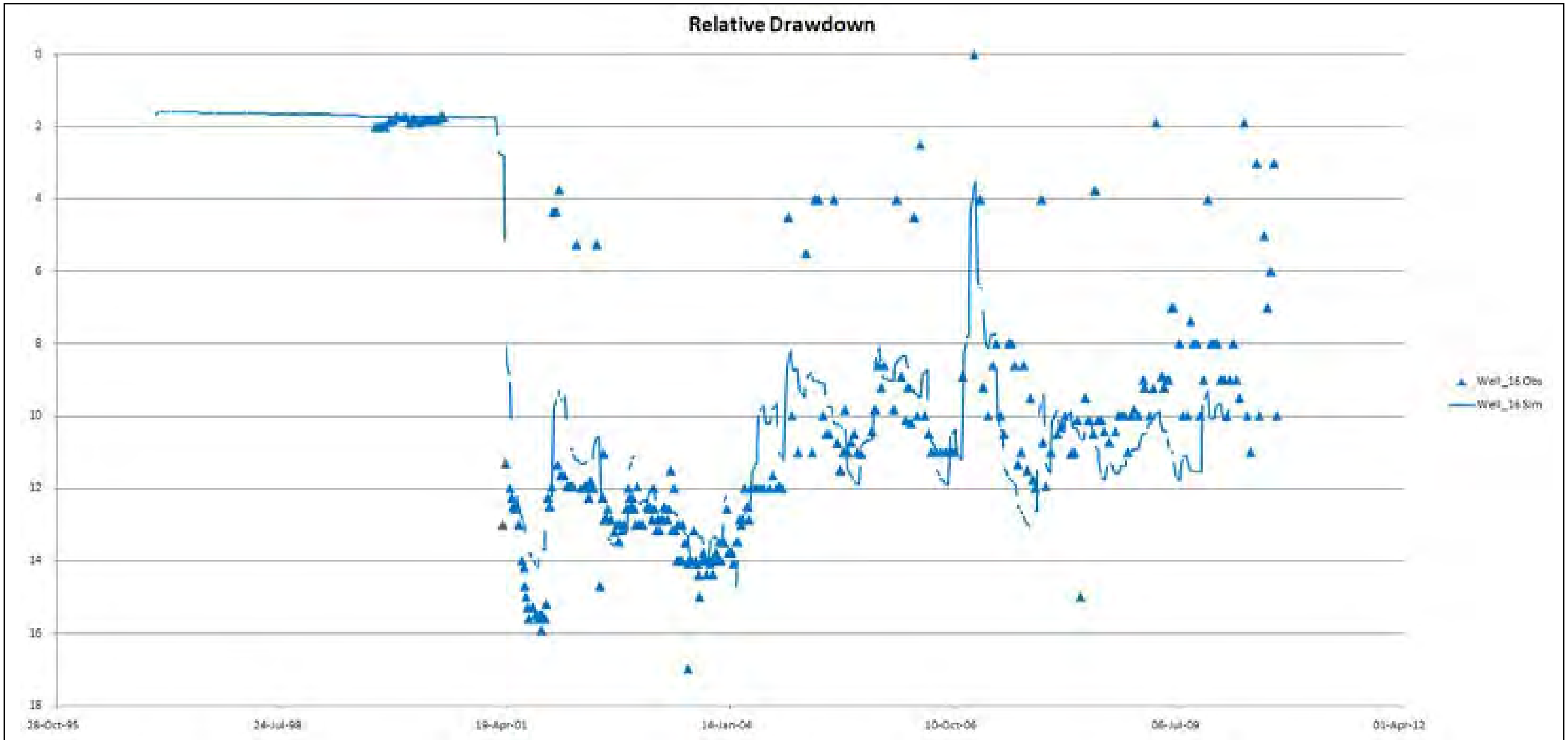
City of Barrie Tier Three Water Budget and Local Area Risk Assessment	Figure C.5.10: Transient Groundwater Model Calibration Results (Well 15)	AquaResource Inc. Integrity · Technology · Solutions; Golder Associates; IWC



City of Barrie Tier Three Water Budget and Local Area Risk Assessment	Figure C.5.11: Transient Groundwater Model Calibration Results (Well 8)	AquaResource Inc. Integrity · Technology · Solutions; Golder Associates; IWC



City of Barrie Tier Three Water Budget and Local Area Risk Assessment	Figure C.5.12: Transient Groundwater Model Calibration Results (Well 10)	AquaResource Inc. Integrity · Technology · Solutions; Golder Associates; IWC



City of Barrie Tier Three Water Budget and Local Area Risk Assessment

Figure C.5.13: Transient Groundwater Model Calibration Results (Well 16)

AquaResource Inc. Integrity · Technology · Solutions

Golder Associates

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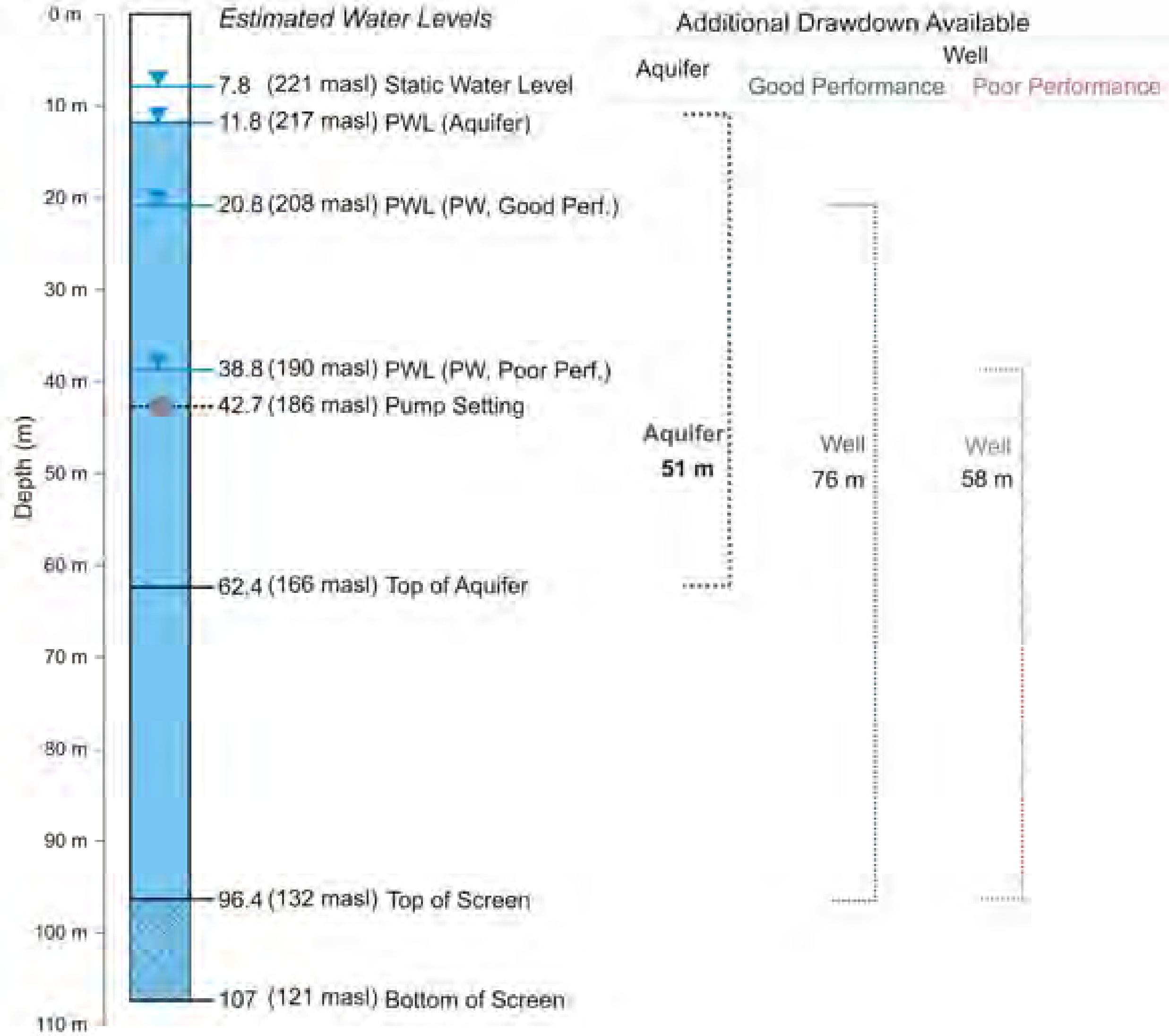
BARRIE TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

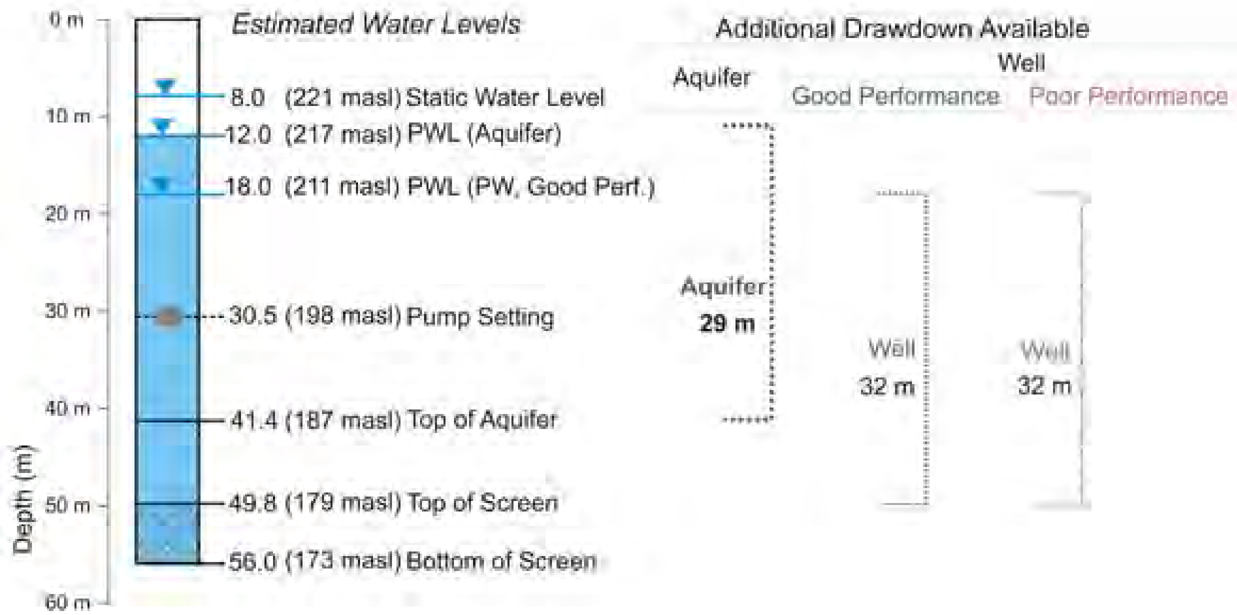
APPENDIX D: SAFE AVAILABLE DRAWDOWN ESTIMATION FOR INDIVIDUAL MUNICIPAL WELLS

Safe Drawdown Well 3A



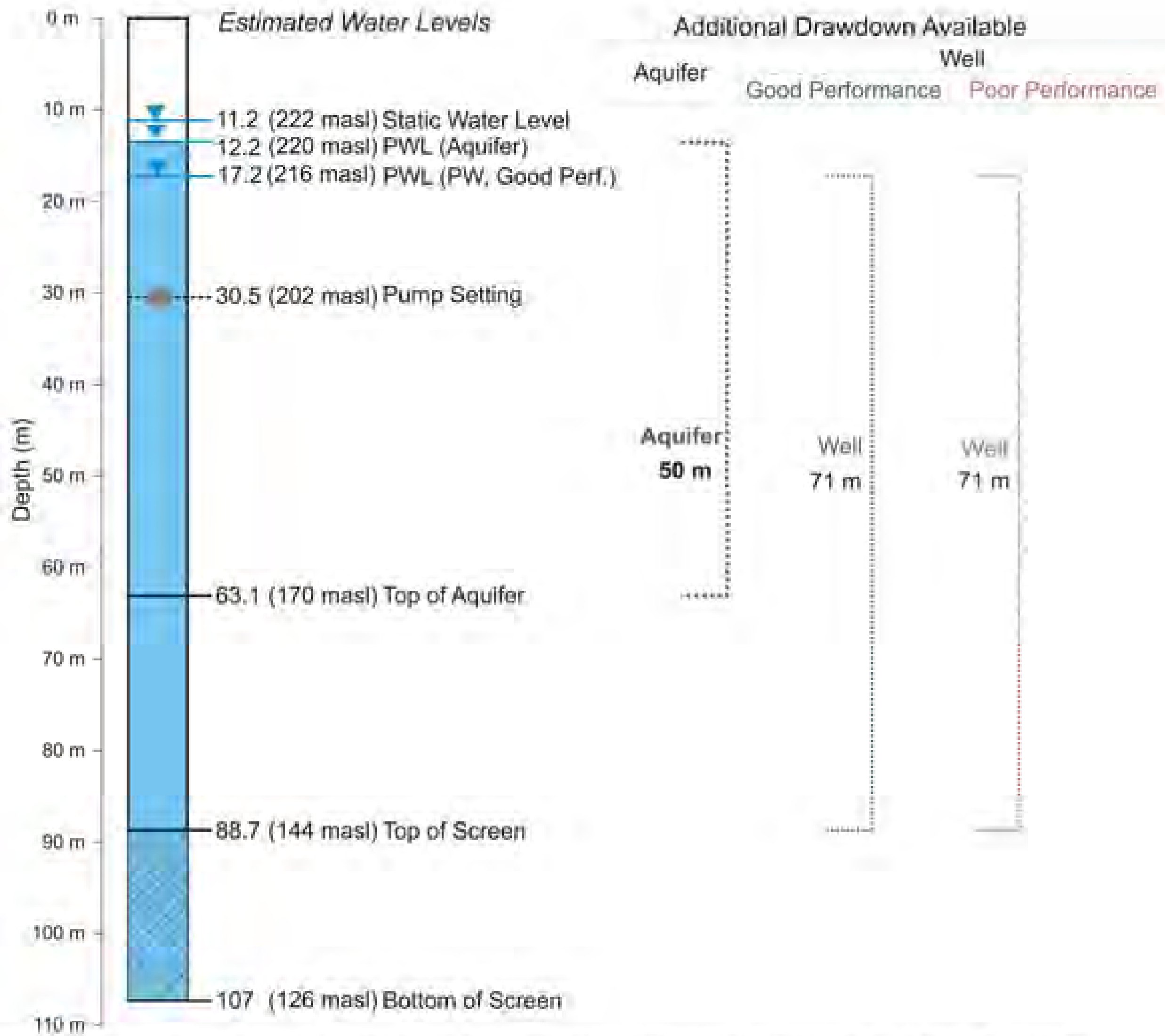
PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)

Safe Drawdown Well 4



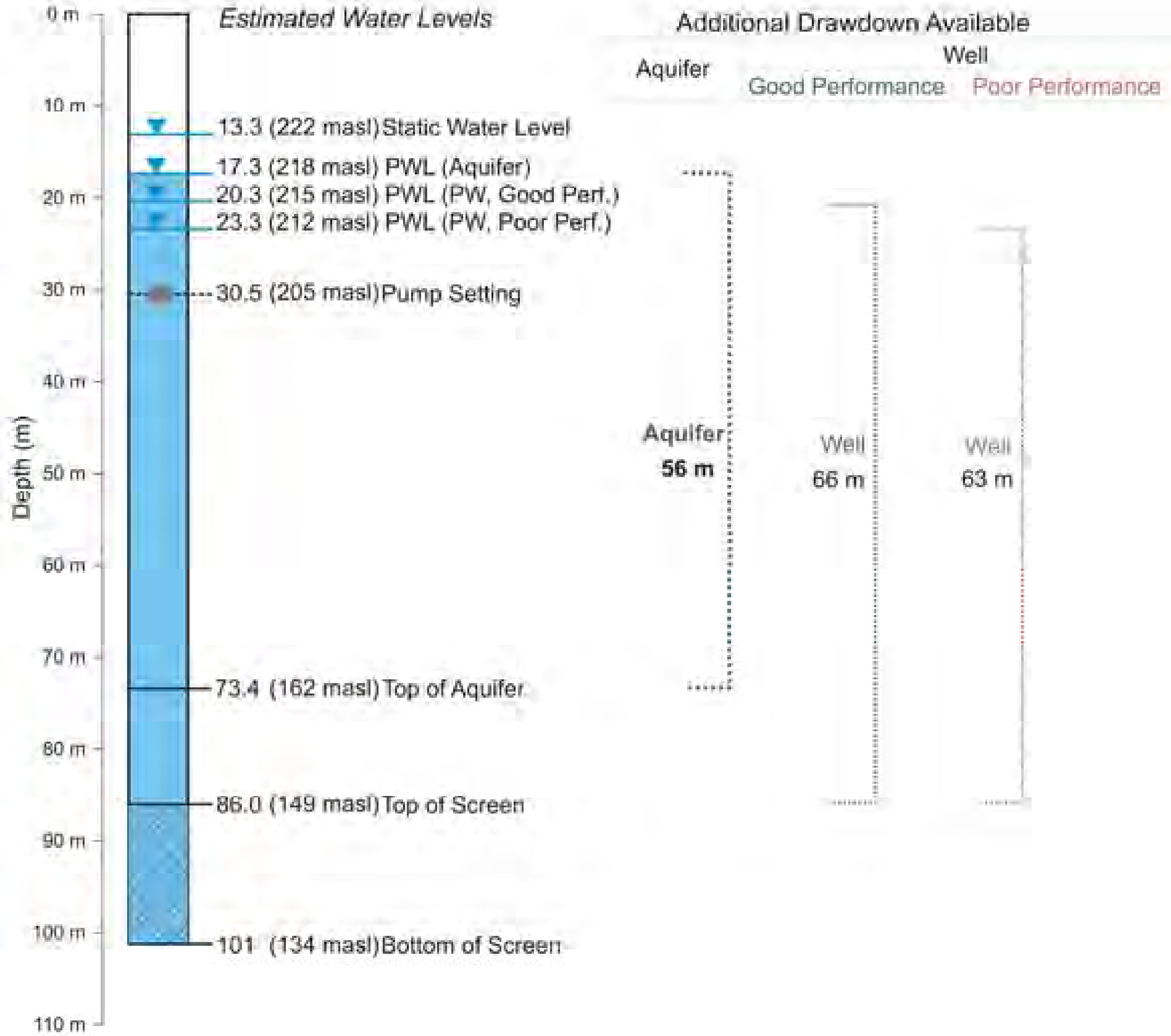
PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)
*No significant difference between 'good' and 'poor' well performance

Safe Drawdown Well 5



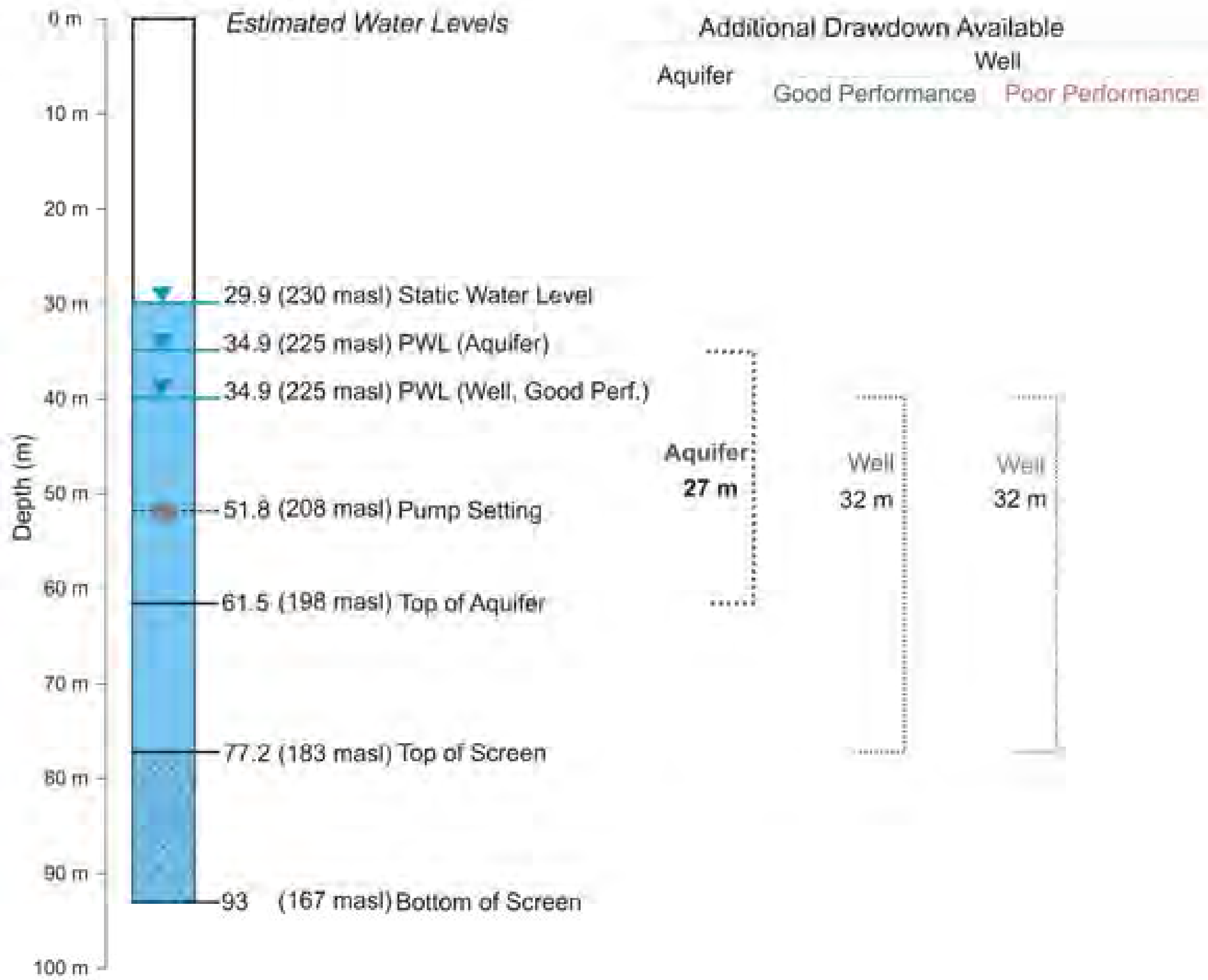
PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)
*No significant difference between 'good' and 'poor' well performance

Safe Drawdown Well 7



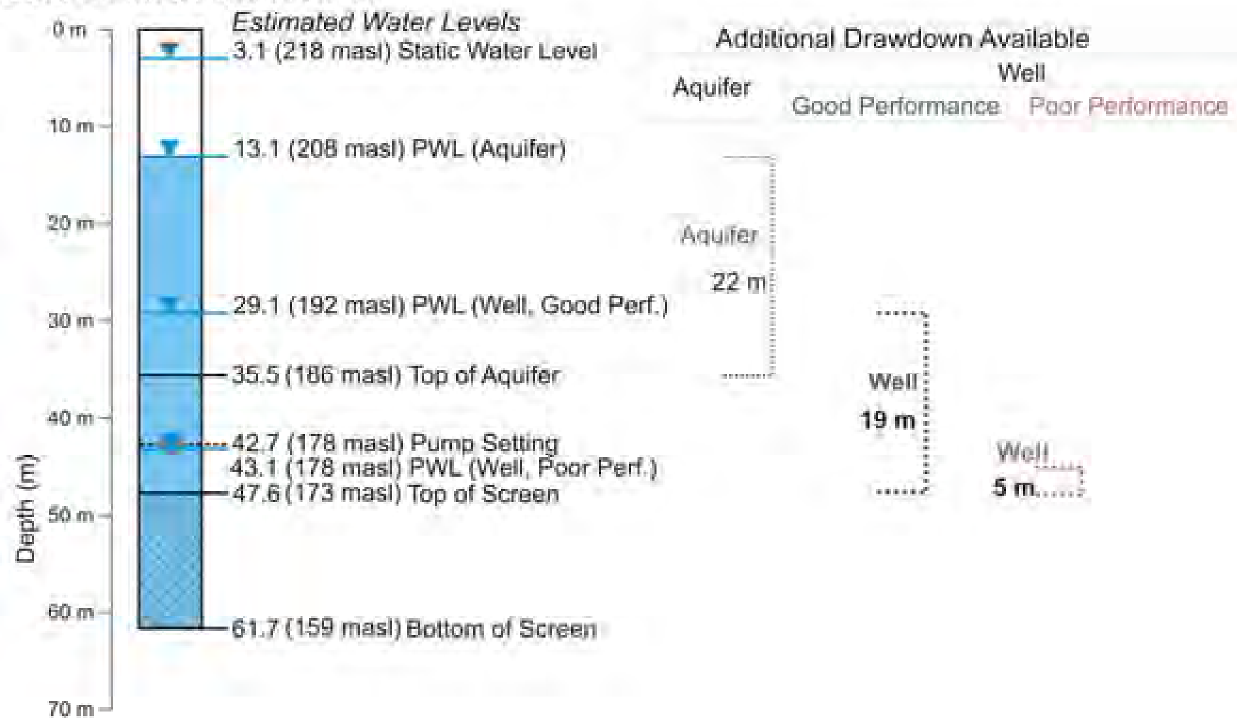
PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)

Safe Drawdown Well 9



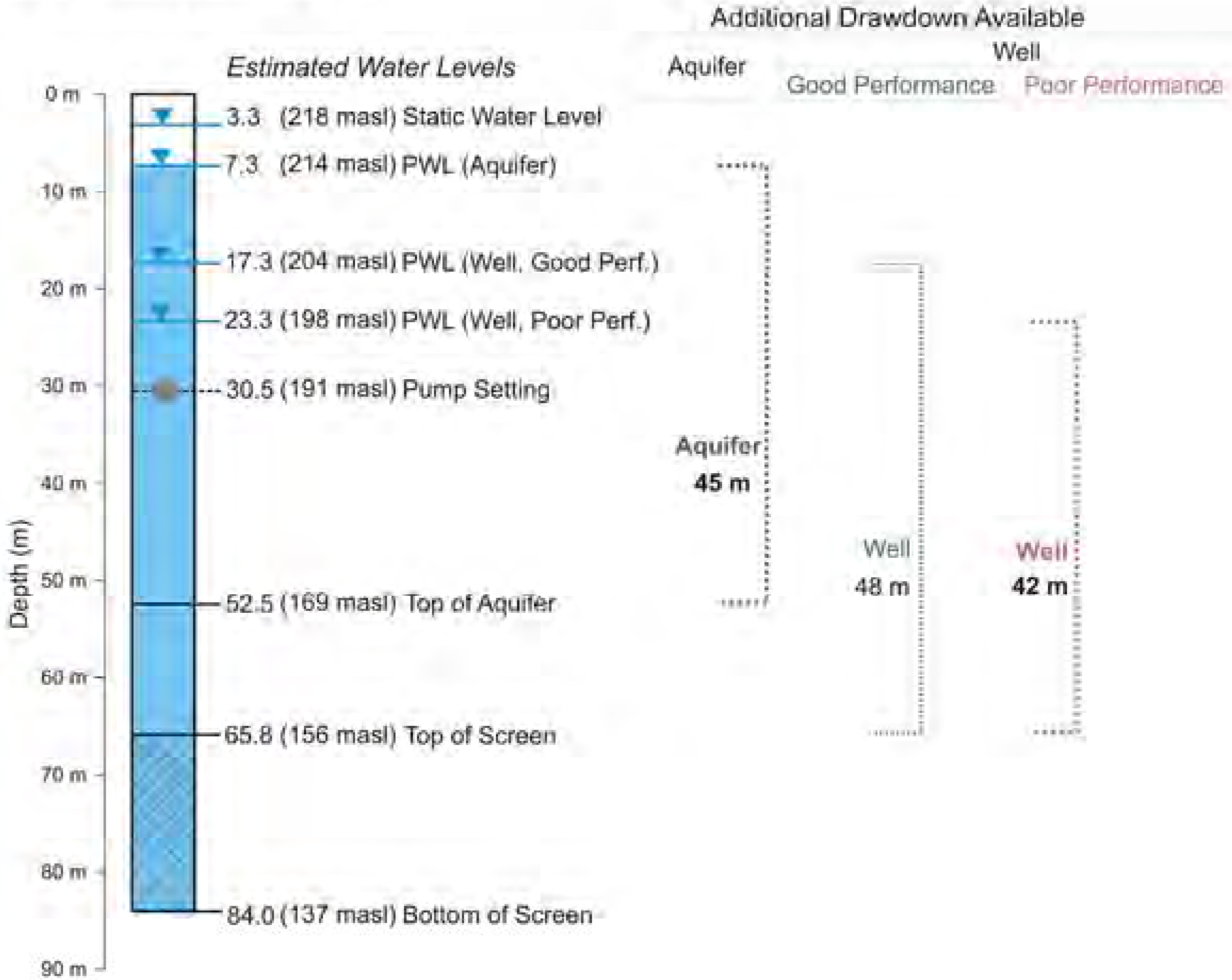
PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)
*No significant difference between 'good' and 'poor' well performance

Safe Drawdown Well 11



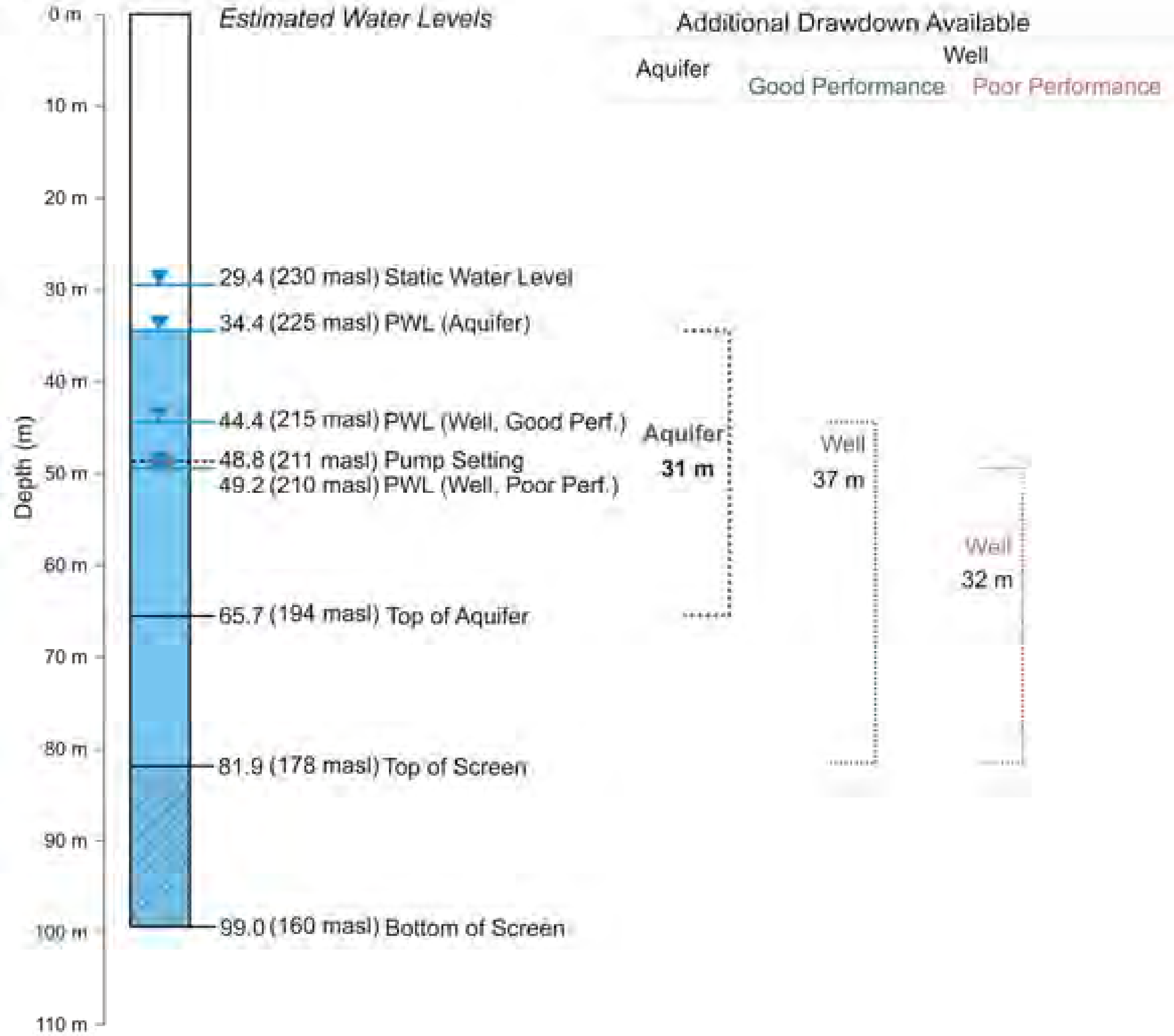
PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)

Safe Drawdown Well 12



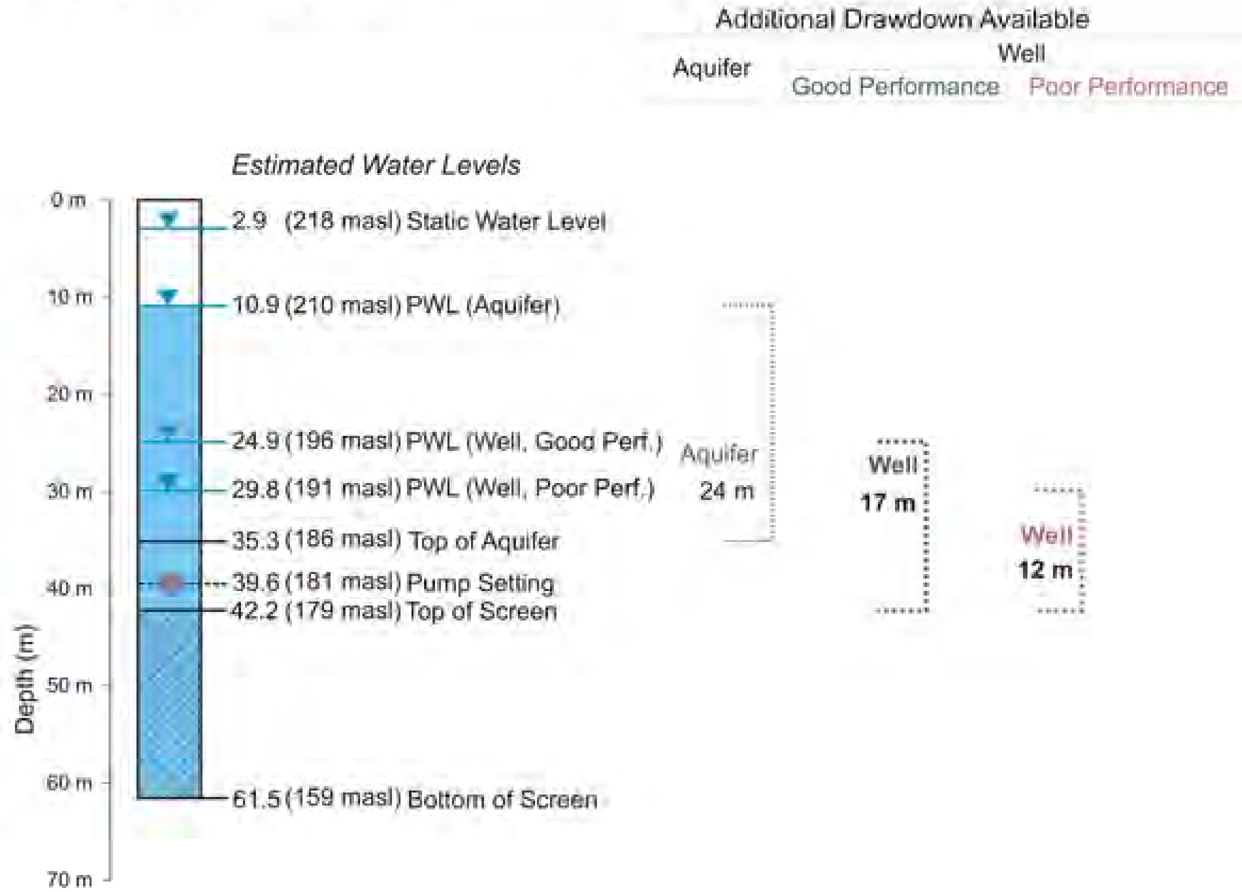
PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)

Safe Drawdown Well 13



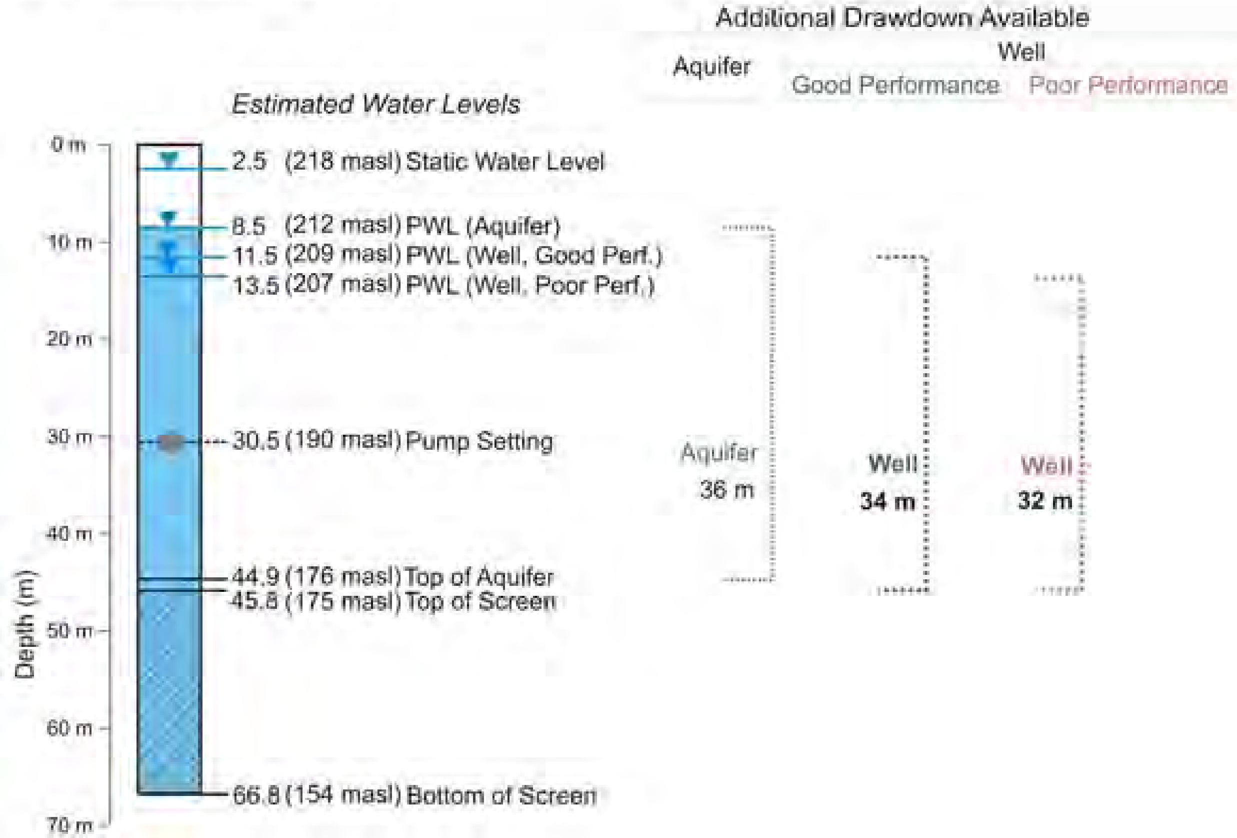
PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)

Safe Drawdown Well 14



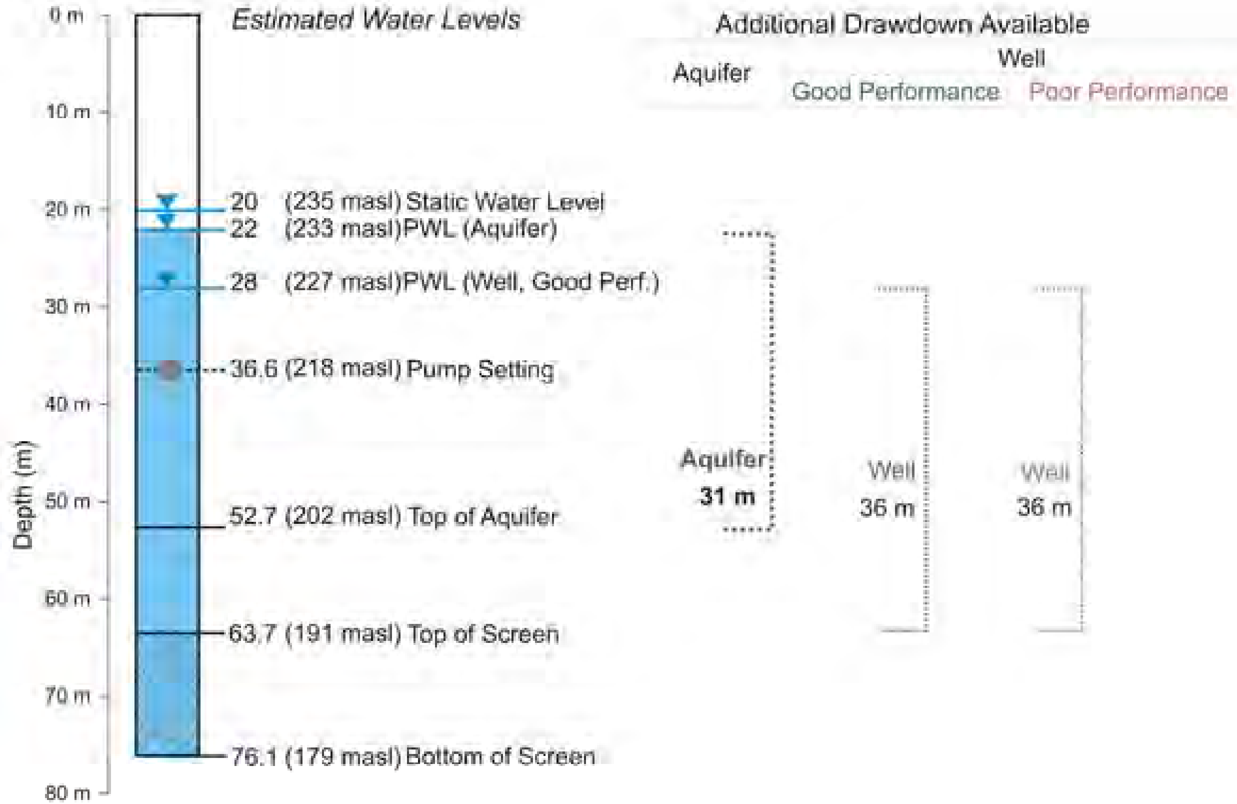
PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)

Safe Drawdown Well 15



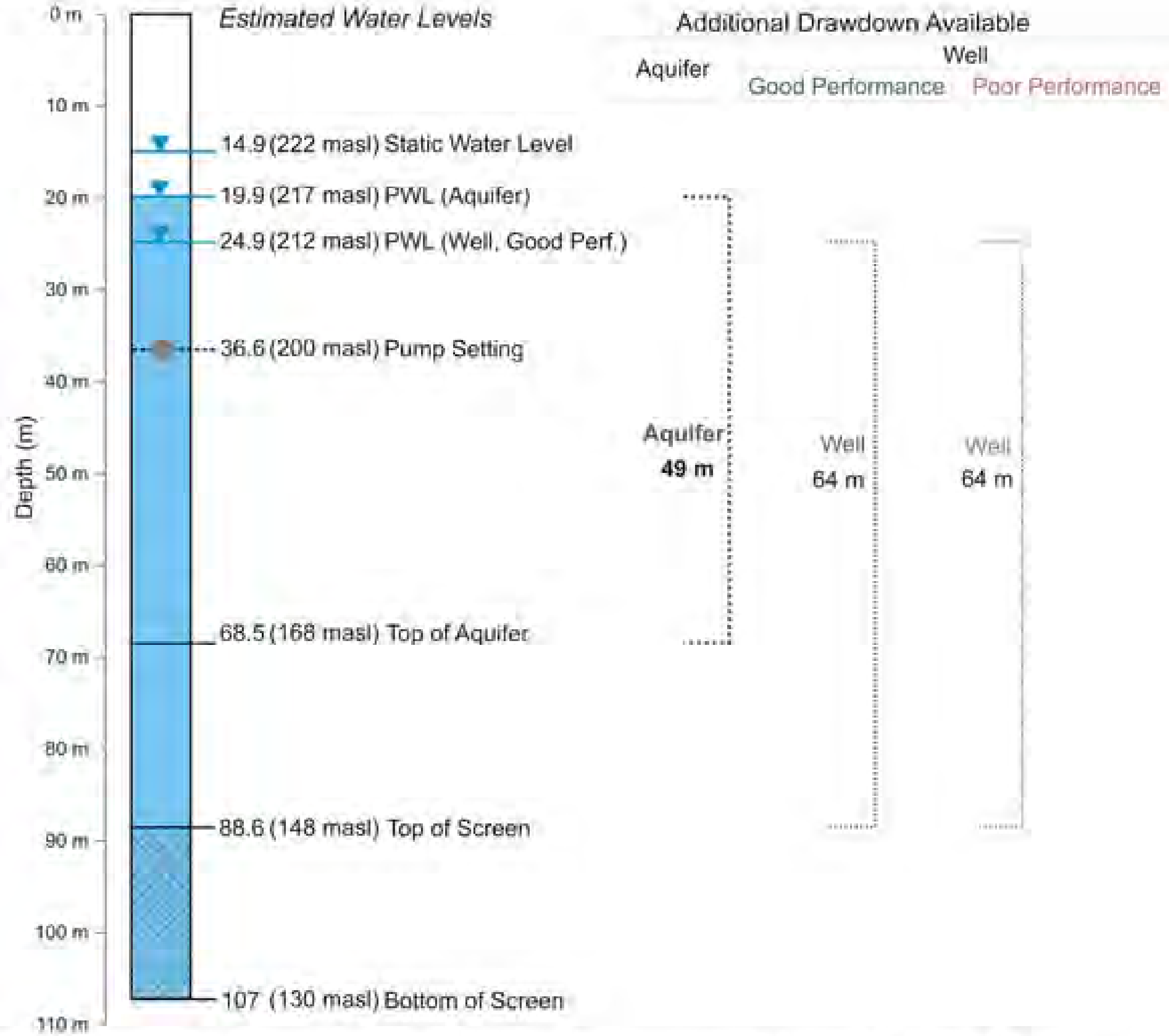
PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)

Safe Drawdown Well 16



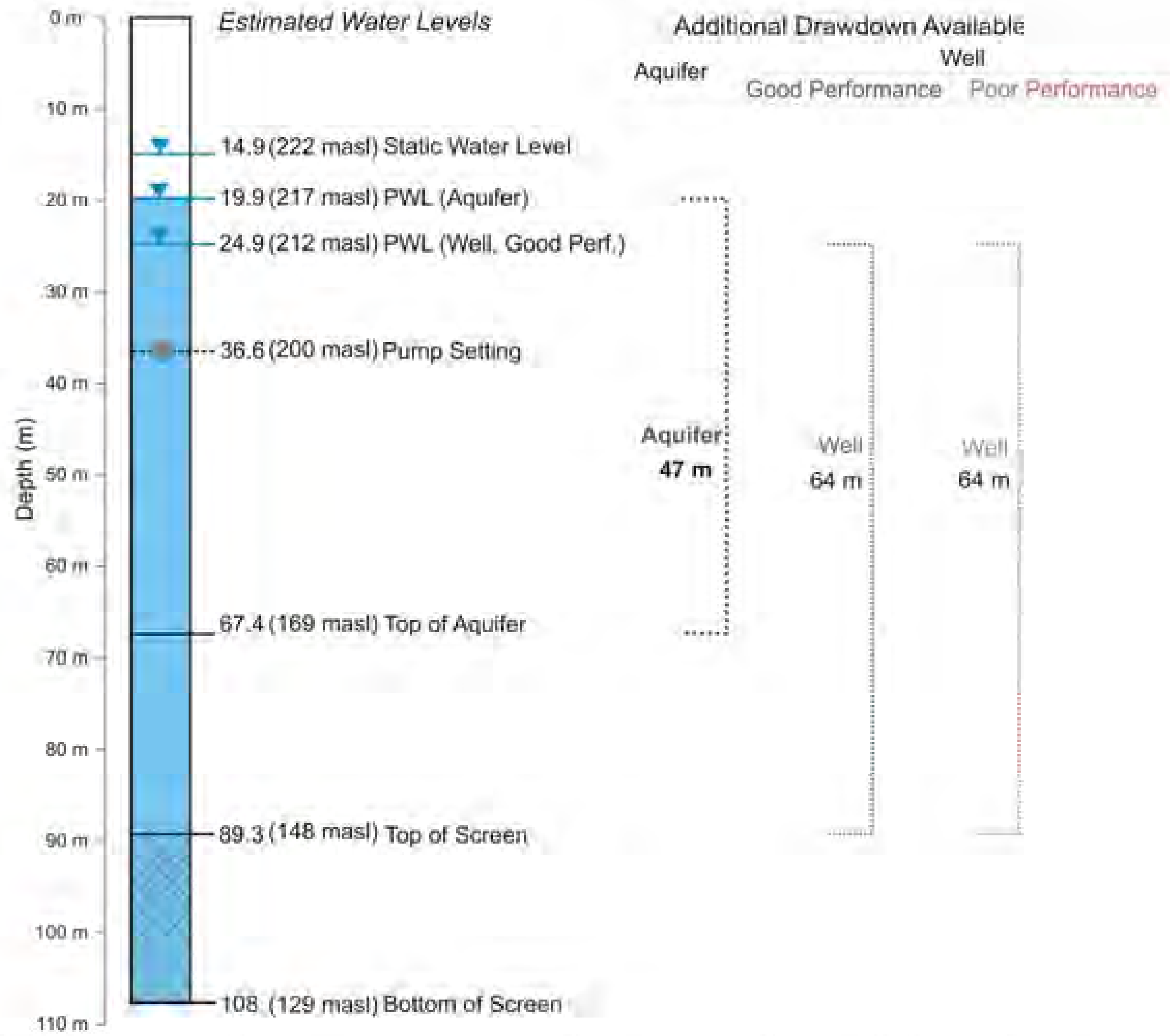
PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)
*No significant difference between 'good' and 'poor' well performance

Safe Drawdown Well 17



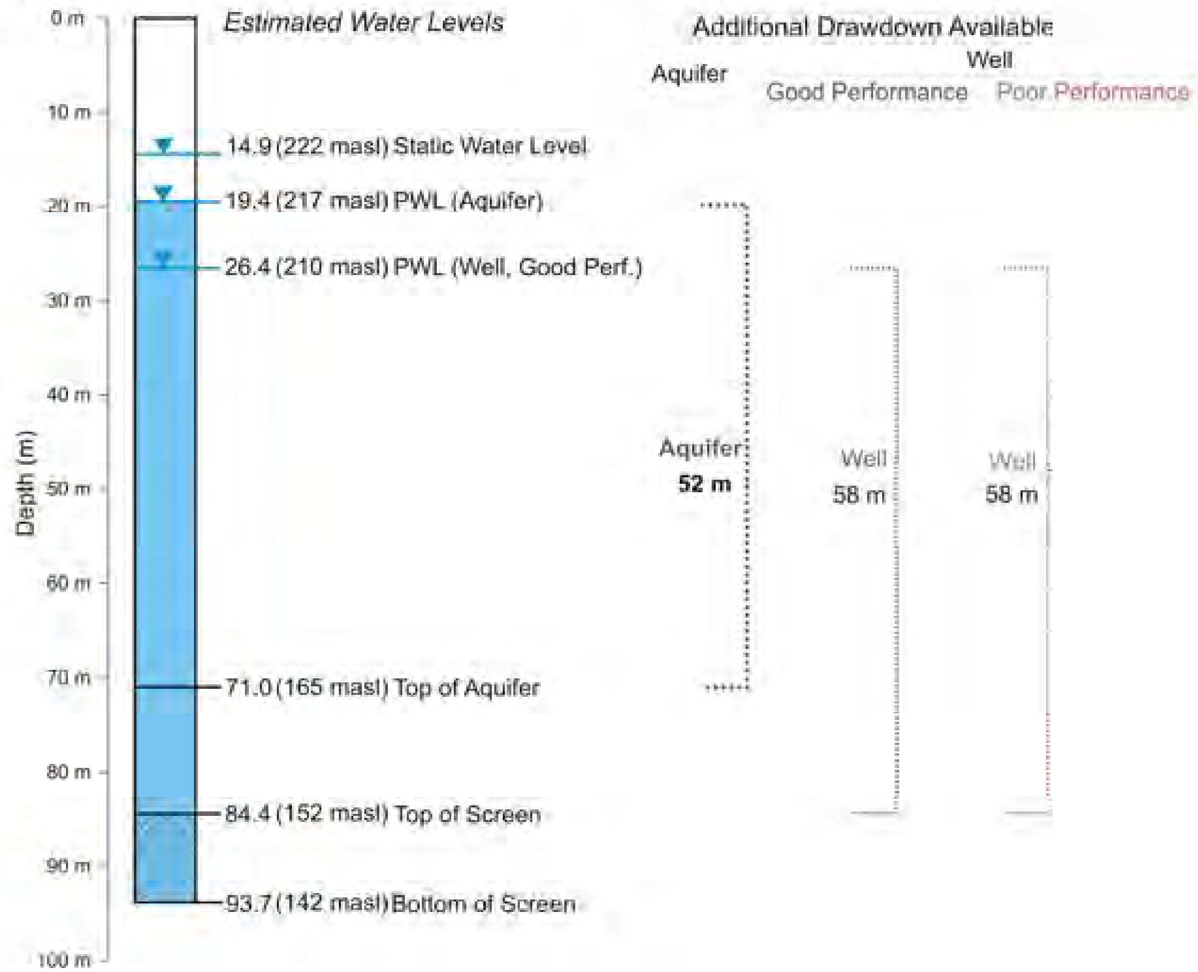
PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)
*No significant difference between 'good' and 'poor' well performance

Safe Drawdown Well 18



PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)
*No significant difference between 'good' and 'poor' well performance

Safe Drawdown Well 19



PWL: Representative Pumped Water Levels Estimated from Hydrographs (Appendix C: Concept. Report)
*Well not in operation, well performance estimated

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BARRIE TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

APPENDIX E: WHPA-Q2 IMPACT ON MUNICIPAL WELLS FROM INDIVIDUAL AREAS OF LAND USE CHANGE

AquaResource
A Division of Matrix Solutions Inc.

- MEMORANDUM –

May 18, 2012

RE: WHPA-Q2 – Impact on Municipal Wells from Individual Areas of Land Use Change

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According to the Technical Rules (MOE, 2009), the WHPA-Q2 is defined as the WHPA-Q1 plus any area where a future reduction in recharge would have a measurable impact on the cone of influence or the available drawdown at the municipal wells. Areas where future reduction in recharge may occur were identified using the Official Plans, and the maximum recharge reduction that may result from the land use developments is considered. These areas are shown on Figure 1.

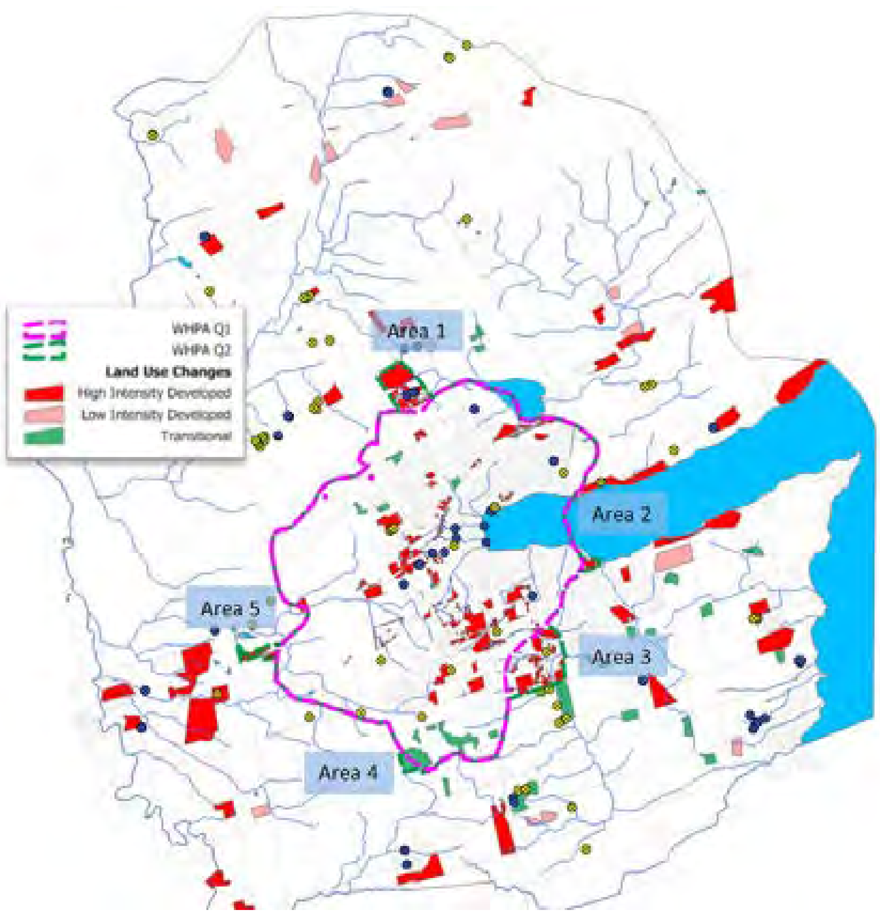

Figure 1: Land Use Changes

For the draft Risk Assessment Report, the process of delineating the WHPA-Q2 began with decreasing the recharge by 50% within all areas where land use changes indicated an increase in imperviousness.

Water Levels at the municipal wells were noted before and after the recharge reduction, and drawdown was recorded (Table 1, last column).

Table 1: Drawdown Due to Decreased Recharge

Well	Safe Available Drawdown (m)	Drawdown (m)					
		Area 1	Area 2	Area 3	Area 4	Area 5	All Areas Combined
Well_5	50	0	0	0.01	0	0.01	0.12
Well_7	56	0	0	0.01	0	0.01	0.13
Well_9	27	0.01	0	0	0	0	0.07
Well_12	45	0	0	0	0	0.01	0.10
Well_11	19	0	0	0	0	0.01	0.08
Well_4	29	0	0	0.01	0	0.01	0.13
Well_17	49	0	0	0.01	0	0.01	0.13
Well_18	47	0	0	0.01	0	0.01	0.13
Well_3A	51	0	0	0.01	0	0.01	0.12
Well_16	31	0.03	0	0	0	0	0.06
Well_15	34	0	0	0	0	0.01	0.09
Well_14	17	0	0	0	0	0.01	0.08
Well_13	31	0.01	0	0	0	0	0.06
Well_19	52	0	0	0	0	0.02	0.13

As seen in Table 1, the maximum simulated drawdown of 0.13 m at the wells occur in wells 4, 7, 17, 18 and 19. Compared to the seasonal water level fluctuation (1-2m) and the safe available drawdown within these wells (e.g., 30 – 50m), the simulated additional drawdown due to increased impervious areas is negligible. For this reason, all increased impervious areas outside of the WHPA-Q1 were not included in the WHPA-Q2.

To further investigate the validity of excluding these individual areas from the WHPA-Q2, the recharge reduction within each area was assessed independently; in this manner the potential impact from development of each area was isolated as individual contributions to the drawdown at the wells. The drawdown contribution from each of these scenarios is also included in Table 1. The largest drawdown that occurs from an individual area recharge reduction is is 0.03 m; that occurs in Well 16 due to the independent recharge reduction in Area 1 (see Figure 1). This drawdown (0.03 m) is too small to be considered "effective", nor is it likely to be measureable given typical seasonal fluctuations.

Published capture zones (Golder, 2008) for the municipal wells were also reviewed to confirm areas of recharge that may be strongly contributing to the wells. Area 1 does not intersect the Well 16 capture zone, as that well is mainly recharged from the northeast, in the uplands of the Oro Moraine. Particle tracking within the current model is consistent with the previously delineated capture zones. Further, particle tracking from Area 1 also indicates that recharge from this area predominantly travels to Willow Creek, and not to the Barrie wells. This analysis further supports the evaluation that the recharge reduction in Area 1 would not create an "effective" reduction in available drawdown at the City of Barrie municipal wells.

As for the remainder of the wells, the major recharge areas replenishing the wells are simulated to be: deep recharge from Kempenfelt Bay, areas within the uplands of Snow Valley, deep recharge from the tunnel channel, and upland regions in the South of Barrie which are already developed (i.e. Essa Road and Mapleview) and/or the Ardagh Bluffs area. Few of these areas contain areas of future urbanization.

As a result of the lack of effective drawdown caused by recharge reduction in the increased impervious areas as well as the additional knowledge provided by the capture zones of the wells, it is recommended that Areas 1-5 not be included in the WHPA-Q2 delineation.

<u>References:</u>

Golder Associates Inc. 2008. *City of Barrie Source Water Protection Capture Zone Modelling: Increased Yield of Wells 17/18.* Unpublished report to the City of Barrie.

Ontario Ministry of the Environment (MOE), 2009. *Technical Rules: Assessment Report. Clean Water Act*. November 16, 2009.