Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

TOWN OF HANOVER AND THE COMMUNITY OF LAKE ROSALIND TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

Report Prepared for:
SAUGEEN VALLEY CONSERVATION AUTHORITY

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TOWN OF HANOVER AND THE COMMUNITY OF LAKE ROSALIND

TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

Report prepared for Saugeen Valley Conservation Authority, February 2016

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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 of the Town of Hanover and Community of Lake Rosalind in the Province of Ontario. As a requirement under the *Clean Water Act* (Bill 43; MOE 2006a), the purpose of this project was to identify water quantity threats to these municipal drinking water systems.

Tier One and Tier Two Water Quantity Stress Assessments require technical studies and these have been completed for many subwatersheds across the Province. Water Quantity Stress Assessments compare available groundwater and surface water supply to demand from existing and future drinking water systems. Where the ratio of water demand to water supply is high, subwatersheds are classified as having a Moderate or Significant water quantity stress. Source Protection Authorities are required to complete Tier Three Assessments when municipal wells or surface water intakes are located within subwatersheds classified as having a Moderate or Significant water quantity stress.

The Tier Two Water Budget and Subwatershed Stress Assessment completed for the Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region (AquaResource 2010) identified the "Lake Rosalind Groundwater Assessment Area" as having a Moderate potential for hydrologic stress for groundwater. The identification of stress led to the requirement for a Tier Three Assessment for the municipal well fields within that area. The Ruhl Lake surface water intake also lies within the Lake Rosalind Groundwater Assessment Area and because it is interpreted to be hydraulically connected to the groundwater system, was also included in this Tier Three Assessment.

A companion report summarizes the development of the conceptual hydrogeologic model and the development or refinement of numerical models used to complete the risk assessment (Appendix A).

Scope of Work

The scope of work completed in this Tier Three Assessment and documented in this report follows the Province's *Technical Rules: Assessment Report, Clean Water Act, 2006* (*Technical Rules*; MOE 2009) and *Technical Bulletin: Part IX Local Area Risk Level* (MOE and MNR 2010; MOE 2013).

The following tasks were completed for this study:

- Refine and calibrate an existing FEFLOW groundwater flow model developed during the Tier One and Tier Two Assessments with sufficient detail to simulate groundwater flow near the municipal wells and surface water features.

- Develop a surface water spreadsheet-based water budget model based on output from an existing Guelph All-Weather Storm Event Runoff (GAWSER; Schroeter and Associates 2004) watershed-based flow generation model and apply it to predict surface water levels and outflow from Ruhl Lake.

- Apply the GAWSER and FEFLOW water budget models to assess the water budget components within refined subwatershed areas within the Lake Rosalind Groundwater Assessment Area.
- Complete a Local Area risk assessment for the municipal wells located in the Study Area that extend beyond the Lake Rosalind Groundwater Assessment Area.

Water Budget Tools

As part of the Tier Three Assessment, hydrologic and groundwater modelling tools were utilized (GAWSER), refined (FEFLOW), or developed (spreadsheet-based) to help assess the sustainability of the municipal water sources. The models were based on a detailed characterization of the groundwater and surface water systems, were refined to a level supported by available data and were linked through the integration of water budget components. The models were calibrated to represent typical operating conditions under average (steady-state) and/or variable (transient) pumping and climate conditions.

The groundwater flow model was developed and refined using FEFLOW during the Tier One (AquaResource 2008a) and Tier Two (AquaResource 2010) Assessments, and refined again near the municipal wells of Hanover and Lake Rosalind for this Tier Three Assessment. The GAWSER model (Schroeter & Associates 2004), previously developed and applied for the Tier One (AquaResource 2008b) and Tier Two Assessments, was applied again for the Tier Three Assessment to develop a spreadsheet-based water budget model for Ruhl Lake. The reports from the Tier One and Tier Two Assessments describe the initial development and calibration of the original FEFLOW and GAWSER models in greater detail.

Local Area Risk Assessment

Three distinct Local Areas were delineated for the municipal supply wells and intake in the Study Area. These areas were delineated following the *Technical Rules*. For groundwater, these areas were based on a combination of the cone of influence of each municipal well, as well as land areas where reductions in recharge have the potential to have a measurable impact on the municipal wells. For surface water, this area was based on the drainage area of the municipal intake and the additional area that provides recharge to an aquifer that contributes groundwater discharge to the drainage area. The Local Areas encompass the two Hanover municipal wells (Local Area A), the two Lake Rosalind Wells (Local Area B), and the Ruhl Lake intake (Local Area C).

A set of risk assessment scenarios was developed to represent the municipal Allocated Quantity of Water (Existing plus Committed demands up to the current permitted water takings) and current land uses. The groundwater and spreadsheet-based water budget models were used to simulate the changes in groundwater elevations in the municipal supply aquifer, the changes in Ruhl Lake water level and the impacts to groundwater discharge.

Conclusions

Based on the results of the risk assessment modelling scenarios, two of the Local Areas (Local Areas A and C) were classified as having a Low Risk Level. This is due to the capacity and resiliency of the Hanover wells and intake to take on additional demands both individually, and as a system as a whole.

The Local Area surrounding the two Lake Rosalind Wells (Local Area B) was classified as having a Significant Risk Level. This is due to the wells' historical inability to sustain pumping during some summer seasons, either individually, or in combination, despite having demands that are well below permitted rates. Three consumptive water uses (i.e., two municipal and one domestic) were identified as Significant Water Quantity Threats. There are no future land use development areas within Local Area B, so there are no Significant threats associated with areas of reduced groundwater recharge within Local Area B.

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1 INTRODUCTION

The Province of Ontario introduced the *Clean Water Act* (Bill 43; MOE 2006a) 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 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 Water Quantity Threats.

Tier Three Assessments are required where municipal wells or intakes are located in subwatersheds that were classified as having a Moderate or Significant stress as part of a Tier Two Water Quantity Stress Assessment completed under the requirements of the *Clean Water Act*. Tier Three Assessments identify municipal wells or intakes that may be unable to meet their Allocated Rates under average or drought conditions.

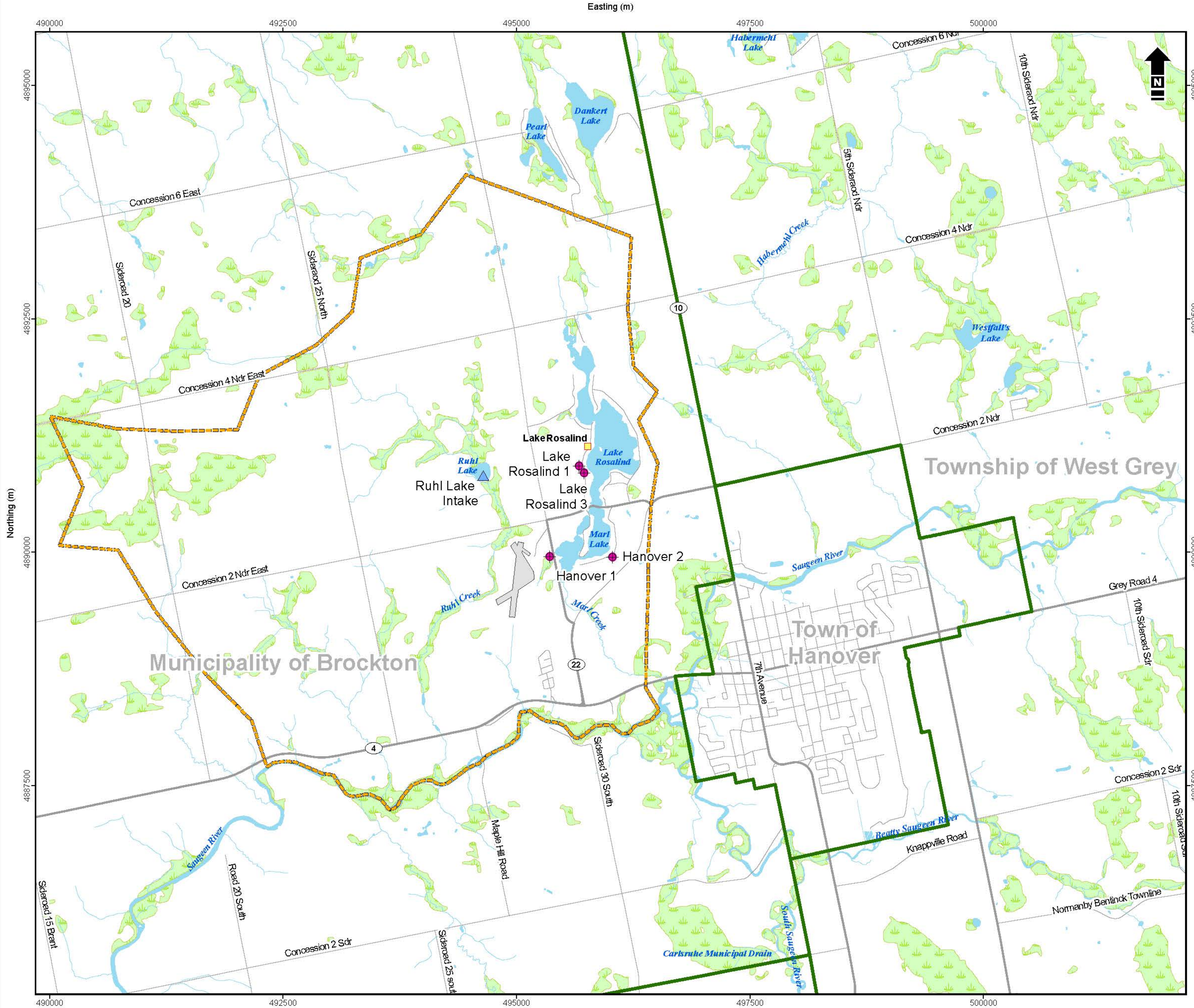
A Tier Two Water Budget and Subwatershed Stress Assessment (Tier Two Assessment) was completed for the Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region (AquaResource 2010). The Tier Two Assessment focused entirely on groundwater resources, as surface water intakes were not required to be evaluated. During this assessment, the “Lake Rosalind Groundwater Assessment Area” was identified as having a Moderate potential for hydrologic stress as the percent water demand was 19% under Existing conditions (AquaResource 2010). As such, a Tier Three Assessment for the groundwater supply sources was initiated to examine the long-term sustainability of the Hanover and Lake Rosalind municipal water supply. The Ruhl Lake surface water intake also lies within this “Lake Rosalind Groundwater Assessment Area” and supplies approximately 45% of the Hanover water demand. Ruhl Lake is interpreted to be hydraulically connected to the groundwater system and will also be investigated as part of this Tier Three Assessment (Figure 1.1).

This report details methodologies and results of the Tier Three Water Budget and Local Area Risk Assessment carried out for the Hanover and Lake Rosalind municipal water supplies. The Physical Characterization, Model Development, and Calibration Report is included as Appendix A of this document.

1.1 Study Team

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

- Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region
- Saugeen Valley Conservation Authority (SVCA)
- Town of Hanover
- Ministry of Natural Resources and Forestry (MNRF)
- Ontario Ministry of the Environment and Climate Change (MOECC)



Lake Rosalind Groundwater Assessment Area (Tier Two Assessment)
Airport
Municipality
Wetland
Water Body
Watercourse
Highway
Road
Municipal Well
Municipal Surface Water Intake
Community

Reference: Data obtained from GeoBase®, Ontario Ministry of Natural Resources and SVCA used under license.
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Matrix Solutions Inc.
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Local Area Risk Assessment Report

Study Area

Date:	Project:	Technical:	Reviewer:	Drawn:
03 Feb 2016	21581-527	S. Davies	P. Meyer	M. Pfeifer

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Figure 1.1

All documents produced in this assessment were reviewed by a peer review team consisting of Stan Denhoed, P.Eng. (Harden Environmental Services Ltd.) and Hugh Whiteley, P.Eng. (University of Guelph).

1.2 *Clean Water Act* Water Budget Framework

The *Clean Water Act* (MOE 2006a) requires that each Source Protection Committee prepare an Assessment Report for their Source Protection Area in accordance with Ontario Regulation 287/07 (General Regulation) and the *Technical Rules: Assessment Report, Clean Water Act, 2006* (*Technical Rules*; MOE 2009). A requirement of the Assessment Report is the development of water budgets to assess water availability to meet municipal water demand within a tiered framework. Tier One and Tier Two Assessments evaluate the level of potential subwatershed hydrologic stress under various climate and water use scenarios. The Tier Three Assessment establishes the risk that a community's sources of water will not be able to meet Allocated water demands, taking into consideration climate and other water uses.

Water Budgets developed under the *Clean Water Act* 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 analyses include the watershed-based flow generation models and groundwater flow models, which are available for future use and application.

The Tier One and Tier Two Water Quantity Stress Assessments estimate the potential hydrologic stress within a subwatershed and identify those subwatersheds that have the potential to become stressed from a water quantity perspective. The subwatershed stress assessment is dependent on hydrologic parameters estimated in the water budget.

A Tier Three Assessment is completed for two reasons:

- To estimate the likelihood that a municipality will be able to sustain its' Allocated (Existing plus Committed) Rates.
- To identify threats placed on the drinking water sources that may influence the municipality's ability to meet their Allocated Rates.

A Tier Three Assessment uses numerical groundwater and/or hydrologic models that are refined to the accuracy needed to evaluate hydrologic or hydrogeologic conditions at a water supply well or surface water intake.

1.2.1 Tier Three Water Budgets and Local Area Risk Assessments

A Tier Three Assessment is undertaken for a municipal supply when it is located within a subwatershed that has been assigned a Moderate or Significant water quantity hydrologic stress level in the Tier Two Assessment. 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 threats located within local vulnerable areas.

The Tier Three Assessment is completed for the "Local Area" and focuses the water budget assessment around municipal drinking water wells or surface water intakes. For groundwater wells, the Local Area is the combination of the cone of influence of the municipal wells and other water takings whose cones of influence intersect that of the wells, and areas where reductions in recharge would have a measurable impact on the cone of influence of the wells. For a surface water intake, the Local Area is the combination of the drainage area that contributes surface water to an intake, and the area that provides recharge to an aquifer that contributes groundwater discharge to the drainage area.

Calibrated Tier Three Assessment models estimate the impact of increased water demand, variations in climate, and land use development on a groundwater well or surface water intake. 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 identified as drinking water threats and are classified as Moderate or Significant depending on the Local Area Risk Level. The risk assessment modelling scenarios consider the need to meet water demand requirements of other uses, such as wastewater assimilation flows or the ecological flow requirements of a coldwater fish habitat.

Rules and technical guidance for completing Tier Three Assessments are provided in Part IX of *Technical Rules,* the *Technical Bulletin: Part IX Local Area Risk Level* (MOE and MNR 2010; MOE 2013), and the *Water Budget and Water Quantity Risk Assessment Guide: Drinking Water Source Protection Program* (AquaResource 2011).

1.2.2 Tier Three Methodology

Each Tier Three Assessment is required to complete the following steps:

- Develop conceptual and numerical Tier Three Assessment models with detailed hydrogeologic and/or hydrologic characterization surrounding municipal wells and intakes. The conceptual model forms the basis for the development of numerical model(s) that are calibrated to represent typical operating conditions under average and variable climate conditions.

- Characterize the municipal wells and intakes and identify the low water operating constraints of those wells and intakes.

- Estimate the Allocated and Planned Quantity of Water by compiling and describing the Existing, Committed, and Planned Rates for each municipal well and intake.

- Identify and characterize drinking water quantity threats, including municipal and non-municipal consumptive water demands.

- Evaluate the potential impact of future land use changes on drinking water sources. This task is done by comparing Official Plans and current land use mapping, and using assumptions related to imperviousness values on future development lands.

- Characterize and identify other water uses (e.g., ecological flow requirements) that might be influenced by municipal pumping, and identify water quantity constraints according to those other uses.

- Delineate vulnerable areas (WHPA Q1, WHPA Q2, and IPZ-Q) using the Tier Three Water Budget Model.

- Define the Local Area based on the delineation of the WHPA Q1, WHPA Q2, and IPZ-Q areas.

- Evaluate the risk assessment scenarios, using the Tier Three Water Budget Model(s) to simulate the conditions at each well and intake during average and drought conditions, and under varied municipal pumping and recharge conditions due to future land use development. The scenarios are evaluated in terms of the ability to sustain pumping at each well or intake along with the impact to other water uses.

- Assign a Risk Level (Low, Moderate, or Significant) to the Local Area(s) based on the results of the risk assessment scenarios. An uncertainty level (i.e., High and Low) will accompany each Risk Level.

- Identify drinking water quantity threats such as consumptive water uses or reductions in recharge for Local Areas where the Risk Level is Significant and Moderate.

1.2.3 Study Area

The Study Area for the Tier Three Assessment is illustrated on Figure 1.1 and includes the water supply systems for the Town of Hanover and the Community of Lake Rosalind within the Saugeen Valley Source Protection Area. Hanover is located in Grey County; Lake Rosalind is located within the Municipality of Brockton in Bruce County.

Land use in the Study Area is primarily agricultural with natural areas such as forests and wetlands scattered throughout. Urban areas exist within the Town of Hanover and along the shores of Lake Rosalind and Marl Lake.

The largest watercourses in this Study Area include the Saugeen, South Saugeen, and Beatty Saugeen rivers (Figure 1.1). The Saugeen River lies south of the Tier Three Assessment municipal water supply sources and forms a valley that trends in an east-west direction along the northern part of the Town of Hanover. The Beatty-Saugeen River meets the South Saugeen River south of Hanover and the combined rivers drain into the Saugeen River just west of Hanover. Several tributaries feed these two larger rivers and numerous wetlands are located along the river valleys (Figure 1.1). Water bodies located close to the Tier Three municipal water supplies include Ruhl Lake (a natural kettle lake), and two man-made lakes (Lake Rosalind and Marl Lake) located northwest of Hanover (Figure 1.1). Surface water flows from Lake Rosalind south to Marl Lake, and then southward through Marl Creek to the Saugeen River. Ruhl Lake flows southward via Ruhl Creek to the Saugeen River.

The Community of Lake Rosalind relies entirely upon groundwater resources for potable water, while the Town of Hanover uses both groundwater (Hanover Wells 1 and 2) and surface water (Ruhl Lake intake). The Lake Rosalind system is comprised of two overburden wells (Lake Rosalind Wells 1 and 3) located within 100 m of one another and within 100 m of the west bank of Lake Rosalind (Figure 1.1). The Town of Hanover system includes two overburden wells located on the western and eastern sides of Marl Lake and one surface water intake located in Ruhl Lake (Ruhl Lake intake; Figure 1.1).

1.3 Tier Three Assessment Water Budget Tools

Two water budget tools were applied in the Tier Three Assessment; a groundwater flow model used to evaluate the municipal groundwater wells, and a spreadsheet-based water budget model, used to evaluate the Ruhl Lake surface water intake.

A FEFLOW (Finite Element subsurface FLOW simulation system; DHI 2012) groundwater flow model was developed, calibrated, and applied as a tool to assess groundwater flow at the regional-scale for the Tier One Assessment (AquaResource 2008a). Refinements were made to the hydrogeologic conceptual understanding of the assessment areas, and to the numerical FEFLOW groundwater flow model as part of the Tier Two Assessment (AquaResource 2008a). Further refinements were made to the conceptual and numerical models around the Hanover and Lake Rosalind municipal supplies as part of this Tier Three Assessment. The final Tier Three Assessment calibrated model was used to estimate water levels and groundwater discharge to surface water features. Details of the groundwater model refinement and calibration are provided in Appendix A.

A spreadsheet-based water budget model was used to estimate water levels and discharge from Ruhl Lake. It relied on output from the GAWSER (Guelph All-Weather Storm Even Runoff) watershed-based flow generation model (Schroeter and Associates 2004) developed and applied for the Tier One (AquaResource 2008b) and Tier Two assessments. It also relied upon groundwater discharge output data from the Tier Three groundwater flow model. The water budget model incorporated all significant inflows and outflows into a mass balance calculation, which considered hydraulic characteristics (e.g., storage and outlet channel characteristics) of the Ruhl Lake. Details of the Ruhl Lake water budget model are provided in Appendix A.

1.4 Project Scope

The scope of work completed in this Tier Three Assessment and documented in this report follows the *Technical Rules*. The following tasks were completed for this study:

- characterize the physical setting, including ground surface topography, hydrology, hydrogeology, and the municipal and non-municipal water demands in the Study Area (Appendix A)
- update, refine, and calibrate a groundwater flow model with sufficient detail in the Study Area to simulate groundwater flow near wells, lakes and streams (Appendix A)
- develop a surface water, spreadsheet-based, water budget model to predict water levels and lake outflow for Ruhl Lake (Appendix A)
- delineate the vulnerable areas for the municipal wells and intake and complete a Local Area risk assessment for those systems (Section 5)
- apply the groundwater and spreadsheet-based models to assess the water budget components near municipal wells and intakes (Section 7)
- complete a Local Area Risk Assessment for the municipal wells located in the Study Area (Section 5.3)
- identify Significant and Moderate Drinking Water Quantity Threats (Section 6)
- prepare and deliver all relevant spatial/tabular datasets from the Tier Three Assessment

Updating Significant Groundwater Recharge Area (SGRA) mapping is also a common task of the Tier Three Assessment; however, as the GAWSER model was not updated from the Tier Two Assessment, there will be no updates to the delineation of SGRAs as part of this Tier Three Assessment.

1.5 Report Organization

This report is organized into the following sections:

Section 1: Introduction - outlines the *Clean Water Act* water budget framework and the scope of this project.

Section 2: Risk Assessment Methods – outlines the method of delineating vulnerable areas, the Local Area and summarizing risk assessment scenarios for both groundwater and surface water municipal sources.

Section 3: Risk Assessment Data Requirements - summarizes available land use data, anticipated land use change and consumptive water uses and demand within the Study Area.

Section 4: Risk Assessment Thresholds – summarizes the drawdown thresholds and ecological thresholds.

Section 5: Vulnerable Area Delineation and Risk Assessment Results - summarizes the delineation of vulnerable areas, the Local Areas, and the Risk Assessment scenario results; assigns the Local Area Risk Level; and presents an assessment of uncertainty of this Risk Level.

Section 6: Water Quantity Threats – discusses water quantity threats identified in this study.

Section 7: Tier Three Water Budget - outlines the groundwater water budget results compiled using output of the FEFLOW models.

Section 8: Conclusions - summarizes the key components of the study; outlines the study conclusions, and provides recommendations for future work.

Section 9: References - lists resources used to provide information in this document.

Appendix A: Physical Characterization, Model Development and Calibration Report - provides a detailed description of the conceptual model for the Study Area, and the development and calibration of the water budget models used to carry out the risk assessment.

Appendix B: Selection of Appropriate WHPA-Q1 Drawdown Contour - summarizes the methodology used to select a WHPA-Q1 drawdown contour.

Appendix C: Municipal Wells and Intake – Summary Hydrographs - summarizes the important well and intake construction details, water levels and pumping data that were used in the risk assessment.

Appendix D: Calculation of In-Well Losses - summarizes the methodology for calculating in-well losses.

2 RISK ASSESSMENT METHODS

2.1 Water Quantity 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, water quantity vulnerable areas are delineated to protect the quantity of water required by a municipality to meet their current or future water supply needs. There are two water quantity vulnerable areas for groundwater systems: the Well Head Protection Areas for Quantity (WHPA-Q), WHPA-Q1, and WHPA-Q2. For surface water intakes, the Surface Water Quantity Vulnerable Area, IPZ-Q, is delineated. The *Technical Rules* require that WHPA-Q1, WHPA-Q2, and IPZ-Q areas be delineated for all municipal water supply wells and intakes that extract water from a subwatershed assigned a stress level of Moderate or Significant in the Tier Two Assessment. The methodology used to delineate the water quantity vulnerable areas is outlined in the following subsections.

2.1.1 WHPA-Q1 Delineation

The WHPA-Q1 is delineated as the cone of influence of the municipal well and the whole of the cones of influence of all other wells when the wells are pumped at a rate equivalent to their Allocated Quantity of Water (MOE 2009). The cones of influence for the wells were estimated by calculating the difference in the potentiometric heads in each of the municipal production aquifers in the following two scenarios:

1. Steady-state model simulating existing land use, and no permitted pumping. This simulation establishes groundwater elevations that would exist without municipal or other permitted demands.

2. Steady-state model simulating existing land use, and municipal wells pumping at their Allocated Rates. Non-municipal permitted wells are pumping at their current estimated rates, because in the absence of other information, their demands are assumed to remain constant into the future.

The difference in the model-predicted heads in each modelled municipal aquifer under the non-pumping and Allocated pumping conditions were subtracted to produce drawdown contour maps that were subsequently used to generate the WHPA-Q1 areas.

A water budget guidance document (AquaResource 2011) developed for the Province recommends the consideration of seasonal water level fluctuations in the aquifer when selecting an appropriate drawdown threshold for the WHPA-Q1. Due to the lack of municipal monitoring wells and Provincial Groundwater Monitoring Network wells located outside the cone of influence and completed within the overburden, monitoring wells from the Hanover Landfill were used to determine seasonal water level variation in the aquifer. The average observed seasonal water level fluctuation in Hanover Landfill monitoring wells completed in the overburden and located upgradient of the municipal wells is approximately 2 m (see Appendix B for details). Therefore, a 2 m drawdown contour interval was selected for use in delineating the WHPA-Q1 in the Study Area. This interval was selected because a variation of at least 2 m in observed groundwater water level elevation would be required before considering whether the change was due to increased pumping or seasonal variability.

2.1.2 WHPA-Q2 Delineation

The WHPA-Q2 is defined in the *Technical Rules* 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. The cone of influence is the area within the depression created in the water table or potentiometric surface when the wells are pumped at their Allocated Rates. Land use change has the potential to reduce recharge and, as a result, impact the available drawdown at the municipal wells. Existing and future land uses are outlined in Section 3.1.

2.1.3 IPZ-Q Delineation

The Surface Water Quantity Vulnerable Area, IPZ-Q, corresponds to the drainage area that contributes surface water to an intake, and the area that provides recharge to an aquifer that contributes groundwater discharge to the drainage area. Part VI.7 of the *Technical Rules* specifies the rules with respect to the delineation of IPZ-Q.

2.1.4 Local Area Delineation

The term, "Local Area" is introduced in the MOE Director's Rules (Part III.2) and is defined as the area that combines the cone of influence of the municipal supply wells (WHPA-Q1) and the areas where a reduction in recharge would have a measurable impact on the cone of influence of the wells (WHPA-Q2). The Local Area for the Ruhl Lake Intake is the IPZ-Q.

2.2 Risk Assessment Scenarios

2.2.1 Community of Lake Rosalind

The two wells that supply water to the Community of Lake Rosalind have had historical issues with meeting the existing residential demands. As recently as the summer of 2012, the water levels in both wells fell below safe operating levels and the wells were unable to supply demand to the community. The water levels in both wells have fallen below the safe operating levels in the past, and as such are noted as having the inability to meet the Existing or future (Allocated) Rates for the community.

As such, Directors approval (MOECC 2015) was provided to bypass the running and evaluation of the risk assessment scenarios for the Lake Rosalind system in this Tier Three Assessment. The risk assessment scenarios for the Town of Hanover wells and Ruhl Lake surface water intake were evaluated and are discussed in Section 2.2.2.

2.2.2 Town of Hanover

Table 2.1 summarizes the surface water and groundwater risk assessment scenarios listed in the *Technical Rules*.

TABLE 2.1 Summary of Risk Assessment Scenarios (MOE 2009)

Scenario	Time Period	Data Restrictions
Surface Water Risk Scenarios		
A	The period for which climate and stream flow data are available for the Local Area	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the study year.
B	2-year or greater drought period	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the study year.
E	The period for which climate and stream flow data are available for the Local Area	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the year in which the planned or existing system with a Committed Demand is operating at its Allocated Rates.
F	2-year or greater drought period	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the year in which the planned or existing system with a Committed Demand is operating at its Allocated Rates.
Groundwater Risk Scenarios		
C	The period for which climate and stream flow data are available for the Local Area	Data related to average pumping rates for water takings and land cover reflect conditions during the study year.
D	2-year or greater drought period	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the study year.
G	The period for which climate and stream flow data are available for the Local Area	Data related to average pumping rates for water takings and land cover reflect conditions during the year in which the planned or existing system with a Committed Demand is operating at its Allocated Rates.
H	2-year or greater drought period	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the year in which the planned or existing system with a Committed Demand is operating at its Allocated Rates.

In Table 2.1, Scenarios A, B, C, and D correspond to Existing pumping rates and land use under average climate (Scenarios A and C) and drought conditions (Scenarios B and D). Scenarios E, F, G, and H correspond to future land use development and Allocated Rates for intakes and wells under average climate (Scenarios E and G) and drought conditions (Scenarios F and H). As such, the surface water and groundwater scenarios were interpreted as follows:

- Surface water scenarios representing average climate (i.e., A and E) were simulated transiently for the entire climate record and assessed using average water levels.
- Groundwater scenarios representing average climate (i.e., C and G) were simulated using steady-state conditions.

- Surface water scenarios representing drought conditions (i.e., B and F) were simulated transiently for the drought periods of the 1960s and 1990s and assessed using minimum water levels.

- Groundwater scenarios representing drought conditions (i.e., D and H) were simulated using a transient model for the drought periods of the 1960s and 1990s.

- Multiple versions of Scenarios E, F, G, and H are traditionally required to evaluate the impact of Allocated pumping rates separate from impacts of land cover and the cumulative impact of both; however, as will be discussed in greater detail in Section 3.1, there is no anticipated land use change and commensurate reduction in recharge that is anticipated to impact the outcome of the risk assessment scenarios. As a result, there was only a single version of these scenarios (i.e., E[2], F[2], G[2], and H[2]), which represents Allocated Rates and existing land cover.

Impacts to other uses (e.g., wetlands and coldwater fisheries) were not evaluated for the drought scenarios (i.e., B, F, D, and H). The drought scenarios only serve to identify the potential for water levels to fall beneath a minimum operating elevation for each municipal well or intake. These thresholds are discussed in Section 4.

Table 2.2 summarizes the surface water and groundwater modelling scenarios conducted for the Town of Hanover water supply system. These scenarios were designed to assist in identifying the potential impacts to other water uses associated with pumping each of the current municipal wells and intake and drought. The data required for each of the modelling scenarios are outlined in Section 3.

TABLE 2.2 Surface Water and Groundwater Risk Assessment Model Scenarios

Scenario	Time Period	Model Scenario Details		
		Land Cover	Municipal Water Demand	Model Simulation
Surface Water Risk Scenarios				
A	Full Climate Record (1950 to 2005), Including Drought Periods	Existing	Existing	Simulate transient water levels using hourly climate and monthly pumping. Assess using average water levels.
B	Full Climate Record (1950 to 2005), Including Drought Periods	Existing	Existing	Simulate transient water levels using hourly climate and monthly pumping. Assess using minimum water levels.
E(2)	Full Climate Record (1950 to 2005), Including Drought Periods	Existing	Allocated	Simulate transient water levels using hourly climate and monthly pumping. Assess using average water levels.
F(2)	Full Climate Record (1950 to 2005), Including Drought Periods	Existing	Allocated	Simulate transient water levels using hourly climate and monthly pumping. Assess using minimum water levels.

Scenario	Time Period	Model Scenario Details		
		Land Cover	Municipal Water Demand	Model Simulation
Groundwater Risk Scenarios				
C	Average of Climate Record (1950 to 2005)	Existing	Existing	Steady-state, simulate water levels using average annual recharge and average annual pumping
D	Full Climate Record (1950 to 2005), Including Drought Periods	Existing	Existing	Transient, simulating water levels using monthly recharge and monthly pumping
G(2)	Average of Climate Record (1950 to 2005)	Existing	Allocated	Steady-state, simulate water levels using average annual recharge and average annual pumping
H(2)	Full Climate Record (1950 to 2005), Including Drought Periods	Existing	Allocated	Transient, simulating water levels using monthly recharge and monthly pumping

2.3 Surface Water Risk Assessment Scenarios

2.3.1 Scenario A – Existing Demand

Scenario A evaluates the ability for the current municipal water supply intake to maintain Existing average monthly pumping rates over long-term climate conditions. This scenario was simulated transiently using the spreadsheet-based water budget model and using 2013 (Existing) monthly pumping rates obtained from the Town of Hanover simulating seasonal municipal demand for the intake (Table 2.3) and hourly precipitation from 1950 to 2005. The selection of 2013 as the Existing conditions year is described in Section 3.2.1.1.

The water budget spreadsheet model was used to predict the long-term average water level in the lake and the rate of outflow from the lake.

TABLE 2.3 Existing Rates Applied in the Risk Assessment Scenarios

Well / Intake Name	Existing Rate (2013) (m^3/day)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hanover												
Ruhl Lake Intake	1,277	1,318	1,452	1,263	1,616	1,720	1,790	1,786	1,580	1,487	1,435	1,471
Hanover Well 1	688	623	712	691	875	956	1,010	1,012	884	834	813	834
Hanover Well 2	859	889	991	861	1,084	1,192	1,258	1,259	1,103	1,044	1,017	1,051

Well / Intake Name	Existing Rate (2013) (m^3/day)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lake Rosalind												
Lake Rosalind Well 1	6	6	6	8	7	7	8	8	8	8	8	9
Lake Rosalind Well 3	15	15	16	21	19	21	22	25	22	20	20	21

2.3.2 Scenario B – Existing Demand

Scenario B aims to evaluate whether the intake is able to pump at Existing Rates (observed monthly 2013) during a drought period. This scenario was simulated transiently for the period of 1950 to 2005. Any drought periods from 1950 to 2005 were included to provide the lowest simulated water level. Average monthly pumping rates were applied to simulate seasonal demand variability (Table 2.3).

The *Technical Rules* refer to a minimum 2-year period to define drought conditions for the scenarios. However, this assessment went beyond the requirements of the *Technical Rules* and examined two longer drought periods that occurred within the 55-year climate period examined (i.e., 1960s and late 1990s). The scenario included the two drought periods as well as periods where precipitation was above normal.

As outlined in the *Technical Rules*, the impacts of municipal pumping on other uses were not considered in this drought scenario. As a result, the water budget model was only used to predict the minimum water level at the intake for the full 55-year climate period.

2.3.3 Scenario E – Allocated Demand, Future Land Development

Scenario E evaluates the ability for existing intakes to maintain Allocated Rates, considering future development conditions (reductions in recharge), and with other permitted water takings. Monthly Allocated pumping rates for this scenario are presented in Table 2.4, and the development of these rates is discussed in Section 3.2.1.2. This scenario was simulated transiently using the same time period as Scenario A: 1950 to 2005. The simulated long-term average water level decline in Ruhl Lake is compared to the available water level decline (see Table 2.2).

Scenario E is traditionally subdivided into three Scenarios: E(1), E(2), and E(3). The purpose of multiple scenarios is to isolate the impacts of municipal pumping from impacts related to land developments and assess the cumulative impact of the two stresses. However, because future land use change and associated recharge reduction are not interpreted to impact the intake (see Section 3.1), only Scenario E(2) was considered. Scenario E(2) evaluated only the impact of increased municipal pumping rates (to Allocated Rates) on the intake and other water uses. The existing conditions land use was simulated in this scenario. Only this surface water scenario is considered when evaluating the impact on other water uses (i.e.., assessing reduction in lake outflow and thereby reducing flow downstream).

TABLE 2.4 Allocated Rates Applied in the Risk Assessment Scenarios

Well / Intake Name	Allocated Rate (m^3/day)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hanover												
Ruhl Lake Intake	1,277	1,318	1,452	1,263	1,616	1,720	1,790	1,786	1,580	1,487	1,435	1,471
Hanover Well 1	734	665	759	737	934	1,020	1,077	1,079	943	890	866	889
Hanover Well 2	916	948	1,057	918	1,156	1,271	1,341	1,342	1,176	1,113	1,084	1,121
Lake Rosalind												
Lake Rosalind Well 1	6	6	6	8	7	7	8	8	8	8	8	9
Lake Rosalind Well 3	17	17	18	24	22	24	26	28	25	23	23	24

2.3.4 Scenario F - Allocated Demand, Future Land Development

Scenario F evaluates the ability of the intake to maintain Allocated municipal pumping rates through a drought period using the same temporal period as Scenario B: 1950 to 2005. Average monthly Allocated pumping rates were applied to simulate future seasonal demand variability. These transient intake pumping rates are provided in Table 2.4. The minimum water level in Ruhl Lake is calculated from the simulated results and compared to the available water level decline.

Similar to Scenario E, Scenario F is traditionally subdivided into three Scenarios: F(1), F(2), and F(3) to evaluate the relative contribution of municipal water takings and land use development at the municipal intake under drought conditions. However, because future land use change and the associated recharge reduction is interpreted to impact the intake (see Section 3.1), only Scenario F(2) was considered. Scenario F(2) evaluated the impact of increased municipal pumping rates (to Allocated Rates) on the intake during a drought period considering current land use. Impacts to other water uses were not considered in Scenario F.

2.4 Groundwater Risk Assessment Scenarios

2.4.1 Scenario C – Existing Demand, Average Climate

Scenario C evaluated the ability for current municipal water supply wells to maintain Existing average annual pumping rates under average climate conditions. This scenario was simulated in steady-state in the groundwater flow model using average 2013 (Existing) pumping rates (see Section 3.2.1) and average annual groundwater recharge.

The groundwater flow model was constructed and calibrated to predict groundwater levels in the respective aquifers at the municipal pumping wells, and to predict groundwater discharge rates.

2.4.2 Scenario D – Existing Demand, Drought

Scenario D evaluated whether each municipal well is able to pump at their Existing Rates during an extended drought period. This scenario was simulated using the calibrated groundwater flow model in continuous transient mode (1950 to 2005). Average monthly recharge rates from the Tier Two GAWSER model were applied in the groundwater flow model throughout the duration of the simulations (1950 to 2005).

While the *Technical Rules* refer to a minimum 2-year period to define drought conditions, this assessment went beyond these requirements and examined two drought periods that occurred within the 55-year climate period examined (i.e., 1960s and 1990s). The 55-year period examined with the transient model also included periods where precipitation (and in turn recharge) were above normal.

As outlined in the *Technical Rules*, 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 simulated drawdown or groundwater elevations at each of the municipal wells.

2.4.3 Scenario G – Allocated Demand, Future Land Development, Average Climate

Scenario G evaluates the ability for existing wells to maintain the Allocated pumping rates under average climate conditions, future development conditions (reductions in recharge), and with other permitted water takings. This scenario was simulated using the calibrated groundwater flow model in steady-state conditions, using groundwater recharge rates that reflect long-term average climate conditions

Scenario G is traditionally 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 impacts related to land developments and assess the cumulative impact of the two stresses. However, because no land use change and associated recharge reduction is interpreted to impact the wells (see Section 3.1), only Scenario G(2) was considered. Scenario G(2) evaluated only the impact of increased municipal pumping rates (to Allocated Rates; Table 2.4) on the well and other water uses. The existing conditions land use was simulated in this scenario. Only this groundwater scenario is considered when evaluating the impact on other water uses (e.g., assessing reduction in groundwater discharge to coldwater streams).

2.4.4 Scenario H – Allocated Demand, Future Land Development, Drought

Scenario H evaluates the ability for existing wells to maintain Allocated Rates through a drought period (using the same temporal period as Scenario D). The groundwater flow model was run transiently and average monthly Allocated Rates were applied to simulate future seasonal demand variability (Table 2.4). The groundwater level drawdown is calculated from the simulated results and compared to the available drawdown.

Similar to Scenario G, Scenario H is traditionally subdivided into three Scenarios: H(1), H(2) and H(3) to evaluate the relative contribution of municipal water takings and land use development at the municipal wells under drought conditions. However, because future land use change and the associated recharge reduction is not interpreted to impact the wells (see Section 3.1), only Scenario H(2) was considered. Scenario H(2) evaluated the impact of increased municipal pumping rates (to Allocated Rates) on the wells during a drought period considering current land use. Impacts to other water uses were not considered in Scenario H.

3 RISK ASSESSMENT DATA REQUIREMENTS

The following sections document the data examined and compiled for the Tier Three Assessment. In particular, the land use cover and municipal and non-municipal water demands that will be represented in the risk assessment model scenarios are discussed.

3.1 Land Use

In addition to consumptive water uses, the *Technical Rules* identify reductions in groundwater recharge due to land use development as potential water quantity threats. As such, the Tier Three Assessment modelling scenarios considered the impact of future land development, via reductions in groundwater recharge, on municipal water sources. As the *Technical Rules* require the assessment of unmitigated threats as part of the risk assessment, the potential impact of stormwater management measures and low impact development techniques was not considered when estimating recharge reductions on future land development areas.

The following steps were undertaken in consultation with Drinking Water Source Protection staff from the Saugeen, Grey Sauble, Northern Bruce Peninsula Region, to identify where potential land use development is expected to occur within the Study Area:

- Drinking Water Source Protection staff from the Saugeen, Grey Sauble, Northern Bruce Peninsula Region compared the existing land use mapping in the Southern Ontario Land Resource Information

System (SOLRIS) against ortho-imagery to ensure existing land use development areas were in agreement.

- Future land use was obtained from "Town of Hanover Official Plan" (OP; Town of Hanover 2014, Draft) and the *County of Bruce Official Plan* (County of Bruce 2010).
- Areas of potential land use change were assessed by comparing the future official plans against the existing land uses, particularly in areas where the change in land use development may have the potential to impact the long-term sustainability of the municipal wells and intake.

The results of this analysis are discussed in the following sections.

3.1.1 Land Use Change and Imperviousness Near Lake Rosalind

Lands encompassing Lake Rosalind and Marl Lake are Inland Lake Development Areas according to the *County of Bruce Official Plan* (County of Bruce 2010), and any new developments are restricted to residential infilling. Analysis of this area by Drinking Water Source Protection staff from the Saugeen, Grey Sauble, Northern Bruce Peninsula Region resulted in the identification of six empty lots that could be developed in the future. Development of these areas is interpreted to have a negligible effect on groundwater recharge to the municipal wells as the areal extent of development will be small, and runoff from new impervious surfaces (e.g., driveways and rooftops) will runoff onto adjacent pervious sand-rich soils where it will infiltrate and recharge the groundwater flow system. While risk assessment scenarios were not completed for the Lake Rosalind system, we expect that recharge reduction due to land use development and increased impervious cover would have negligible impact on the water levels in the wells.

3.1.2 Land Use Change and Imperviousness Near Hanover

According to the "Town of Hanover Official Plan" (Town of Hanover 2014), land use development is planned for areas around the periphery of current urban areas. The approximate location of potential land use development is illustrated on Figure 3.1. This development is located over 2.5 km from the Ruhl Lake intake and over 1.4 and 2.0 km from Hanover Wells 1 and 2, respectively. The future development in Hanover that occurs south of the Saugeen River is hydraulically separated from the Hanover municipal water supply aquifers as the Saugeen River represents a regional groundwater discharge location. Potential residential and industrial land development areas that lie north of the Saugeen River are outside the zone of influence for the Hanover municipal supplies (WHPA-Q1; Section 5.1.1). Therefore, recharge reduction due to land use change and increased imperviousness were not assessed for the Hanover municipal supplies as part of the risk assessment scenarios (as described in Section 2.3 and 2.4).

3.2 WATER DEMAND

This section outlines the consumptive water uses within the Study Area. 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.

The following sections outline the consumptive water takers within the Study Area, including the municipal (Section 3.2.1) and non-municipal (Section 3.2.2), large permitted (Section 3.2.2.1) and non-permitted water takings (Section 3.2.2.2). The large (permitted) consumptive water takings were simulated as groundwater and surface water takings within the water budget models as they have the potential to influence simulated water levels and impact model calibration.

The evaluation of water demands within the Study Area also considers other non-consumptive water uses, such as groundwater discharge for ecological use and to support waste water assimilation. Only groundwater discharge to streams and leakage from streams to aquifers is represented explicitly in the groundwater flow model in this Tier Three Assessment. The outflow at Ruhl Lake is simulated in the spreadsheet-based water budget model. However, other water uses may rely on a minimum flow or minimum variation in groundwater elevations from the groundwater and surface water systems, so they were assessed as part of the risk assessment. Other water uses are described in Section 3.2.3.

3.2.1 Municipal Water Demand

As part of the Local Area risk assessment, the Allocated and Planned quantities of water need to be estimated for each existing and planned groundwater well or intake. The Allocated Quantity of Water is estimated based on the Existing and Committed municipal water demands, and the Planned Quantity of Water is the amount of water that meets the criteria of a planned system (MOE 2013).

As outlined in the *Technical Rules* and relevant technical guidance (MOE 2013), the Existing, Committed, and Planned Demand for this Assessment needed to be established. The definitions of these terms, as outlined in the revised technical guidance document, are below.

- Existing Demand refers to the amount of water currently taken from each well/intake during the study period.

- Committed Demand is an amount greater than the Existing Demand that is necessary to meet the needs of the approved Settlement Area within an Official Plan. The portion of this amount that is within the Current Lawful Permit to Take Water (PTTW) taking is part of the Allocated Quantity of Water. Any amount greater than the Current Lawful PTTW Taking is considered part of the Planned Quantity of Water.

- Planned Demand from an Existing Well/Intake is a specific additional amount of water required to meet the projected growth identified within a Master Plan or Class Environmental Assessment (EA), but is not already linked to growth within an Official Plan.

- Planned Demand from a new Planned Well/Intake is a specific amount of water required to meet the projected growth identified within a Master Plan or Class Environmental Assessment, but is not already linked to growth within an Official Plan.

In summary, the Allocated Rates are the combined demand of the Existing plus Committed Demands up to the Current Lawful PTTW Taking (MOE 2013). All of the municipal pumping rates proposed in this project are within the permitted rates, so there are no Planned Demands in this assessment.

3.2.1.1 Existing Municipal Water Demand

As noted above, Existing Demand refers to the amount of water determined to be currently taken from each well/intake during the study period. The municipal pumping rates for the 2013 calendar year were selected as the most representative of existing conditions since all wells were in operation and pumping in 2013 and groundwater level data (representing pumping or non-pumping conditions) were available for all municipal sources. The Existing Rate, representing average annual 2013 demands, was provided by the municipalities for each well and intake and is summarized in Table 3.1, along with the maximum permitted rate, Committed Rate and Allocated Rate for comparison. Average annual Existing municipal pumping rates were used in Scenario C (Table 2.2), and average monthly Existing Rates were used in Scenarios A, B and D (Table 2.3).

TABLE 3.1 Municipal Pumping Rates Applied in the Water Budget Models

Well / Intake Name	Maximum Permitted Rate (m^3/day)	2013 Existing Rate (m^3/day)	Committed Rate (m^3/day)	Allocated Rate – Existing plus Committed (m^3/day)
Hanover				
Hanover Well 1	4,546	829	55	884
Hanover Well 2	4,582	1,052	70	1,122
Ruhl Lake intake	None (Grandfathered)	1,518	0	1,518
Total	**9,128 + Ruhl Lake takings**	**3,399**	**125**	**3,524**
Lake Rosalind				
Lake Rosalind Well 1	30	7	0	7
Lake Rosalind Well 3	110	20	3	23
Total:	**141**	**27**	**3**	**30**

3.2.1.2 Population Growth, Committed Demand and Allocated Demand

As part of the Tier Three Assessment, a water demand assessment was completed to quantify future water supply needs in Lake Rosalind and Hanover. Drinking Water Source Protection staff from the Saugeen, Grey Sauble, Northern Bruce Peninsula Region provided an estimate of the number of empty lots that may be developed and connected to the Lake Rosalind water supply system. Similarly, the number of approved vacant lots was determined for the Town of Hanover by town staff for a hydraulic capacity assessment (Town of Hanover 2015). These lots represent the growth that the municipalities plan to provide water for in the near term. Using the total number of future lots and an estimate of the number of people per lot, the population increase was estimated for each community as outlined in Table 3.2.

TABLE 3.2 Population Growth

Community	Current Population	Unconnected Lots	People / Lot	Population Increase	Future Population
Lake Rosalind	151[A]	6[B]	2.6[C]	16	167
Hanover	7,490[D]	109[D]	2.3[D]	251	7,741

[A] Based on an estimate of 58 residences (MOE 2014a) and 2.6 people per residence (Municipality of Brockton; Stats Canada 2012b)
[B] Milanetti 2015, Pers. Comm.
[C] Stats Canada (2012b)
[D] Town of Hanover (2015)

In addition to increased water use due to population growth, the Town of Hanover anticipates additional future demands due to a proposed medicinal marijuana production facility that would use municipal water supplies. The demand associated with this facility is expected to be 11 m^3/day once it is fully operational (Groleau 2015, Pers. Comm.).

Assuming the current per capita water use remains constant, the anticipated increase in water demand (Committed Rate) from the population increase and increase due to medicinal marijuana production was estimated (Table 3.1). The anticipated increases in pumping over average 2013 demand was estimated to be 10.3% (3 m^3/day) in Lake Rosalind and 3.7% in Hanover (125 m^3/day).

For the purposes of the risk assessment scenarios, the Committed increase in each community was distributed among the wells depending on the ability of those wells to take on additional demand. For the Town of Hanover, the Committed increase was distributed among the two groundwater wells equal to the ratio of their current demand (i.e., 44% of the total municipal groundwater demand was sourced from Well 1, and 56% from Well 2 in 2013). While all or a portion of the Committed Demand could be distributed by the Ruhl Lake intake, partitioning all the pumping on the municipal groundwater wells is considered more conservative for the groundwater wells (as no additional demand was simulated to come from the Ruhl Lake intake). A Committed increase of 55 m^3/day was applied to Well 1, while 70 m^3/day was applied to Well 2.

As there are no planned water supply systems in either of the communities, there were no Planned Demands in this assessment. Therefore, the total Allocated Demand (Existing plus Committed Demand) is 3,524 m^3/day in Hanover and 30 m^3/day in Lake Rosalind (Table 3.1). These average rates will be applied in risk assessment Scenario G(2) and used to delineate the WHPA-Q1 (Section 5.1.1). For both municipal systems, the Allocated Rates are below the permitted rates.

Variable Climate

As outlined in Table 2.2, Scenarios C and G represent average climatic conditions and therefore, were simulated using the steady-state groundwater flow model. Scenarios A, B, D, E(2), F(2), and H(2) were simulated transiently (incorporating variable climatic conditions) using the spreadsheet-based water budget model for the Ruhl Lake intake and the groundwater flow model to evaluate the municipal groundwater wells. The transient scenarios required realistic estimates of how the Town of Hanover will vary pumping on a monthly basis over the long-term going forward. The Existing monthly pumping rates applied in select scenarios are outlined in Table 2.3 and represent 2013 average monthly demand conditions that were repeated on a monthly basis throughout the relevant transient scenarios. The monthly Allocated Rates are summarized in Table 2.4 and were proportioned seasonally based on the demand trends observed in 2013 (Table 2.3).

3.2.2 Non-Municipal Water Demand

3.2.2.1 Permitted Water Uses

In addition to the municipal supply wells, a total of 13 non-municipal permitted takings (sources) exist within the Study Area, and these permits were examined in detail as part of the Tier Three Assessment Physical Characterization, Model Development and Calibration Report (Appendix A). The 2015 PTTW database and 2011 Water Taking Reporting System (WTRS) database were the most up–to–date databases containing permit and source names, geographic data, coordinates of permits/sources, period of water taking and daily reported pumping rates. The PTTW database does not contain screened or open borehole interval information, so assumptions were made on the elevation of the production aquifer for each of the sources located within and surrounding the Study Area.

Recognizing the uncertainty associated with the non-reported permitted water takings, the study team examined the MOE WTRS database for 2011 to refine the non-municipal water demand estimates. The best available water taking information was carried forward and applied in the groundwater flow models. The daily reported rates were averaged over the month to obtain monthly pumping rates and over the year to obtain average annual pumping rates. Where data were not available in the WTRS, water demands were estimated using consumptive use factors (Kinkead Consulting and AquaResource Inc. 2009) applied to the maximum permitted rates and maximum allowable days of pumping recorded in the PTTW database.

3.2.2.2 Non-Permitted Water Uses

With some exceptions, water takings that do not exceed 50,000 L/day do not need a PTTW. Among other purposes, non-permitted takings are used for supplying rural residences with potable water in areas where municipal systems do not exist. These domestic water demands were not simulated in the groundwater flow model as the majority of the withdrawn water for domestic water takers is returned to the same groundwater system via private septic systems. Consumptive water demands associated with this water use sector are relatively low. As such, consumptive use for this water use sector was considered negligible and not included in the numerical model or water budget calculations.

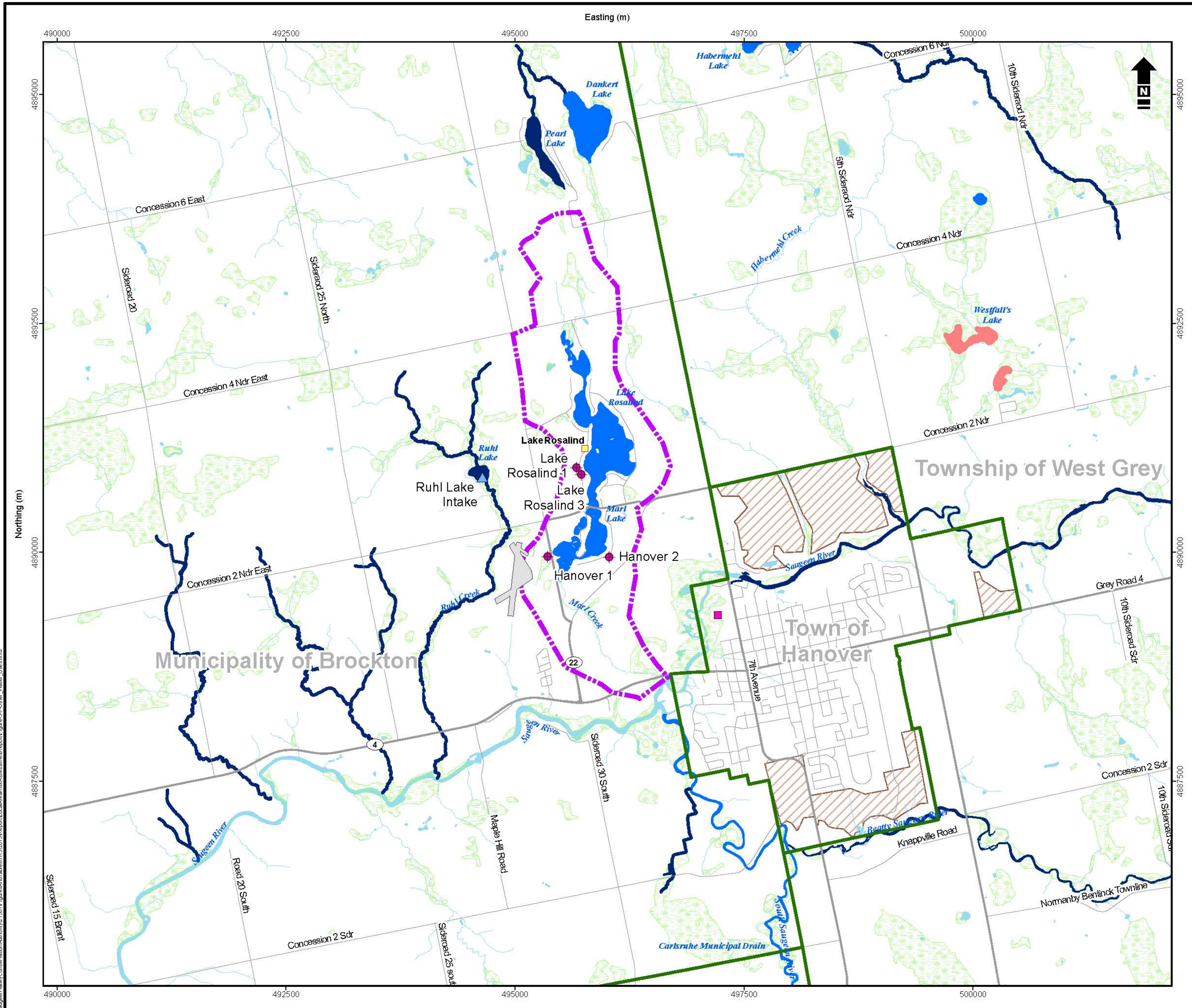
3.2.3 Other Water Uses

The Tier Three Assessment must identify all other water uses and estimate the water quantity requirements for those uses where possible (Figure 3.1). Other water uses that are relevant to the Study Area include non-municipal groundwater takings (discussed above), aquatic habitat, Provincially Significant Wetlands (PSWs), and waste water assimilation.

Establishing the quantity of water required by other water uses is challenging because:

- System function is often not well enough understood to generate definitive unit flow rate estimates (e.g., the impacts of a reduction in groundwater discharge into the aquatic habitat are not easily defined due to a lack of characterization of local groundwater/surface water interactions or aquatic needs).

- System function is not always tied to a unit flow rate of water (e.g., the health and ecological integrity of a PSW may be dependent on the unit rate of change in the water table elevation).



Reference: Data obtained from GeoBase® and Ontario Ministry of Natural Resources and SVCA used under license. Evaluated Wetlands: Ministry of Natural Resources, 2003. Produced using information provided by the Ministry of Natural Resources, Copyright © Queen's Printer, 2015.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Local Area Risk Assessment Report

Other Water Uses

Date:	Project:	Technical:	Reviewer:	Drawn:
03 Feb 2016	21581-527	S. Davies	P. Meyer	M. Pfeifer

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Figure 3.1

The Province of Ontario introduced the use of thresholds to evaluate other water uses. Thresholds applied in this Tier Three Assessment are discussed in Section 4.

3.2.3.1 Aquatic Habitat

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* (Revised Statutes of Ontario 1990, Chapter O. 40) and O. Reg. 387/04 – *Water Taking*. Section 34 of the *Ontario Water Resources Act* requires anyone taking more than a total of 50,000 L/day from a lake, stream, river or groundwater source (with some exceptions) to obtain a PTTW.

The PTTW application process places an emphasis on environmental considerations, such as the potential impact of proposed takings on surface water features and ecological habitats that depend on the interrelationship between groundwater and surface water, to maintain their function in the ecosystem.

Figure 3.1 shows the boundaries of the Marl Creek subwatershed, which has an area of 5.3 km^2. Figure 3.1 also shows coldwater streams in the Study Area (Aquatic Resource Area; MNR 2012) that are subject to the Province's groundwater discharge reduction thresholds (discussed in Section 4.3.1). Coldwater streams and water bodies that support coldwater fish communities are present along the Saugeen and Beatty Saugeen rivers and select tributaries, upstream of Hanover, Lake Rosalind and Marl Lake, and tributaries and water bodies north of the Saugeen River. Both Ruhl Lake and the streams that flow into or flow out of Ruhl Lake are considered coldwater features.

3.2.3.2 Provincially Significant Wetlands

Wetlands are classified and evaluated by biologists and ecologists under a standard methodology, taking into account the biological, hydrological, and socio-economic features and functions of a wetland. When wetlands are evaluated as PSWs, they are protected under the wetland component of the *Provincial Policy Statement* (OMMAH 2005). The *Technical Rules* identify PSWs as other water uses that, if significantly impacted by municipal pumping, would result in an elevated Risk Level for the Local Area.

Some wetland systems within the Study Area are located in topographic lows on the landscape and others are located adjacent to rivers, streams, and lakes (Figure 3.1); however, none of these wetlands have been evaluated or classified by the MNRF or the SVCA as being PSWs. Therefore, the potential impacts of increased water demands on wetlands were not evaluated in the risk assessment portion of this Tier Three Assessment.

3.2.3.3 Wastewater Assimilation

The Town of Hanover's Wastewater Treatment Plant (WWTP) discharges treated water into the Saugeen River on the northwest side of the Town (Figure 3.1). The municipal intake and wells in this assessment have the potential to reduce groundwater discharge into the Saugeen River and/or its tributaries, which could reduce the assimilative capacity of the river. The magnitude of decreased groundwater discharge due to increased municipal pumping from the Existing to the Allocated Rates is interpreted to be small compared to the total flows of the Saugeen River; however, for completeness, the impact of municipal pumping on the Saugeen River's ability to assimilate waste from the WWTP was considered in this Tier Three Assessment.

4 RISK ASSESSMENT THRESHOLDS

Following delineation of the vulnerable areas (Section 5), a series of risk assessment scenarios were run to assess change in groundwater elevations at the municipal wells, the change in Ruhl Lake water elevation, the change in groundwater discharge to specified surface water features, and the change in Ruhl Lake outflow. The predicted change in water level, groundwater discharge and surface water outflow values were compared to an established set of drawdown and ecological thresholds to determine if the predicted changes exceeded the respective thresholds. The following sections outline the thresholds used in this Tier Three Assessment.

4.1 Groundwater Drawdown Thresholds

Safe additional available drawdown (SAAD) is defined as the additional depth that the water level within a pumping well could fall and still maintain the well's Allocated Rate. It is calculated as the additional drawdown that is available above the drawdown created by the Existing (2013) average annual pumping rate. To establish the SAAD for each municipal well examined in the Tier Three Assessment, the following components were calculated:

- **Safe Groundwater Level Elevation:** The lowermost water level elevation within a municipal pumping well that an operator can pump a well. This elevation may be related to the well screen elevation, pump intake elevation, top of aquifer, or other operational limitations.

- **Existing Water Level Elevation in the Municipal Pumping Well:** The elevation of the observed average annual pumped water level within the municipal well in 2013.

- **Estimated Non-linear Well Losses at Each Well:** The drawdown within a well in response to well inefficiencies (e.g., entrance losses and turbulent flow around pump fittings) that occurs due to well construction characteristics and well condition.

Each component is discussed in the following sections.

4.1.1 Safe Groundwater Level Elevation

The safe groundwater level elevations for the Town of Hanover municipal wells were established based on well construction details and recommendations from well maintenance reports, or more specifically:

- the current elevation of the pump intake
- the elevation of the top of the screened interval (the highest water producing feature)

The second case listed above recognizes that regardless of the current pump setting, if required, the pumps could be lowered within respective wells to the limit of the well screen plus a modest buffer, while still maintaining well capacity and the cooling flow required to prevent pump failure. Based on this approach, the estimated safe water level elevations are presented in Table 4.1.

Pumped water level elevations were unavailable for the Lake Rosalind Wells, and as such, SAAD values could not be estimated.

TABLE 4.1 Safe Additional Available Drawdown

Name	Ground Surface Elevation (m asl)	(A) Intake Elevation (m asl)	(B) Existing Pumped Water Level Elevation (m asl)	(C) Safe Water Level Elevation (m asl)	(B – C) Safe Additional Available Drawdown (m)	Safe Water Level Based On
Hanover						
Hanover Well 1	273.9	N/A	265.7[3]	251.4	14.3	Top of Screen + 1.8 m[1]
Hanover Well 2	279.8	238.0	267.9[3]	238.0	29.9	Intake Elevation (Top of Screen + 1.8 m)[2]
Lake Rosalind						
Lake Rosalind Well 1	278.7	275.7[4]	N/A	N/A	N/A	N/A
Lake Rosalind Well 3	277.0	260.6	N/A	N/A	N/A	N/A

[1] Assumed same buffer distance (1.8 m) as observed in Hanover Well 2
[2] Based on lowest intake depth recommended by IWS (2008)
[3] Existing Pumped Water Level Elevation is the interpreted pumped water level from 2013
[4] Intake depth from S. Gowan 2015, Pers. Comm.
N/A – data not available
asl – above sea level

4.1.1.1 Existing Water Level Elevations in Municipal Pumping Wells

The existing water level elevation represents the average water level in the well when it is pumped at rates consistent with normal operational patterns. Water level data measured during uncharacteristically high or low production, as would occur during aquifer testing or well maintenance, were not used to calculate the average pumped water level.

The raw data provided by the Town of Hanover represents a relatively continuous dataset of water levels collected every 15 minutes. These levels represent the height of water above pressure sensors and the datasets were converted to elevations using the known elevations of the pressure sensors in the wells. As this water level data included pumping and non-pumping conditions, a representative pumping depth was estimated from the lowest water levels. While Hanover Well 2 contains a pressure sensor, the elevation of the pressure sensor could not be verified. Therefore, the water level data from the observation well, located less than 8 m from the Hanover Well 2, and completed in the same aquifer, was used to determine the pumped water level elevation for Well 2.

Table 4.1 outlines the available existing water level groundwater elevations for the municipal wells in 2013, and these groundwater elevations, along with other relevant well construction information, are illustrated on hydrographs in Appendix C.

4.1.1.2 Estimated Non-Linear In-Well Losses

Well losses refer to the difference between the theoretical drawdown in a well and the observed drawdown, and are due to factors such as turbulence in the well itself, and momentum changes as the water flows through the screen and changes direction to flow up the well casing and into the pump intake. These well losses were considered in the Tier Three Assessment, as the SAAD refers specifically to the groundwater elevation in the well (limiting factor for the well to continue pumping water) and not the average groundwater elevation in the aquifer in the vicinity of the well. The in-well losses were calculated as the increased drawdown that is expected within the pumping well due to the incremental increase in pumping from the Existing Rates to the Allocated Rates (Existing plus Committed Rates).

Convergent head losses derived from differences in simulating an average water level at a finite element node and the pumping well are negligible due to the small node spacing around the wells in the model and are less important than the in-well losses and were not considered in the analyses.

Additional drawdown resulting from the in-well losses were calculated for the increase in pumping from Existing to the Allocated Rates, using pumping rates and additional well loss coefficient data (see Appendix D). The process used to calculate in-well losses for the Tier Three Assessment is explained in Appendix D, and the calculated values for each well are listed in Table 4.2.

TABLE 4.2 Estimated Drawdown due to Non-Linear Head Losses

Well Name	Existing Rate (2013)	Allocated Rate	Pumping Rate Increase (ΔQ)	Drawdown due to Non-Linear Head Losses	Well Loss Coefficient (C)	Step Test Date	Reference
	m^3/day	m^3/day	m^3/day	m	$m/(m^3/day)^2$		
Hanover Well 1	829	884	55	0.04	3.82×10^{-7A}	n/a	Walton 1962
Hanover Well 2	1,052	1,122	70	0.01	8.12×10^{-8}	Oct 2008	IWS 2008

Well Name	Existing Rate (2013)	Allocated Rate	Pumping Rate Increase (ΔQ)	Drawdown due to Non-Linear Head Losses	Well Loss Coefficient (C)	Step Test Date	Reference
	m^3/day	m^3/day	m^3/day	m	$m/(m^3/day)^2$		
Lake Rosalind Well 1	7	7	0	0.00	3.82×10^{-7A}	n/a	Walton 1962
Lake Rosalind Well 3	20	23	3	0.00	3.82×10^{-7A}	n/a	Walton 1962

[A] Reliable step test data were not available for this well. Therefore a C-value of 3.82E-07 $m/(m^3/d)^2$ was selected based on the assumption that the well is mildly deteriorated (Walton 1962).
n/a - Step test data not available

4.1.1.3 Safe Additional Available Drawdown

Table 4.1 lists the SAAD value calculated as the difference between the 2013 interpreted pumped water level elevation and the safe water level elevation (see Appendix C for municipal well hydrographs). The SAAD provides a general indication of a well's ability to sustain pumping in the event of changes in groundwater level elevation in the municipal well. Where the SAAD is low, the well may have a higher risk of not being able to meet pumping requirements in the future, if the same or additional pumping volumes are required to be produced by that well.

The SAAD ranges from 14.3 m at Hanover Well 1 to 29.9 m at Hanover Well 2 (Table 4.1). As current and historic pumped water levels are not collected at Lake Rosalind Well 1 or Well 3, SAAD values for the Lake Rosalind Wells could not be estimated.

4.2 Surface Water Level Decline Thresholds

Evaluation of surface water level decline at Ruhl Lake is analogous to evaluation of groundwater drawdown in the municipal wells; there is an existing water level, a safe water level and the difference between the two is the available amount of water level decline. At Ruhl Lake, the existing water level is the stage elevation of the lake (274.2 m asl) as estimated from a 0.5 m Digital Elevation Model (DEM) and the safe water level is represented by the intake elevation (268.7 m asl). Based on these values, the available water level decline is estimated to be 5.5 m.

4.3 Ecological Thresholds

As the Tier Three Assessment evaluates whether or not municipal groundwater wells can meet their Allocated Rates, while maintaining the requirements of other water uses in the area, the assessment must identify all other water uses and estimate the water quantity requirements for those uses where possible. As noted previously, no PSWs are found within the Study Area and therefore were not evaluated as part of this Tier Three Assessment. The focus of this study was on assessing potential impacts on coldwater streams as the health of these features are at least partially reliant on groundwater discharge.

4.3.1 Coldwater Fisheries

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 using the groundwater flow models. Consequently, the Province introduced the use of thresholds to evaluate the potential for impacts due to reductions in groundwater discharge into coldwater streams.

The Province prescribed specific baseflow reduction thresholds to be used when assigning a Risk Level associated with predicted impacts to coldwater fish community streams due to increased municipal pumping (Scenarios E[2] and G[2] only). For coldwater streams, and when considering only the Allocated Quantity of Water, a Moderate Risk Level is assigned when groundwater discharge is predicted to be reduced by at least 10% of existing monthly baseflow (as defined by the MOECC; MOE 2009, 2013). Baseflow is defined by the MOE (2009) as the monthly Qp80 (the flow that is exceeded 80% of the time) or using another method where gauged stream flow data are unavailable.

Potential baseflow reductions on coldwater streams due to changes in land use were not taken into account when assigning the Risk Level in the Tier Three Assessment; however, the impact of municipal pumping at the Allocated Rates on coldwater streams was evaluated as part of the project (Scenario G[2]). Figure 3.1 illustrates the coldwater streams and lakes located within the Study Area that are subject to the Province's groundwater discharge reduction thresholds.

4.3.2 Wastewater Assimilation

As described in Section 3.2.3.3, municipal withdrawals have the potential to reduce baseflow to the Saugeen River and/or its tributaries, which could effectively reduce the assimilative capacity of those watercourses on treated wastewater effluent. This assessment evaluated the reduction in groundwater discharge on the Saugeen River near the waste water treatment plant.

5 VULNERABLE AREA DELINEATION AND RISK ASSESSMENT RESULTS

5.1 Vulnerable Area Delineation

The first step in the Local Area risk assessment was the delineation of vulnerable areas. Water quantity vulnerable areas were delineated to protect the quantity of water required by the Town of Hanover and Community of Lake Rosalind's Existing and Allocated Rates. The methodology used to delineate the WHPA-Q1 and WHPA-Q2 areas were outlined in Section 2.1, and the results are described in the following sections.

5.1.1 WHPA-Q1

The WHPA-Q1 was delineated as the combined area that is the cone of influence of a well and the whole of the cones of influence of all other wells that intersect that area (MOE 2009). Section 2.1.1 outlines the methodology used, and Appendix B describes the selection of the 2 m contour interval used in the delineation of the WHPA-Q1.

Two WHPA-Q1 areas lie within the Study Area as illustrated on Figure 5.1. The largest (WHPA-Q1-A) is circular in shape, encompasses the municipal wells of the Town of Hanover and extends radially outward from those wells southeast to the Saugeen River, and north to the Lake Rosalind Wells. As noted in the Characterization Report (Appendix A), the water level elevations in the production aquifer at Hanover Wells 1 and 2 were simulated in the model to be lower than observed. As such, the drawdown associated with municipal pumping at the Allocated Rates, and the delineated WHPA-Q1, may be larger than reality. Therefore, the extent of the WHPA-Q1-A for the Hanover Wells (Figure 5.1) is conservative.

In Lake Rosalind, the maximum drawdown was predicted to be less than 2 m at each of the Lake Rosalind wells and extend in the vicinity immediately surrounding each well. As such, the WHPA-Q1 surrounding the Lake Rosalind Wells is represented by a single 100 m buffer zone (WHPA-Q1-B) that surrounds each well (Figure 5.1). There are no permitted non-municipal consumptive water users located within the WHPA-Q1-A or WHPA-Q1-B areas.

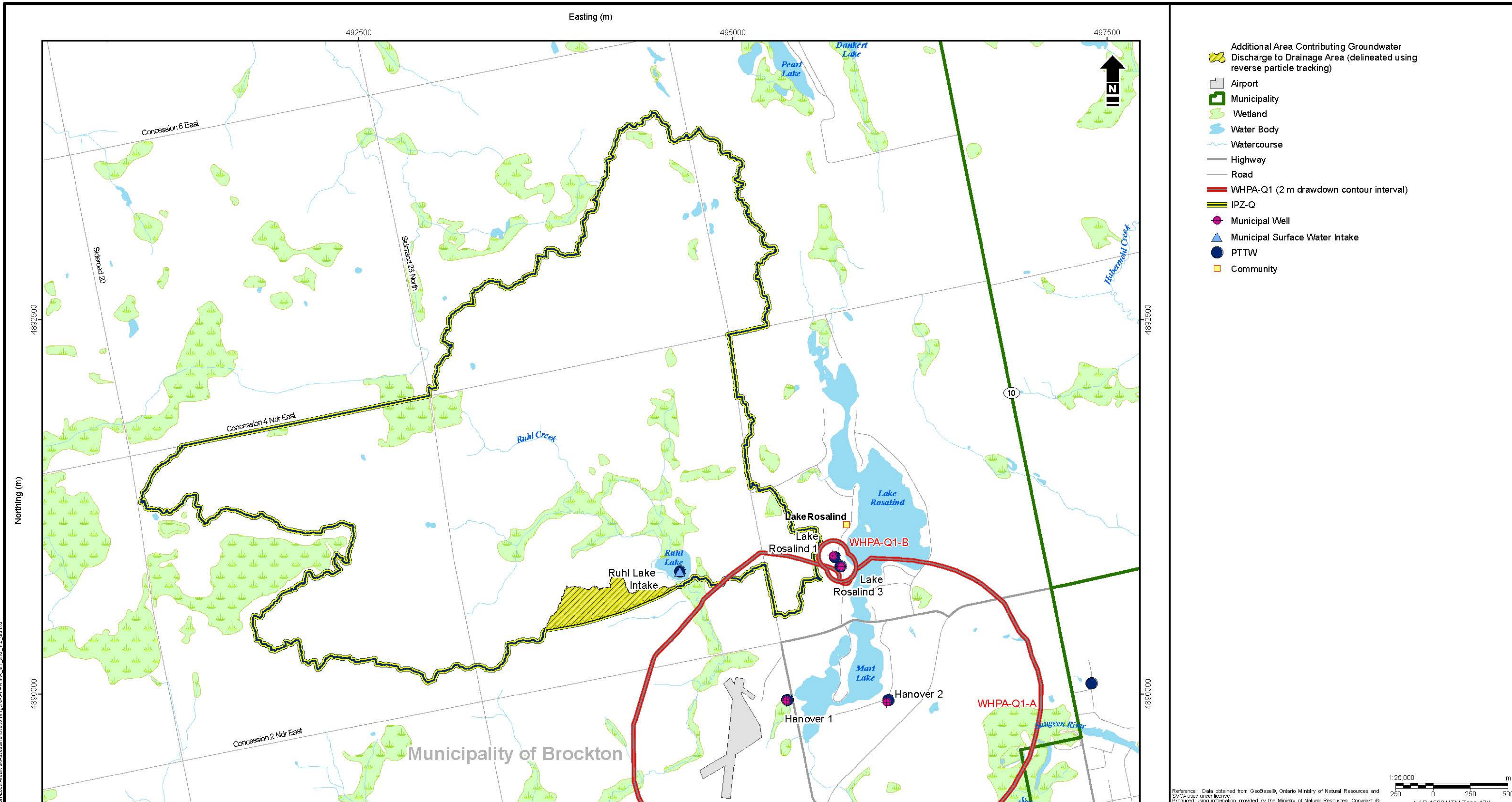
While the WHPA-Q1-A and WHPA-Q1-B areas overlap, they remain separate due to the inferred hydraulic separation between the two aquifers. The two Town of Hanover wells are completed within a deep confined overburden aquifer, while the two Lake Rosalind Wells are completed in a shallow unconfined aquifer. Previous characterization (Appendix A) and field studies in the area (Luinstra Earth Sciences 2008) demonstrated that the two flow systems are separate. The deeper aquifer has a high yield, is of good quality, and is not influenced by surface water of the shallow aquifer. The Luinstra study (2008) included drilling shallow and deep wells roughly 2 m apart near Ruhl Lake 1 km west of the Lake Rosalind Wells. The observed water level in the shallow aquifer was 5 m higher than the water level in the lower aquifer, suggesting hydraulic isolation between the two units in the area. Due to the small magnitude of pumping by the Lake Rosalind system (27 m^3/day) and the apparent hydraulic separation between the two aquifers, the delineation of each WHPA-Q1 area (and subsequent Local Areas) remain as separate areas and therefore any elevated (i.e., Moderate or Significant) Risk Level assigned to one area will not automatically be assigned to the other area.

5.1.2 WHPA-Q2

The WHPA-Q2 is defined in the *Technical Rules* as the WHPA-Q1 area, plus any area where a future reduction in recharge may have a measurable impact on wells located in that area. However, because no land use change and associated recharge reduction is interpreted to exist within the vicinity of the municipal wells (see Section 3.1.1 for Lake Rosalind and Section 3.1.2 for the Town of Hanover), risk assessment scenarios that include the impact of recharge reduction (i.e., Scenarios E[1], E[3], F[1], F[3], G[1], G[3], H[1] and H[3]) were not conducted. As a result, the WHPA-Q2 (WHPA-Q2-A, WHPA-Q2-B and WHPA-Q2-C) is identical to the respective WHPA-Q1 areas shown on Figure 5.1.

5.1.3 IPZ-Q

The Surface Water Quantity Vulnerable Area, IPZ-Q, corresponds to the drainage area that contributes surface water to an intake, and the area that provides recharge to an aquifer that contributes groundwater discharge to the drainage area. Part VI.7 of the *Technical Rules* specifies the rules with respect to the delineation of IPZ-Q.



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Local Area Risk Assessment Report

WHPA-Q1 and IPZ-Q

Date:	Project:	Technical:	Reviewer:	Drawn:
03 Feb 2016	21581-527	S. Davies	P. Meyer	M. Pfeifer

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Figure 5.1

In the case of the Ruhl Lake surface water intake, the drainage area contributing to the intake was delineating using a high quality 0.5 m DEM and encompasses ephemeral and permanent tributaries that extend north and northeast of Ruhl Lake.

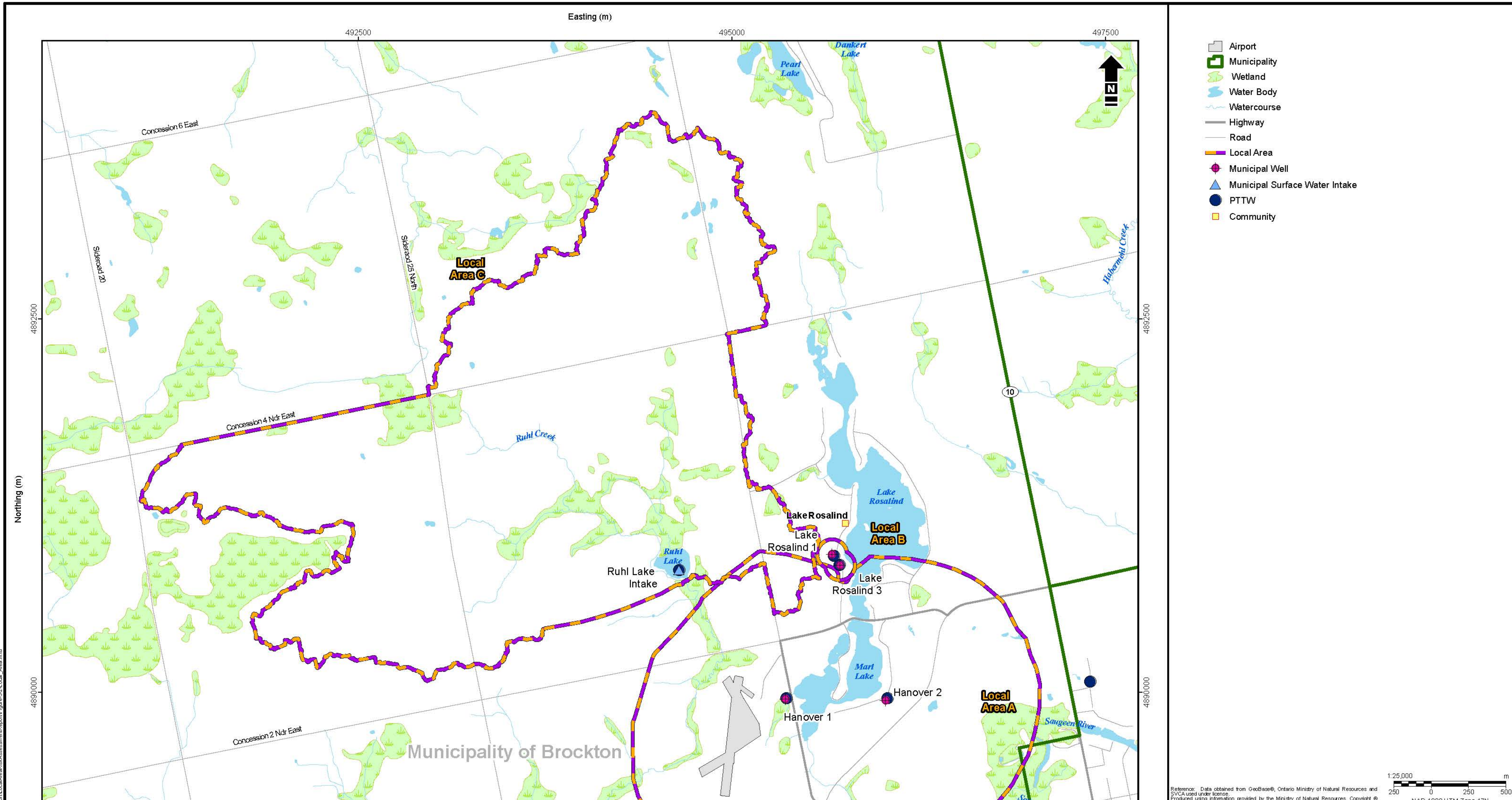
Reverse particle tracking was conducted in the groundwater flow model, whereby fictitious particles of water were released at the bottom of Ruhl Lake and tracked backward in time to their source area to identify any additional areas that provide recharge to the Ruhl Lake drainage area. This exercise predicted that a component of groundwater discharge originates from outside the catchment area, in an area southwest of the lake (Figure 5.1) on a topographically high characterized by coarse-grained deposits. Water recharging in this area was simulated to flow through the shallow groundwater system and discharges into Ruhl Lake.

Therefore, the final IPZ-Q for Ruhl Lake was delineated as the combination of both areas described above and is shown on Figure 5.1.

5.1.4 Local Areas

Local Areas for groundwater are 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). As noted in Section 5.1.2, the WHPA-Q1 and WHPA-Q2 areas are coincident, as there is no potential for measureable impact on groundwater elevations at the municipal wells due to proposed changes in land use on the margins of, or within, the WHPA-Q1 areas. The Local Area for surface water was delineated by combining the drainage area that contributes surface water to the intake, and the area that provides recharge to an aquifer that contributes groundwater discharge to the drainage area (IPZ-Q; Figure 5.1).

The Local Areas for the municipal water supplies of the Town of Hanover and Community of Lake Rosalind are illustrated on Figure 5.2. There are three Local Areas in this Assessment: Local Area A surrounding the Hanover Wells, Local Area B surrounding the Lake Rosalind Wells and Local Area C encompassing the Ruhl Lake intake (Figure 5.2). Local Areas A and B overlap, and Local Area A also overlaps with Local Area C. As the deep (Local Area A) and shallow (Local Area B) groundwater flow systems are hydraulically disconnected from one another, and as the deep groundwater flow system and the surface water flow system (Local Area C) are similarly disconnected, the Local Areas remain separate and unique delineations. Therefore, an elevated Risk Level assigned to any one of the Local Areas will not automatically be applied to those Local Areas that it intersects, unless there is an inferred hydraulic connection.



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Local Area Risk Assessment Report

Local Area

Date:	Project:	Technical:	Reviewer:	Drawn:
03 Feb 2016	21581-527	S. Davies	P. Meyer	M. Pfeifer

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Figure 5.2

5.2 Risk Assessment Scenario Results

The model results of each risk assessment scenario were evaluated according to the source of the municipal water supply. For the municipal intake at Ruhl Lake, the model results were evaluated with respect to the estimated water level decline and the predicted change to outflow from Ruhl Lake. For the municipal wells, the model results were evaluated with respect to the SAAD at each municipal well, and the simulated impact to groundwater discharge along coldwater streams and other water uses. Section 5.2.1 and 5.2.2 outlines the risk assessment scenario results for the Ruhl Lake intake, which was evaluated using the spreadsheet-based water budget model. Section 5.2.3 and 5.2.4 outlines the results of the risk assessment scenarios for the Hanover Wells, which were evaluated using the groundwater flow model.

5.2.1 Surface Water Level Decline

Using the spreadsheet-based water budget model, the simulated water level decline at Ruhl Lake for each of the surface water risk assessment scenarios was compared to the available depth of water level decline at the intake (see Table 5.1). The available water level decline (5.5 m) is calculated as the difference between the existing water level (274.2 m asl) and the intake elevation (268.7 m asl). Impacts to other uses were evaluated as the change in predicted outflow from Ruhl Lake into Ruhl Creek, a stream hosting coldwater fish communities.

For Scenarios A and E(2), the simulated water level decline was calculated using the long-term average lake water level elevation, whereas simulated water level decline for Scenarios B and F(2) were calculated using the minimum water level elevation simulated in the 1950 to 2005 period. In either approach, the water level decline was assessed relative to the simulated water level elevation from Scenario A (Table 5.1).

Simulation results were compared to Scenario A as this scenario represents baseline, average existing conditions. If the simulated water level decline was greater than the available amount of decline (5.5 m), the intake was considered unable to sustain the required demand, and it would trigger a Significant Risk Level for the Local Area. The minimum simulated water level elevation of the lake for all scenarios is shown on the summary hydrograph presented on Figure C5. To maintain a common reference point on this figure, this simulated water level elevation was calculated by subtracting the simulated water level decline (Table 5.1) from the existing water level (274.2 m asl).

TABLE 5.1 Risk Assessment Water Level Decline Results

Intake Name	Available Water Level Decline (m)	Water Level Decline (m)			
		A	E(2)	B	F(2)
		Existing Demand	Allocated Demand[1]	Existing Demand	Allocated Demand[1]
Ruhl Lake	5.5	0.0	0.0	0.4	0.4

[1] no increased demand from Existing to Allocated Rates was partitioned to the Ruhl Lake intake; the increased demand was added to Hanover Wells 1 and 2.

5.2.1.1 Scenario A

Scenario A examined the predicted change in the Ruhl Lake water level under Existing Rates at the surface water intake, under existing land use conditions. This scenario is the base case scenario representing existing conditions and water level decline from each subsequent surface water scenario has been calculated relative to Scenario A.

5.2.1.2 Scenario B

Scenario B examined the predicted water level fluctuations at the intake through variable climatic conditions including drought periods, existing transient variation in pumping, and existing land use. The lowest water level predicted by the model during this scenario was recorded for the intake. The difference between the lowest predicted water level and the water level predicted under Scenario A was 0.4 m, and this water level decline is less than the available decline of 5.5 m (Table 5.1). As such, the intake is predicted to maintain Existing Demand pumping throughout simulated drought periods considering current land use.

5.2.1.3 Scenario E(2)

Scenario E(2) examined the predicted water level fluctuations at the intake under the Allocated Rates considering existing land use. As the Allocated Demand in Scenario E(2) is equivalent to the Existing Demand (Scenario A), there was no decline in water levels relative to Scenario A (Table 5.1). Given these results, the intake was simulated to be able to pump throughout the climate period.

5.2.1.4 Scenario F(2)

Scenario F(2) examined the model-predicted fluctuations in water level at the intake under drought conditions and considering the Allocated Rates, which are the same as the Existing Rates simulated in Scenario B. The difference between the lowest water level predicted by the model during this model scenario and the water level under Scenario A was 0.4 m, which is significantly less than the estimated amount of available decline of 5.5 m (Table 5.1). As such, the intake is predicted to be able to maintain demand throughout drought periods.

5.2.2 Impacts to Downstream Flow

The impact to downstream flow, which may impact other downstream water uses, was also considered for Ruhl Lake using the results of Scenario E(2). As there was no increase in demand from Existing to Allocated Rates associated with the Ruhl Lake intake (Table 3.1), there was no simulated change to the Ruhl Lake outflow. Any reductions in streamflow in Ruhl Creek due to drought are not evaluated in the scope of work of the Tier Three Assessments.

5.2.3 Drawdown at Town of Hanover Municipal Wells

The simulated drawdown in each of the groundwater risk assessment scenarios was compared to the estimated SAAD at each municipal well in Hanover and is summarized in Table 5.2. For ease of comparison, the additional drawdown due to non-linear head losses (related to the increase in demand from Existing to the Allocated Rates; Table 4.2) was incorporated into the SAAD estimates that were presented in Table 4.1. The results of the risk assessment scenarios are outlined in the following sections.

For the groundwater steady-state scenario (Scenario G[2]), the difference between the groundwater elevations at the well in the existing conditions scenario (Scenario C) and the groundwater elevations at the end of Scenario G(2) was recorded as the additional simulated drawdown (Table 5.2). For the transient scenarios (Scenarios D and H[2]), the lowest simulated water level elevation in the aquifer at each municipal pumping well were compared to the water levels in Scenario C, and these value were recorded in Table 5.2. The model simulated drawdowns in each scenario were then compared to the field-based SAAD values to identify municipal wells that may be unable to sustain their Allocated Rates. The risk assessment scenario results are presented in the following sections.

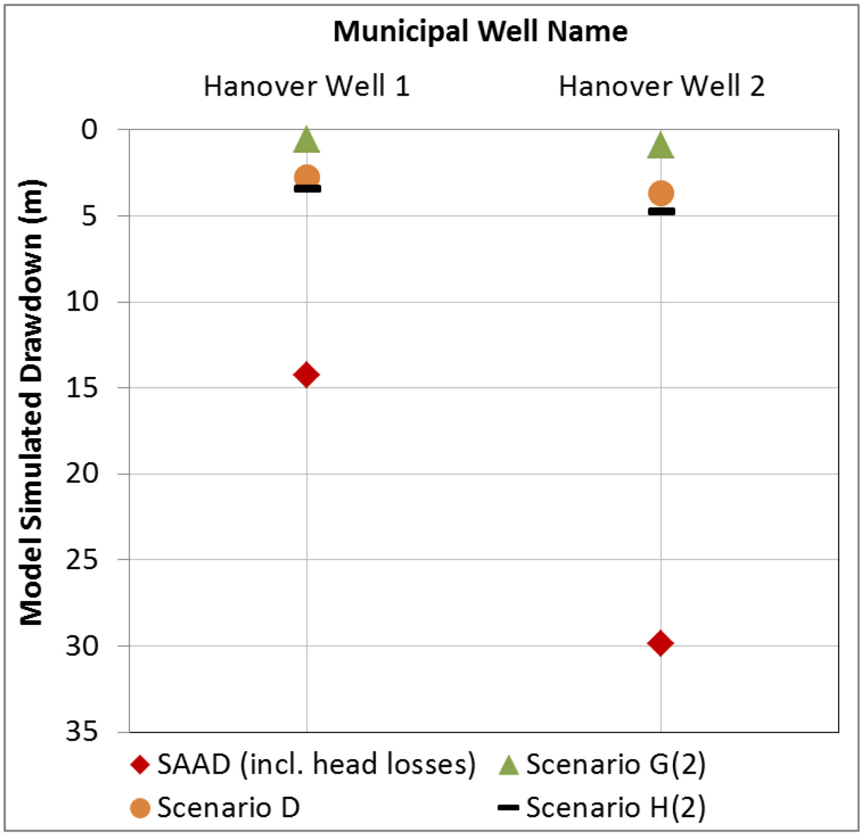
The minimum simulated water level elevation for each well, representing the maximum simulated drawdown (including non-linear well losses) of all the scenarios is summarized on Chart 5.1 and in hydrograph form in Appendix C (Figures C1 to C4).

TABLE 5.2 Risk Assessment Groundwater Drawdown Results

Well Name	Safe Additional Available Drawdown (m)	Safe Additional Available Drawdown, incl. Head Losses[1] (m)	Average Climate (Steady-State) Drawdown (m)		Drought (Transient) Maximum Drawdown (m)	
			C Existing Demand	G(2) Allocated Rates	D Existing Demand	H(2) Allocated Rates
Hanover Well 1	14.28	14.24	0.0	0.5	2.8	3.4
Hanover Well 2	29.88	29.87	0.0	0.9	3.6	4.7

[1] SAAD including non-linear well losses (Table 4.2)

CHART 5.1 Model Simulated Drawdown in Risk Assessment Scenarios



The simulated drawdown in the risk assessment scenarios was less than the safe additional drawdown at each of the Hanover wells, indicating the wells are able to pump at their Existing and Allocated Rates over the long-term (including drought conditions), under existing and future land use development conditions.

Scenario C examined the simulated change in water level under Existing Demands at each Hanover well under average climate and existing land use conditions. This scenario is the base case scenario representing existing conditions. Drawdown from each subsequent groundwater scenario was calculated relative to Scenario C.

Scenario G(2) evaluates only the increase in municipal pumping due to the increase from Existing to the Allocated Rates, under average annual climatic conditions. As outlined on Table 5.2, an additional 0.5 and 0.9 m of additional drawdown were simulated in Wells 1 and 2, respectively. These simulated drawdown values are much less than the SAAD for both wells suggesting that if municipal pumping were to increase to the Allocated Rates both municipal wells would be able to pump sustainably under average climatic conditions.

Scenario D examined the simulated water level fluctuations at the two wells under variable climatic conditions including short and long-term drought, existing seasonal variations in pumping, and existing land use. The greatest simulated drawdown during this scenario was 2.8 m and 3.6 m at Hanover Wells 1 and 2, respectively. This drawdown is attributed to increased demand in the summer months and during drought periods. The simulated drawdown in this scenario is still less than the available drawdown estimated for each well (14.2 and 30.0 m; Table 5.2) suggesting the wells are able to pump sustainably throughout short and long-term drought conditions.

Scenario H(2) examined the model-simulated water level fluctuations at each of the Hanover wells under short and long-term drought climatic conditions, and under increased municipal pumping at the Allocated Rates. The greatest simulated drawdown values recorded during the scenario were 3.4 and 4.7 m at Hanover Wells 1 and 2, respectively. These values are well below the SAAD estimated for each well (Table 5.2) indicating the wells are able to pump at their Allocated Rates sustainably throughout short and long-term drought conditions.

5.2.4 Impacts to Groundwater Discharge

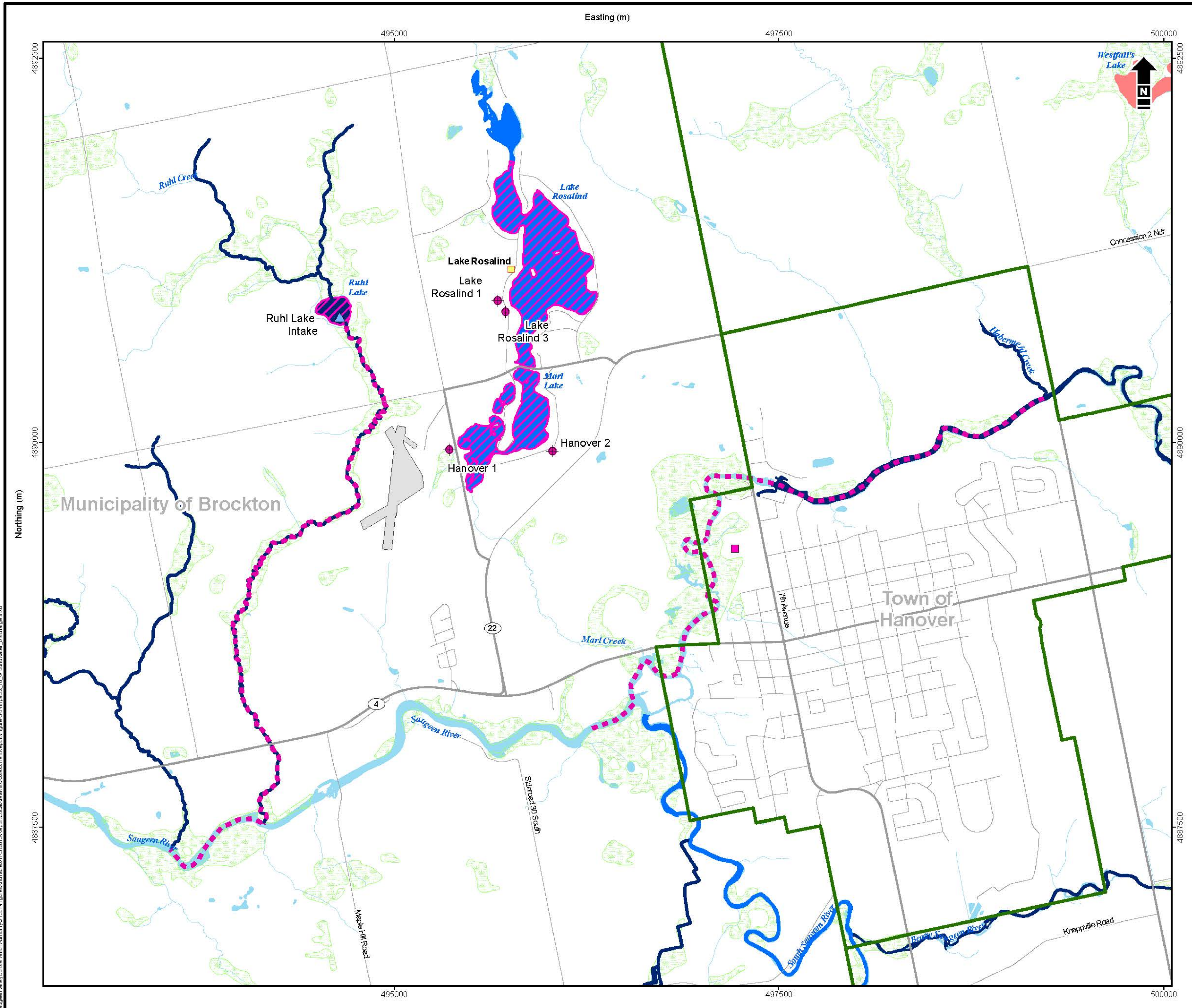
The *Technical Rules* specify that streams and creeks hosting coldwater fish communities cannot be negatively impacted by increases in municipal pumping from the Existing to the Allocated Quantity of Water. Any reduction in groundwater discharge to coldwater streams under the G(2) scenario that exceeds 10% or more of the Existing conditions groundwater discharge would result in the assignment of a Moderate Risk Level for the Local Area (MOE 2013).

The simulated impact of increased municipal pumping at the Allocated Rates on groundwater discharge to coldwater rivers, streams and water bodies of interest was evaluated using the numerical model. Lake Rosalind and Marl Lake were mapped by the MNRF as coolwater features and were also included in this assessment due to their proximity to the municipal water takings. The decrease in average annual groundwater discharge for each stream reach or water body between Scenarios C and G(2) was less than 1%. Figure 5.3 presents a map of the locations of assessed water features.

The increase in pumping from the Existing to the Allocated Rates is minor (i.e., 128 m^3/day; Table 3.1) and was determined not to impact other water uses including aquatic habitat in coldwater streams, and wastewater assimilation.

5.3 Local Area Risk Assessment Results

The Local Areas for the Town of Hanover and Community of Lake Rosalind are illustrated on Figures 5.2. The Water Quantity Risk Level is assigned to the Local Areas based on the ability to meet peak demand (“Tolerance”), the results of the risk assessment scenarios listed above and consideration of the uncertainty surrounding those results.



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Local Area Risk Assessment Report

Impacts To Groundwater Discharge

Date:	Project:	Technical:	Reviewer:	Drawn:
03 Feb 2016	21581-527	S. Davies	P. Meyer	M. Pfeifer

Figure 5.3

5.3.1 Tolerance

Municipalities may implement physical solutions (e.g., storage reservoirs, peaking / back-up 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 shortages. A municipality's existing water supply system may be designed such that the wells or intakes alone cannot meet peak water demands; however, storage systems such as reservoirs and water towers may be 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.

The Community of Lake Rosalind is not able to meet peak demands with the two municipal wells during some summer seasons. The community does not have any other redundancy in the event a well is taken off-line, or any storage systems (reservoirs, elevated tanks, etc.) in place to help them meet peak demands. As such, the tolerance of their system is classified as Low.

The Town of Hanover has two elevated water tanks with a combined storage capacity of almost 4,500 m^3 (MOE 2014b). It has been demonstrated historically that when a groundwater well or intake was shut down for an extended period of time (see Section 5.4), the other remaining municipal sources were able to sustain the demand. As such, the tolerance for the Town of Hanover system is classified as High.

5.3.2 Risk Level Circumstances

The Technical Bulletin: Part IX Local Area Risk Level (MOE and MNR 2010) and the recent MOE Technical Memorandum (MOE 2013) list a series of circumstances, where if one of these circumstances is present, the Local Area is assigned a Significant or Moderate Risk Level. In the absence of a Significant or Moderate Risk, the Risk Level is considered Low. The Local Area is assigned a Significant Risk Level if either of the following circumstances is present:

- The wells or intakes are not able to meet their Existing, or Allocated Rates, determined when the drawdown or water level decline exceeds the SAAD or available decline in the risk assessment scenarios.

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

For the surface water intake at Ruhl Lake, all surface water risk scenarios result in water level decline estimates that can be accommodated within the available amount of decline (Table 5.1). Further, there is no Committed increase associated with the Ruhl Lake intake and the Allocated Rate is the same as the

Existing Rate. Therefore, as all of the increase in pumping from Existing to the Allocated Rates is coming from the Hanover wells, there is no change in the Ruhl Lake outflow, and downstream water uses will not be impacted. Based on these results, a Low Risk Level was assigned to Local Area C (Ruhl Lake intake; Figure 5.2).

For the groundwater wells in Hanover, simulated drawdown at both Well 1 and Well 2 is simulated to be less than the SAAD for each scenario (Table 5.2). As a result, a Low Risk Level was assigned to Local Area A (Hanover Wells). As the reductions in groundwater discharge to coldwater streams, as a result of the increase in municipal pumping from the Existing to the Allocated Rates were simulated to be less than the 10% threshold (MOE 2013), the Risk Level of Local Area A remains Low.

For the Community of Lake Rosalind, the Tolerance for the municipal supply system is classified as Low and the drinking water system has an observed and reported inability to meet peak summer demands (MOE 2006b) during drought periods (see Section 3.2.1.2). Historically, water was brought in to meet the Existing Demands, and consequently, Local Area B (Lake Rosalind Wells) was assigned a Significant Risk Level.

5.4 Uncertainty Assessment of Risk Level Assignment

The structure, input parameters, and calibration of the water budget models applied in the risk assessment are documented in Appendix A. The representation of the groundwater and surface water flow systems was calibrated to available hydrogeologic and hydrologic data using a set of parameters (e.g., recharge and hydraulic conductivity) that are consistent with the conceptual model. While the numerical models are considered appropriate for the Tier Three Assessment, it is useful to assess the certainty of the predicted Low Risk Level assignment for Hanover supplies in Local Areas A (wells) and C (Ruhl Lake intake) based on details learned throughout the completion of this study. These details include:

- High System Capacity – Demands are expected to increase by only 4% in Hanover and water use trends suggest that the current capacity of the wells (i.e., represented by the amount of SAAD) is sufficient (approximately 14 to 30 m) to meet future growth projections.

- High System Resiliency – The water supply system of Hanover has built in redundancy, such that if well efficiency deteriorated and increased demand caused an undesirable amount of drawdown in a municipal well, or if the surface water intake had to be taken offline, the operator has sufficient flexibility to reallocate the increased demand to one or more of the remaining water sources. This optimization of the performance of the water supply system is already occurring. The Town of Hanover has historically gone several weeks with the Ruhl Lake intake offline and both municipal wells were able to meet demands. This flexibility is expected to continue.

These factors contribute to a High level of confidence in the Low Risk Level that was assigned to Local Area A (Hanover Wells), and Local Area C (Ruhl Lake intake).

For Local Area B surrounding the Lake Rosalind Wells, the following factor contributes to the High level of confidence in the Significant Risk Level assignment:

- Low Capacity – While demands in Lake Rosalind are expected to increase by only approximately 3 m^3/day, Well 1 and Well 3 cannot meet Existing Demands during certain years, either individually, or when pumping together.

6 WATER QUANTITY THREATS

As outlined in the *Technical Rules,* drinking water quantity threats that may limit the sustainability of the municipal water supply wells or intakes need to be identified in Local Areas assigned a Significant or Moderate Risk Level. Drinking water quantity threats are identified as follows:

- 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 (i.e., a consumptive demand)
- an activity that reduces the recharge to an aquifer.

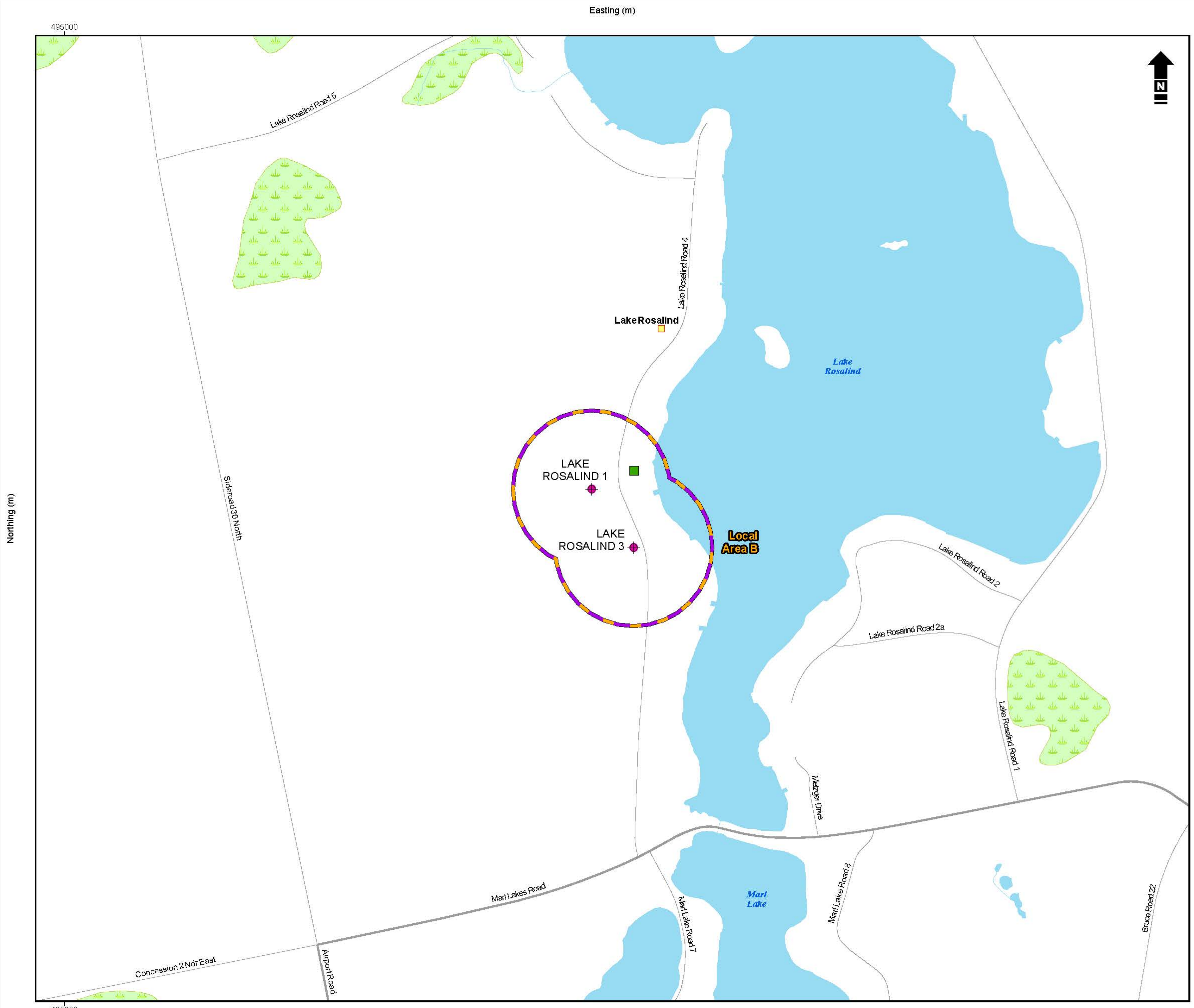
As Local Area B (Lake Rosalind Wells) was assigned a Significant Risk Level, all consumptive demands or areas of recharge reduction (due to land use development) within this area are classified as Significant Water Quantity Threats.

6.1 Consumptive Water Demands

Figure 6.1 illustrates the consumptive water demands within Local Area B (Lake Rosalind Wells), which are classified as Significant Water Quantity Threats. These demands consist of two municipal wells, Lake Rosalind Wells 1 and 3, and one domestic well. No other non-municipal permitted demands or non-permitted water uses are found within Local Area B (Lake Rosalind Wells).

6.2 Reductions in Groundwater Recharge

The *Technical Rules* specify that reductions in groundwater recharge are a potential water quantity threat within the Local Areas. As described in Section 3.1.1, the development of six lots surrounding Lake Rosalind and Marl Lake is interpreted to have a negligible effect on recharge due to the small areal extent of development and because the runoff from new impervious surfaces will largely infiltrate adjacent pervious surfaces and recharge the groundwater system. As a result, there are no areas of recharge reduction classified as Significant Water Quantity Threats.



Reference: Data obtained from GeoBase®, Ontario Ministry of Natural Resources and SVCA used under license.
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Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Local Area Risk Assessment Report

Water Quantity Threats - Local Area B

Date:	Project:	Technical:	Reviewer:	Drawn:
03 Feb 2016	21581-527	S. Davies	P. Meyer	M. Pfeifer

Disclaimer: The information contained herein may be compiled from numerous third party materials that are subject to periodic change without prior notification. While every effort has been made by Matrix Solutions Inc. to ensure the accuracy of the information presented at the time of publication, Matrix Solutions Inc. assumes no liability for any errors, omissions, or inaccuracies in the third party material.

Figure 6.1

6.3 Significant Water Quantity Threat Enumeration

A summary of the number of Significant Water Quantity Threats from permitted and non-permitted uses, lying within various management area categories (i.e., Local Area, Source Protection Area, and Municipal Area), is provided in Table 6.1. Two Significant threats from permitted municipal uses and one Significant threat from a non-municipal, non-permitted (i.e., domestic well) use were identified. No Significant threats are represented by areas of reduced groundwater recharge.

TABLE 6.1 Count of Significant Water Quantity Threats by Threat Group

Threat Group	Local Area		Source Protection Area		Municipal Area	
	Local Area B		Saugeen Valley Source Protection Area		Municipality of Brockton	
Municipal	2		2		2	
Non-municipal Permitted	0		0		0	
Non-Municipal, Non-Permitted	1		1		1	
Recharge Reduction[1]	0 km^2 (0% of Local Area B)		0 km^2 (0% of the Saugeen Valley Source Protection Area)		0 km^2 (0% of the Municipality of Brockton Area)	
Total	Total # of Significant threats within all Local Areas of the Tier Three Assessment	3	Total # of Significant threats within all Source Protection Areas of the Tier Three Assessment	3	Total # of Significant threats within all Municipalities of the Tier Three Assessment	3

7 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. The spreadsheet-based water budget model was used to determine the water budget for Ruhl Lake; this budget is summarized in Section 5.2 of the Physical Characterization, Model Development, and Calibration Report (Appendix A). The calibrated FEFLOW groundwater model (Appendix A) that was refined and applied for this Tier Three Assessment, and the GAWSER model applied in the Tier One and Tier Two Assessments (AquaResource 2008a, 2008b, 2010) were used to estimate average annual values for the various components of the hydrologic cycle. The resultant water budget improved the understanding of the hydrologic and hydrogeologic flow systems in the vicinity of the Town of Hanover and Community of Lake Rosalind municipal wells.

The following section outlines and quantifies the water budget components using FEFLOW and GAWSER, within a refined subwatershed that includes Lake Rosalind, Marl Lake, Marl Creek, and the Tier Three municipal groundwater wells. The subwatershed area is shown on Figure 3.1.

7.1 Marl Creek Subwatershed Water Budget

Table 7.1 presents the water budget for Marl Creek subwatershed calculated using output from the FEFLOW and GAWSER models. The primary water budget components include precipitation as the primary input, and evapotranspiration and groundwater discharge to surface water features as the dominant outflows. Specifically, within the Marl Creek subwatershed (Figure 3.1), precipitation was estimated by the GAWSER model to be approximately 1,000 mm/year and groundwater flow into the subwatershed was estimated to be 200 mm/year. Outflows include ET (500 mm/year), groundwater discharge to surface water features (450 mm/year), groundwater pumping (100 mm/year) and overland runoff (150 mm/year; Table 7.1). The total area of the Marl Creek subwatershed is approximately 5.3 km^2.

TABLE 7.1 Water Budget Summary

	Water Budget Parameter	Marl Creek Subwatershed (mm/year)	Percent of Precipitation (%)
Inflow	Precipitation[2]	1,000	100%
	Groundwater Flow In[1]	200	20%
	Total Inflow	1,200	120%
Outflow	Evapotranspiration[2]	500	50%
	Groundwater Discharge to Baseflow[1]	450	45%
	Total Average Annual Pumping (Permitted Takings) [1]	100	10%
	Overland Runoff[2]	150	15%
	Total Outflow	1,200	120%

[1] Estimates obtained from FEFLOW model
[2] Estimates obtained from the GAWSER model

8 SUMMARY AND CONCLUSIONS

The Province of Ontario introduced the *Clean Water Act* to ensure that all residents have access to safe drinking water. Under the *Clean Water Act*, Source Protection Regions 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 Assessment to assess the ability of the municipal water sources to meet their Allocated Rates. Municipalities that are unable to meet these demands are required to identify the Moderate or Significant threats that may prevent them from meeting these demands.

This report detailed the Tier Three Assessment carried out for the Towns of Hanover and Community of Lake Rosalind. The report summarizes background information relating to the geology, hydrology, and hydrogeology of the area, water demands, and the process and results of the Local Area risk assessment. A companion report (Appendix A) summarizes the development of the conceptual and numerical water budget models used to complete this Tier Three Assessment.

8.1 Summary of the Water Budget Tools and Results

The Tier Two Assessment completed for the Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region (AquaResource 2010) identified the Lake Rosalind Groundwater Assessment Area as having a Moderate potential for groundwater stress. This identification of stress potential led to the requirement of a Tier Three Assessment for the municipal supply wells of the Town of Hanover and Community of Lake Rosalind. As Ruhl Lake supplies a significant proportion (45%) of Hanover's water supply, and because it is considered hydraulically connected to the shallow groundwater system that also contains the Lake Rosalind groundwater flow system, the intake at Ruhl Lake was included in this Tier Three Assessment.

The Tier Three Assessment involved a detailed review and representation of the physical system within the area of the Hanover and Lake Rosalind municipal water supplies in Bruce County. The conceptual model used within the Tier Three Assessment was refined and enhanced from an earlier conceptualization from the Tier Two Assessment.

A regional FEFLOW groundwater flow model developed for the Tier One Assessment (AquaResource 2008a) was updated and refined in the Tier Two Assessment (AquaResource 2010) and further refined in this Tier Three Assessment. The areas of refinement were focused around the four Tier Three municipal wells and the Ruhl Lake area to assess groundwater flow and the potentiometric surface impacts at a well field scale. The groundwater flow model was calibrated to observed water levels at both a local (municipal well field scale) and regional (regional groundwater model domain) scale. The Tier Three Assessment groundwater flow model was calibrated at the municipal well field-scale to steady-state (long-term average) conditions. A transient calibration was not completed due to a lack of observed pumping and water level data and hydraulic conductivity and storage estimates were noted as a data gap (see Appendix A).

The GAWSER watershed-based flow generation model was developed, peer-reviewed, and applied for the Tier One (AquaResource 2008b) and Tier Two Assessments (AquaResource 2010) and was applied to determine a water budget for the Marl Creek subwatershed area (Figure 3.1). GAWSER outputs were also used to develop a spreadsheet-based, water budget model to estimate water level and discharge from Ruhl Lake. The spreadsheet model was linked to the groundwater model through the groundwater discharge component. As the FEFLOW and GAWSER models were calibrated to observed steady-state water levels and transient stream flows, they were considered reliable tools for water budget estimation.

8.2 Local Area Risk Assessment Summary

Three Local Areas (Local Areas A, B, and C) were delineated surrounding the municipal intake and supply wells in the Study Area (Figures 5.2). The areas were delineated following the *Technical Rules* based on a combination of the cone of influence of each municipal well (WHPA-Q1), land areas where recharge has the potential to have a measurable impact on the municipal wells (WHPA-Q2), and the surficial drainage area, which may contribute water to surface water intake and associated area that provides recharge to an aquifer that discharges to the drainage area (IPZ-Q).

A set of risk assessment scenarios, consistent with the *Technical Rules,* were developed to represent the municipal Allocated Rates (Existing plus Committed pumping rates) and current land uses. Recharge reduction due to land use change in the vicinity of the Town of Hanover municipal wells was negligible and was not represented in the risk assessment scenarios. The calibrated groundwater and spreadsheet-based water budget models were used to estimate water level decline in the Ruhl Lake and drawdown in the Town of Hanover municipal supply aquifers under average and drought conditions. Impacts to other water uses under average climate conditions were evaluated with the groundwater model through the assessment of impacts to groundwater discharge to coldwater features. The estimates of drawdown in all scenarios were based on the assumption that wells are maintained in their current conditions to ensure constant well performance with no deterioration over time. The results from the risk assessment scenarios assume this level of maintenance is continued.

The risk assessment scenarios predicted that there was a Low Risk Level associated with the operation of the Ruhl Lake intake (Local Area C) and wells in Hanover (Local Area A). Risk assessment scenarios were not completed for the Lake Rosalind Wells due to the historical observation that the municipal system has not been able to meet Existing Demands during some summer season periods and the recognition that a Significant Risk Level would automatically apply to Local Area B, surrounding the Lake Rosalind Wells.

A High confidence rating was given to the Low Risk Level assigned for Local Area A (Ruhl Lake intake) and Local Area C (Hanover wells) because of the high capacity of the systems to accommodate additional demand. Further, the Hanover water supply system is sufficiently flexible and resilient to increased demands based on the operators' ability to reallocate pumping from a well to the intake and vice versa during prolonged periods, based on historical operations.

A High confidence rating was given to the Significant Risk Level assigned to Local Area B (Lake Rosalind Wells) due to the lack of capacity of Lake Rosalind Wells 1 and 3, individually and combined to meet demands of the community during historic drought periods as documented by past performance (MOE 2006b).

Following the *Technical Rules*, all consumptive water users in Local Area B (Lake Rosalind Wells) were classified as Significant Water Quantity Threats. These consumptive water users include the permitted water demands (i.e., two municipal takings) and non-permitted water demands (i.e., one domestic water well). No areas of reduced groundwater recharge were considered Significant Water Quantity Threats.

8.3 Recommendations

The following recommendations are made based on results of this Tier Three Assessment.

8.3.1 Lake Rosalind Wells

The capacity and resiliency of the water supply system in the Community of Lake Rosalind need to be improved to provide the community with a reliable water supply that is able to meet the Existing and future (Allocated Rates) water demands for the community. Lake Rosalind Wells 1 and 3 have properties that make them problematic as sources for municipal water supply. Well 1 is a shallow dug well that extends less than 4 m below surface and is vulnerable from both water quality and quantity perspectives. Well 3 is a deeper well that extends 23 m below surface; however, the static water levels in Well 3 vary dramatically (up to 7 m) from one year to the next and fall to depths below the pump intake, which lies over 16 m below surface. It was interpreted that during these periods, the well could not service the demands of the community.

It is recommended that a hydrogeological study be undertaken to characterize groundwater levels and flow directions, and to estimate the hydraulic properties of the potential municipal water supply aquifers in the area. The study should determine if the interpreted drawdown at Well 3 can be improved through rehabilitation or retrofitting, if drilling and installation of new water supply well(s) are required to service the existing and future demands of the community.

It is also recommended that a monitoring program be put in place to continuously record groundwater levels (especially those representing pumping conditions) from production wells to continue to assess the available drawdown in each well. This would improve the understanding of the seasonal and inter-annual variability in the groundwater flow system within and surrounding the Lake Rosalind Wells.

It is recommended that the existing climate monitoring network be maintained and enhanced as resources allow, as climate data is an important piece in water budget and hydrogeological assessments.

8.3.2 Town of Hanover Wells and Ruhl Lake Intake

If new water takings are proposed within the vicinity of Local Area A (Hanover Wells), the Tier Three Assessment model could be updated to determine the impact of the proposed water taking on municipal water supply reliability and the Risk Level applied level of risk.

The risk assessment scenarios analyzed drawdown assuming constant well performance. The ability of the wells to sustain future pumping rates is dependent on ongoing monitoring of water levels within the municipal wells, as well as regular well maintenance. It is recommended that the Town continue to monitor water levels in the wells, well performance, and to rehabilitate the wells when needed to ensure the validity of the risk assessment results.

Assumptions were made in the Tier Three Assessment regarding the pump intake elevation and the observed water levels within the Hanover municipal wells and monitoring well. It is recommended that additional data be collected to confirm the assumptions and refine the safe water levels and SAAD for the wells. Specifically, the pump intake elevation at Hanover Well 1 and the elevation of the pressure transducer monitoring points should be confirmed, and the correction for atmospheric pressure changes (or lack thereof) of the pressure transducers should be noted for future hydrogeologic studies.

Current water conservation programs should be maintained to maintain or reduce water demand. Opportunities to reduce water demand within the Town could also be considered. Any reduction in the per capita water use will enhance water supply reliability and local ecosystem health.

Flow gauging of streams and water level monitoring of lakes near the Hanover water supply systems could be considered to monitor seasonal changes, potential baseflow reduction, and impacts during times of high demand. In particular, a staff gauge or transducer could be installed in Ruhl Lake to help collect surface water levels. This data could be used to understand seasonal and annual fluctuations in water levels in Ruhl Lake relative to the surface water intake elevation, and to aid the Town in their long-term management of their surface water resources, especially during drought periods.

A stream gauging station could be installed at the outlet of Ruhl Lake, or a suitable downstream location, to better characterize the stream flow and the interaction between the streams and the groundwater flow system. Manual measurements would also need to be collected and a rating curve developed to correlate the stream stage and the flow measurements. This work could be undertaken as part of a cooperative effort between the Town of Hanover and the Conservation Authority.

The Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region maintains water budget modelling tools to help manage and protect the water resources across the watersheds. Hydrogeologic, hydrologic, and operational insights gained from this Tier Three Assessment should be incorporated into the models maintained by this Source Protection Region. These modelling tools should be updated periodically as new information is gathered and insights evolve within the watersheds.

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APPENDIX A
Tier Three Water Budget and Local Area Risk Assessment, Town of Hanover and the Community of Lake Rosalind, Physical Characterization, Model Development and Calibration Report

TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT
TOWN OF HANOVER AND THE COMMUNITY OF LAKE ROSALIND
PHYSICAL CHARACTERIZATION, MODEL DEVELOPMENT, AND CALIBRATION REPORT

Report Prepared for:
SAUGEEN VALLEY CONSERVATION AUTHORITY

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TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

TOWN OF HANOVER AND THE COMMUNITY OF LAKE ROSALIND

PHYSICAL CHARACTERIZATION, MODEL DEVELOPMENT, AND CALIBRATION REPORT

Report prepared for Saugeen Valley Conservation Authority, January 2016

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1 INTRODUCTION

1.1 Overview

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. The *Clean Water Act* requires that each Source Protection Committee prepare an Assessment Report for their Source Protection Area in accordance with Ontario Regulation 287/07 (General Regulation; MOE 2006) and the *Technical Rules: Assessment Report, Clean Water Act, 2006* (MOE 2009). 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 Water Budget and Tier Two Water Budget and Subwatershed Stress Assessments within this framework evaluate the subwatershed's hydrological stresses, while the Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) examines the threats to water quantity sources and evaluates the ability of the sources to meet a community's current and planned drinking water needs.

The Tier Three Assessment is completed for two reasons: 1) to estimate the likelihood that a municipality will be able to sustain its Allocated (Existing, Existing plus 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. It is undertaken for municipal groundwater wells and surface water intakes that are located within subwatersheds that were assigned a Moderate or Significant water quantity stress level in the Tier Two 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 estimate the likelihood that a municipality will be able to meet its current and planned water quantity requirements with consideration of 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. Based on these scenarios, a Local Area(s) is delineated and a Risk Level is assigned to that Local Area(s). If the Local Area Risk Level is classified as Moderate or Significant, water quantity threats located within the Local Area(s) must be identified. 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) and are calibrated to the best extent possible to represent average annual and drought conditions.

A Tier One Assessment for groundwater (AquaResource 2008a) and surface water (AquaResource 2008b) were completed and they identified assessment areas containing the Hanover, Chesley, and Walkerton municipal systems had a potential for hydrologic stress and required a Tier Two Assessment. The Tier Two Assessment (AquaResource 2010) in turn identified four areas, including the "Lake Rosalind Groundwater Assessment Area," which includes Hanover and Lake Rosalind (**Figure 1.1**) as having a Moderate potential for hydrologic stress with a percent water demand of 19% under existing conditions. As such, a Tier Three Assessment for the groundwater supply sources was initiated to examine the long-term sustainability of the Hanover and Lake Rosalind water supply sources. The Ruhl Lake surface water intake lies within this assessment area and supplies approximately 45% of the Hanover's municipal water demand. The water supplying the Ruhl Lake intake was interpreted to be hydraulically connected to the groundwater flow system and as such was also investigated in the Tier Three Assessment.

This report details the physical characterization, and the development and calibration of the numerical groundwater flow model and the hydrologic water budget spreadsheet-based model (which is based on the existing Tier One GAWSER watershed-based flow generation model). This model was used for the Tier Three Assessment for the communities of Hanover and Lake Rosalind in Grey and Bruce counties, respectively.

Matrix Solutions Inc. completed the Tier Three Assessment and was directed by a technical team composed of representatives from the Saugeen Valley, Grey Sauble, North Bruce Peninsula Source Protection Region (SV-GS-NBP-SPR), Saugeen Valley Conservation Authority (SVCA), Town of Hanover, Municipality of Brockton (Community of Lake Rosalind), Ministry of Natural Resources and Forestry (MNRF), and Ministry of the Environment and Climate Change (MOECC).

1.2 Study Area

The Study Area for the Tier Three Assessment is illustrated on **Figure 1.1** and includes the water supply systems for the Town of Hanover (Hanover Wells 1 and 2 and surface water intake on Ruhl Lake) and the Community of Lake Rosalind (Lake Rosalind Wells 1 and 3). Hanover is located in Grey County; Lake Rosalind is located within the Municipality of Brockton in Bruce County.

While the focus of this investigation is on the lands immediately surrounding these communities, the characterization included the areas surrounding the largest watercourses in this Study Area; the Saugeen, South Saugeen, and Beatty Saugeen rivers (**Figure 1.1**). The Saugeen River lies south of the Tier Three Assessment municipal water supply sources and forms a valley that trends in an east-west direction along the northern part of the Town of Hanover. The Beatty-Saugeen River meets the South Saugeen River south of Hanover and the combined stream drains into the Saugeen River just west of Hanover. Several tributaries feed these two larger rivers and numerous wetlands are found along the river valleys.

Lake Rosalind and Marl Lake, which are located northwest of Hanover, are excavated depressions connected by a constructed drainage channel (**Figure 1.1**). Both lakes resulted from the excavation of marl in the early 1900s and from the construction of dams. Surface water flows from Lake Rosalind in the north to Marl Lake in the south, and then southward through Marl Creek to the Saugeen River.

Land use in the Study Area is primarily agricultural with natural areas such as forests and wetlands scattered throughout (**Figure 1.2**). Built-up urban areas exist within the Town of Hanover and along the shores of Lake

Rosalind and Marl Lake. Physiography is dominated by coarse-grained spillway deposits in the lower portion of the Saugeen River watershed and drumlinized till plains in the northern reaches.

1.3 Previous Water Resources Studies in the Hanover/ Lake Rosalind Area

Several groundwater flow models were developed within the Hanover and Lake Rosalind area over the past 10 years. These have included a groundwater flow model developed to delineate wellhead protection areas (WHPAs) for two wells in Walkerton (Waterloo Numerical Modelling Corp. 2011), and a regional groundwater flow model developed for the Tier Two Assessment by AquaResource (2010) for the Saugeen Valley, Grey Sauble, and Northern Bruce Peninsula Conservation Authorities. The Tier Two Assessment groundwater flow model included the Town of Hanover and Community of Lake Rosalind and was built upon the conceptual model developed by AquaResource (2008a). The Tier Two Assessment groundwater model (AquaResource 2008a) was focused on regional features, and refinements were made on the local scale to increase its suitability in this Tier Three Assessment.

Table 1.1 summarizes the hydrologic, geologic, and hydrogeologic studies completed in the Study Area, and that contain information that was referenced during the development and calibration of the conceptual and numerical water budget models.

TABLE 1.1 Water Resources Studies Completed in the Study Area

Project Name	Author	Description
Assessment Report Saugeen Valley Source Protection Area	Saugeen Valley Source Protection Region (SVCA 2011)	This report outlines the results of the Source Protection studies undertaken to date including the Watershed Characterization, and a summary of the Tier One and Tier Two Water Budget, Subwatershed Stress Assessments, and the Water Quality Threats and Issues of the Source Protection Area.
Walkerton Well Field (Wells 7 and 9) Groundwater Modelling and WHPAs Delineation	Waterloo Numerical Modelling Corp. (2011)	This report outlines the delineation of WHPAs for Walkerton Wells 7 and 9 using a groundwater flow model for the Walkerton and Hanover areas.
Saugeen Valley, Grey Sauble, Northern Bruce Peninsula Tier Two Subwatershed Stress Assessment Report	AquaResource Inc. (2010)	This report details the Tier Two Subwatershed Stress Assessment that was completed using the groundwater flow model that was refined from the Tier One Assessment, as well as the surface water model from the Tier One Assessment. The result of the Tier Two Assessment was the classification of the Lake Rosalind Assessment Area as having a moderate potential for stress and identified the need for a Tier Three Assessment.
Hydrogeologic Modelling: Groundwater and Solute Transport Modelling Assessment for Hanover/Walkerton Landfill Assessment	AquaResource Inc. (2009)	This appendix to the Environmental Assessment (EA) supports the hydrogeologic investigation portion of an EA that aimed to examine the potential water quality impacts resulting from the addition of a new expansion area west of the existing Hanover landfill using a groundwater flow and contaminant transport model. The report outlines the conceptual understanding of the geology and hydrogeology of the Hanover Landfill area, and contains onsite hydrogeological data, including borehole logs and hydraulic test data.

Project Name	Author	Description
Drinking Water Source Protection Round 2 Groundwater Technical Study	Conestoga - Rovers and Associates (CRA 2009)	This report provides a summary of the Groundwater Vulnerability Analysis and Drinking Water Quality Risk Assessment undertaken for Type I groundwater-based municipal residential drinking water systems included in the study. The overall objective of this study was to assess the vulnerability of municipal wells to contamination from surface and near-surface sources and identify potential significant drinking water quality threats and issues within each WHPA in accordance with the Assessment Report Regulation and Technical Rules.
Tier One Conceptual Geologic and Water Budget Assessment for the Saugeen Valley, Grey Sauble, and Northern Bruce Peninsula	AquaResource Inc. (2008a)	This report documents the groundwater portion of the Tier One Water Budget and Water Quantity Stress Assessment for the Saugeen Valley/Grey Bruce/Northern Bruce Peninsula Study Area. A regional-scale groundwater flow model was developed and calibrated to available water level and streamflow data. The results of the stress assessment classified the Hanover/Lake Rosalind (Saugeen River) and Owen Sound (Sydenham River) areas as having a significant potential for stress.
Tier One Surface Water Budget and Subwatershed Stress Assessment. For the Saugeen Valley, Grey Sauble, and Northern Bruce Peninsula	AquaResource Inc. (2008b)	This report documents the surface water portion of the Tier One Water Budget and Water Quantity Stress Assessment for the Saugeen Valley/Grey Bruce/Northern Bruce Peninsula Study Area. A regional-scale GAWSER model was developed and calibrated to estimate components of the hydrologic cycle for various watersheds. The results of the stress assessment classified eight subwatersheds as having a Moderate or Significant potential for stress.
Ruhl Lake Water Supply Geological Investigation in Support of Source Water Protection Vulnerability Assessment - DRAFT	Luinstra Earth Sciences (2008)	This report summarizes the work completed to better understand the source of water at Ruhl Lake that provides a significant portion of the Town of Hanover's municipal supply. The report details the drilling and testing of three test wells. The wells were completed in either a shallow or deep aquifer and the hydraulic connections between the two were examined. The results of the study indicated that Ruhl Lake is fed by the shallow aquifer and that there is a lack of connection to the deeper aquifer.
2005-2006 Groundwater Technical Study	CRA (2007)	This report outlines the delineation of wellhead protection zones, data collection/analysis, threat inventory mapping, and vulnerability scoring as part of the province's Source Water Protection Plans for municipal-based residential drinking water supplies.
Town of Hanover Preliminary Groundwater Study	International Water Consultants Ltd. (IWC 2007)	This report summarizes background hydrogeologic data near Ruhl Lake to identify potential additional groundwater supply for the Town of Hanover. Based on the data review and creation of geologic cross-sections, recommendations for test hole, and test wells were made.
Grey and Bruce Counties Groundwater Study	Waterloo Hydrogeologic Inc. (2003)	This study characterizes groundwater and aquifers within Grey and Bruce counties, analyzes intrinsic susceptibility, assesses groundwater use, inventories contaminant sources, models WHPAs, and combines all the data to develop an action plan for groundwater protection and promote public awareness.
Determination of Capture Zones for Walkerton Wells 7 and 9, Municipality of Brockton County of Bruce, Ontario	Golder Associates Ltd. (2003)	This report summarizes the development of a three-dimensional MODFLOW model, including overburden and bedrock units based on hydrogeologic studies, MNRF mapping, and MOECC databases. The goal of the model was to create capture zones for the well field in Walkerton.

Project Name	Author	Description
The Town of Hanover Construction & Testing Well No. 2	International Water Supply Ltd. (1986)	This report provides a summary of the completion and testing of Well 2 in the Town of Hanover. Testing included a 72-hour constant rate test with a flow rate varying from 48 to 53 L/s, as well as a 2-hour step-test with rates ranging from 18 to 53 L/s. The water level response at Well 1 and Marl Lake were monitored during the testing. Transmissivity was approximately 450 m^2/d, an increase of 150 m^2/day over previous estimates (IWS 1975). The final recommended pumping rate was 53 L/s.

1.4 Project Goals and Objectives

The objective of the Tier Three Assessment is to evaluate the long-term sustainability of the water supply systems from a quantity perspective, and to identify potential threats to the water sources. The impact of changes in future municipal water demand, land use development and climatic variability on the water levels in municipal wells and intakes and discharge to sensitive surface water features will be evaluated using calibrated water budget tools. To meet these overall study goals, a detailed physical characterization assessment was undertaken for the Town of Hanover and Community of Lake Rosalind wells (**Figure 1.1**) and the Ruhl Lake surface water intake.

The objectives of the physical characterization and numerical modelling portion of the study were as follows:

- review and characterize the physical setting within the regional and local (well field, surface water intake) areas
- estimate the consumptive groundwater demands
- update the hydrostratigraphic layers represented in the Tier Two Assessment groundwater flow model to represent the regional and local three-dimensional hydrostratigraphy
- analyze available groundwater and surface water monitoring data to assess the lateral and vertical hydraulic interconnections of aquifer / aquitard units and groundwater /surface water interactions (where possible)
- evaluate the water budget components in the Ruhl Lake area
- refine the conceptual and numerical models within the well field areas using additional cross-section interpretation to represent regional and local three-dimensional hydrostratigraphy
- calibrate the models to all available hydrologic and hydrogeologic data to represent existing and future drawdown at the municipal wells and simulate groundwater discharge to surface water features under existing and drought climatic conditions
- assess the level of uncertainty in simulated existing and future conditions specific to the Local Area

1.5 Report Organization

This report is organized into the following sections:

Section 1: Introduction: describes the framework for this study as well as the location, purpose, and a brief review of relevant studies that have been undertaken in the Study Area.

Section 2: Physical Setting: describes physical features of the Study Area such as topography, physiography, and surface water systems.

Section 3: Municipal Water Demands: describes the current municipal water demands within the Study Area.

Section 4: Water Budget Assessment Tools: introduces the surface water and groundwater modelling tools that will be used to support the risk assessment.

Section 5: Ruhl Lake Surface Water Intake Evaluation: summarizes the results of a spreadsheet-based water budget model developed to predict changes in Ruhl Lake water levels as part of the risk assessment scenarios.

Section 6: Groundwater Assessment: describes the refinement and calibration of the groundwater flow model, which will be used for the groundwater portion of the Risk Assessment scenarios. Limitations of the groundwater flow model are also discussed.

Section 7: Summary and Conclusions: summarizes the key outcomes of the report.

2 PHYSICAL SETTING

2.1 Topography

Ground surface topography within the Study Area ranges from highs approaching 345 m above sea level (m asl) on the moraines and drumlinized till plains found east, northeast, and northwest of Hanover to a low of 250 m asl along the Saugeen River valley to the southwest (**Figure 2.1**). Other topographic lows are associated with surface water features such as Marl Lake, Lake Rosalind, Ruhl Lake, and tributaries to the Saugeen River.

2.2 Physiography

Portions of three physiographic regions are present within the Study Area: the Saugeen Clay Plain located northwest of Lake Rosalind; the Teeswater Drumlin Field located south and southwest of Hanover; and the Horseshoe Moraines. The Tier Three Assessment municipal water supplies lie within the Horseshoe Moraines physiographic region, which extends across the majority of the Study Area. These physiographic regions are described in the following subsections and illustrated on **Figure 2.2**.

2.2.1 Saugeen Clay Plain

A small portion of the Saugeen Clay Plain region is located in the northwest portion of the Study Area (**Figure 2.2**). These sediments were deposited by drainage channels from the east that were precursors to the Saugeen River drainage system. The clay associated with this region is highly calcareous, derived primarily from the limestones and dolostones of the nearby bedrock formations. The original relief of this clay plain was flat to undulating, but modern rivers (e.g., Saugeen River) have cut deep valleys into the clay beds (Chapman and Putnam 1984).

2.2.2 Teeswater Drumlin Field

Within the Study Area, the Teeswater Drumlin Field physiographic region is found southwest of Hanover (**Figure 2.2**) and borders the Horseshoe Moraines to the north, west, and northeast (Chapman and Putnam 1984). This region is characterized by drumlins, which are low, broad oval hills with gentle slopes. The till is loamy, moderately compact, and highly calcareous. On drumlins, gravel terraces, kames, and moraines, drainage is usually good; however, the Teeswater Drumlin Field contains many swampy areas northwest and southwest of the Study Area in areas between drumlins. Well-drained soils within this region make it a desirable soil for growing wheat, corn, and alfalfa.

2.2.3 Horseshoe Moraines

The Horseshoe Moraines physiographic region (**Figure 2.2**) is an extensive region that makes its characteristic horseshoe shape around southern Ontario extending beyond this Tier Three Assessment study area. The region encompasses the majority of the Hanover Tier Three Study Area and generally consists of bands of horseshoe-shaped moraines that mark the limits of ice sheets as they advanced out of the Great Lakes Basins towards the central portion of south-central Ontario. North of the Study Area, two till moraines are present (Gibraltar and Singhampton) that are separated by clays of the Saugeen Clay Plain (Chapman and Putnam 1984).

2.3 Surface Water Features

Surface water features (i.e., rivers, streams, wetlands, and lakes) impact shallow groundwater flow and are an important part of the development of a conceptual model. The following sections outline the major surface water features in the Study Area.

2.3.1 Rivers and Creeks

The Saugeen, Beatty Saugeen, and South Saugeen rivers are the primary river features that flow and converge near the Town of Hanover (**Figure 2.3**). The Saugeen River flows from east to west along the northern part of the Town of Hanover and then continues southwest until it converges with Otter Creek just south of Walkerton, west of the Study Area. West of the Study Area the Saugeen changes direction to the north and ultimately drains into Lake Huron in the Southampton area.

The Beatty Saugeen River flows from the southeast to the northwest and feeds the South Saugeen River just south of Hanover. The South Saugeen River and associated tributaries flow from the south near Neustadt, outside the Study Area, to the north where it drains into the Saugeen River on the west side of Hanover before the Saugeen River continues to the southwest (**Figure 2.3**).

Various smaller tributaries provide flow to the Saugeen, South Saugeen, and Beatty Saugeen rivers, including Marl and Ruhl creeks that respectively flow southwards from Marl and Ruhl lakes and ultimately feed into the Saugeen River (**Figure 2.3**). These creeks, while relatively small, may be important features to consider in the Tier Three Assessment as they stem from areas of municipal water supply.

2.3.1.1 Thermal Regimes

The thermal regime of a stream or water body can provide a general indication of groundwater and surface water interactions. Groundwater discharge is important to watercourses and water bodies as the upwelling areas are critical for spawning for coldwater fish communities (e.g., brook and brown trout), and have an important role in moderating temperature (i.e., thermal refuge), and in maintaining flow in the water courses. The rate of groundwater discharge into the watercourse depends on the elevation of the water table in the area surrounding the creek (which varies seasonally), as well as the hydraulic conductivity of the streambed materials. The mapped thermal regimes (Aquatic Resource Area; MNR 2012) of the surface water features in the Study Area are provided on **Figure 2.3**. Coldwater streams represent an important other water user that needs to be considered during the Tier Three Assessment.

Coldwater streams and water bodies that support coldwater fish communities are present along the Saugeen and Beatty Saugeen rivers and select tributaries, upstream of Hanover, and also within tributaries and water bodies north of the Saugeen River. Both Ruhl Lake and the streams that flow into or flow out of Ruhl Lake are considered coldwater features.

2.3.2 Significant Wetland Complexes and Lakes

Provincially Significant Wetlands (PSWs) represent an important water use that needs to be considered during the Tier Three Assessment. A large number of wetlands are located in topographic lows on the landscape and others are located adjacent to rivers, streams, and lakes (**Figure 2.3**); however, none of these wetlands have been evaluated or classified by the MNRF or the SVCA as being PSWs. Many of the wetlands are likely significant from a local ecological perspective as they provide important habitat for species of flora and fauna, but are not mapped as provincially significant. Lake Rosalind, Marl Lake, and Ruhl Lake are the primary lakes of interest in the Study Area due to their proximity to the Tier Three municipal water supplies. These lakes are located northwest of Hanover, within 3 km of the Town (**Figure 2.3**). Marl Lake and Lake Rosalind are man-made lakes that were created in the early 1900s when local cement plants excavated marl from below the water table. Dams were constructed in 1939 and 1946 (French Planning Services Inc. and Gartner Lee Ltd. 2004), and surface water flows from Lake Rosalind into Marl Lake via a culvert, and exits from Marl Lake via Marl Creek to discharge into the Saugeen River. A few small, unnamed, and predominantly intermittent streams drain into Lake Rosalind and Marl Lake from the north and west; however, these lakes are interpreted to be sustained primarily by groundwater discharge.

Ruhl Lake is a kettle lake that is located approximately 1 km west of Lake Rosalind (**Figure 2.3**) and provides almost 50% of the Town of Hanover's water supply from its surface water intake. The lake is relatively small with an aerial extent of 2.63 ha and maximum depth of approximately 9 m. During the 1920s, approximately 0.4 km^2 of the lake's waterfront area was reforested. Land use within Ruhl Lake's drainage area is primarily agricultural, with a mixture of pastures and cash crop. Two small groundwater-fed creeks converge and enter Ruhl Lake from the north. The lake's outlet at Ruhl Creek is located at its southernmost point. Ruhl Creek continues south and eventually flows into the Saugeen River west of Hanover. Flow measurements obtained from the springs north of the lake suggest that these springs are not the primary inputs to the lake. Shallow groundwater discharge from unconfined overburden aquifers is interpreted to be the primary source of inflow based on field investigations (Luinstra Earth Sciences 2008). The water budget of Ruhl Lake is discussed in greater detail in Section 5.2 as part of the evaluation of the surface water intake.

2.4 Regional Scale Geologic Setting

An understanding of the regional and local geologic environment provides a sound basis for investigation of the groundwater flow conditions and the interaction between the groundwater system and surface water features. Bedrock formations, lithology, and bedrock topography are described below, followed by a discussion of the Quaternary overburden deposits, their distribution, and thickness within the Study Area.

2.4.1 Bedrock Geology

Bedrock underlying the Study Area is part of the Michigan Basin and consists of Devonian, Silurian, and Ordovician-aged marine sediments deposited between 345 and 370 million years ago (Johnson et al. 1992). The Michigan Basin is so named because the central portion of the basin lies in central Michigan and all sedimentary rock formations dip toward that point. Bedrock beneath the Study Area dips to the southwest, toward the centre of the Michigan Basin, at an angle less than five degrees. The two uppermost Paleozoic bedrock units beneath the Study Area are the Salina Formation and the underlying Guelph Formation. Descriptions of each bedrock hydrostratigraphic unit beneath the Study Area are outlined AquaResource's (2008a) report.

2.4.1.1 Salina Formation

The Salina Formation subcrops beneath the entire Study Area in a northwest to southeast trending belt and is mapped as the uppermost bedrock unit beneath the Tier Three Assessment municipal water supplies. The Salina Formation is of Upper Silurian age and consists of carbonate rock (limestone/dolostone) with interbeds of evaporites (salts, gypsum, and anhydrite), and shales that alternate from few centimeters up to approximately half a meter in thickness (Johnson et al. 1992).

The Salina Formation is more susceptible to erosion due to the weaker shale and evaporite content within the unit. As a result, buried bedrock valley systems have preferentially formed in this unit across southern Ontario, and valleys have been mapped from Lake Huron eastward to Niagara Falls (Karrow 1973). A linear topographic low is noted in the Study Area (**Figure 2.4**) along a similar orientation to the Salina Formation subcrop boundary and may be associated with preferential erosion of the soft Salina Formation sediments, relative to the harder limestone and dolostone bedrock units that lie stratigraphically below.

2.4.1.2 Guelph Formation

The Guelph Formation forms a northwest-trending belt underlying the Salina Formation in the Study Area and is described as a buff and brown fine to medium crystalline dolomite with a petroliferous odour when broken (Liberty and Bolton 1971). The Guelph Formation is a reefal complex that is moderately resistant to weathering. The beds are typically 0.05 m to 1.2 m thick; however, typically, it weathers into thinner beds. The weathered surface appears to be very soft, severely etched, and sculptured. If strata are composed of a finer texture, it appears that they are regularly bedded and more evenly resistant to weathering and chemical dissolution.

2.4.2 Overburden Thickness

A major unconformity separates Paleozoic bedrock formations from their overlying Quaternary deposits. This unconformity represents the period between the deposition of the Paleozoic bedrock and the deposition of Quaternary-aged, unconsolidated sediments, approximately 200 million years later. This period represents a time where the Paleozoic bedrock surface is interpreted to have been exposed and extensively eroded (Johnson et al. 1992). The thickness of overburden units found in the Study Area is a function of the degree of bedrock erosion and drainage patterns that were established during the period following the deposition of the Paleozoic bedrock, and before the deposition of the most recent Quaternary sediments. Coarse-grained sediments deposited within buried bedrock valley features may impact local groundwater flow rates and directions in the deeper overburden units.

Figure 2.4 illustrates the interpreted overburden thickness beneath the Study Area. Overburden thickness is highly variable, thinning to 0.5 m in the southwest along the Saugeen River and reaching a maximum thickness of approximately 120 m in the north-south trending buried bedrock valley feature west of Ruhl Lake. The valley feature is aligned with the contact between the older Bass Islands Formation to the west and younger Salina Formation to the east.

2.4.3 Quaternary Geology

Overburden sediments in Ontario record a complex history of climatic change throughout the Quaternary Period (2 million years ago to present). Glacial deposits deposited before the Late Wisconsinan are deeply buried within the Study Area, and for this reason, the Late Wisconsinan-aged sediments (~13,000 to 25,000 years ago) are the focus of discussion in the sections below.

The continental scale Laurentide Ice Sheet advanced southward through southern Ontario as a large ice sheet, and at times, as a series of smaller discrete ice lobes, with the flow of ice heavily influenced by the broad topographic depressions of the Great Lakes (Barnett 1992). Smaller ice lobes developed in the lake basins and at times acted independently from one another in response to local ice-bed conditions, rather than, or in addition to, climatic variations. The individual lobes bear the name of the lake basin(s) in which they are located (e.g., Huron sublobe within the Lake Huron basin) and are discussed in the sections below.

Surficial geology for the Study Area is provided on **Figure 2.5**, and was compiled and mapped by the Ontario Geological Survey (OGS 2010). Surficial sediments near the municipal supply wells and intake primarily consist of coarser grained ice-contact, glaciofluvial, and foreshore-basinal deposits and, to a lesser degree, finer grained, and laminated silts and clays or organic deposits. The following sections describe the Quaternary sediments identified at depth within the Study Area according to the glacial period in which they were deposited. Glacial stades are defined as periods within a glaciation (i.e., Late Wisconsinan Glaciation) where the ice front advanced, while interstades are the periods within a glaciation where the ice margin retreated. The discussion of the overburden deposits below is framed starting with a discussion of the oldest deposits to the most recent.

The oldest overburden sediments within the Study Area lie stratigraphically on top of bedrock, and may represent a Mid-Wisconsinan interstadial deposit associated with the buried bedrock valley, or the unit may simply be weathered bedrock (**Table 2.1**). Few logs in the Study Area penetrate through the overburden to bedrock and, as a result, the nature and continuity of this deep overburden unit and the bedrock units are poorly understood. It is likely that the sands and gravels overlying bedrock are restricted to the bedrock topographic lows and have a limited lateral extent in the Study Area.

TABLE 2.1 Summary of Overburden Deposits Mapped in the Study Area

Glaciation	Glacial Period and Age	Deposit	Lithology
Not Applicable	Post-glacial and recent (13,200 ybp to present)	Modern alluvium and organic deposits	Silt, sand, gravel, peat, muck, marl
Late Wisconsinan	Mackinaw Interstade (13,200 to 14,000 ybp)	Glaciolacustrine deposits	Sand, silt
	Port Bruce Stade (15,000 to 14,000 ybp)	Elma Till, Saugeen Kames	Silt till Sand and gravel
	Erie Interstade (15,000 to 18,000 ybp)	Lacustrine deposits	Clay, silt
	Nissouri Stade (18,000 to 25,000 ybp)	Catfish Creek Till	Stoney, sandy silt to silt till
Middle Wisconsinan	(25,000 to 53,000 ybp)	Glaciofluvial sand and gravel; weathered bedrock	Gravel, sand, boulders

Notes:
Table adapted from WHI 2003
ybp - years before present day

2.4.3.1 Nissouri Stade

The Nissouri Stade took place 25,000 to 18,000 years ago (**Table 2.1**). This period marked the initial advance of the Laurentide Ice Sheet through Ontario into the United States (Dreimanis and Goldthwait 1973; Barnett 1992; **Table 2.1**). This ice advance deposited the stoney Catfish Creek Till present at depth across the Study Area. The Catfish Creek Till often directly overlies bedrock and is described as very compact, poorly sorted, highly calcareous till with a sandy sandy-silt to silt matrix. The thickness of the Catfish Creek Till is poorly understood as it is commonly deeply buried; however, the average thickness is believed to be 3 to 6 m in the Saugeen Valley area (Cowan 1979). At the end of the Nissouri Stade, the continental scale ice sheet began to thin, and break up forming a series of sub-lobes that were focused within the Lake Huron, Erie, Ontario, and Simcoe lake basins.

2.4.3.2 Erie Interstade

The climate warmed during the Erie Interstade, a period that was estimated to have taken place between 18,000 and 15,000 years ago (**Table 2.1**). During this period, the Hanover area became ice-free as the Huron sublobe retreated northward (Dreimanis and Goldthwait 1973). Ice contact lakes formed in front of the melting and retreating ice margins at the southern end of Lake Huron, depositing fine-grained silts and clays (Barnett 1992).

2.4.3.3 Port Bruce Stade

The Port Bruce Stade took place approximately 14,000 to 15,000 years ago, and was marked by another advance of the Laurentide Ice Sheet. Ice flow occurred radially out of the centre of the Lake Huron basin (Barnett 1992), and the Elma Till and Saugeen Kame outwash sands and gravels were deposited in the Hanover area.

The Elma Till is a silt to sandy-silt till with 5% to 25% clasts (Barnett 1992). It overlies the fine-grained sediments of the Erie Interstade and the Catfish Creek Till, and the fine-grained nature of these three units makes them difficult to separate from one another in borehole logs.

The Saugeen Kame Moraines consist of belts of ice-contact stratified drift and pro-glacial outwash that suggest the ice front occupied two or three different positions during the Port Bruce Stade (Cowan 1979). Elma Till lies at surface north and south of these kames (Zone 5 on **Figure 2.5**), suggesting the kame deposits are recessional features constructed during retreat of the Georgian Bay ice lobe. The deposits consist of a northeast-southwest trending ridge of coarse-grained sand and gravel northeast and southwest of Hanover, that overlie Elma Till (Sharpe 1975).

2.4.3.4 Mackinaw Interstade and Post-Glacial Events

The Port Bruce Stade discussed in Section 2.4.3.3 above marked the last advance of glacial ice in the Hanover area. The climate warmed approximately 13,500 years ago (Mackinaw Interstade) and ice retreated completely from the Hanover area (Dreimanis and Goldthwait 1973; **Table 2.1**). Glaciofluvial outwash deposits (primarily sandy terrace and fill deposits) related to a network of meltwater channels were deposited as the ice retreated (zones 6 and 7a on **Figure 2.5**).

In addition, as the glacial ice retreated from the Hanover area, meltwater became ponded between the glacier margin to the west, and the higher ground to the east, leading to the creation of a large glaciolacustrine lake focused over the modern day Saugeen River (zone 8a on **Figure 2.5**). The fine-grained glaciolacustrine sediments mapped within the Study Area beneath Lake Rosalind and Marl Lake are primarily varved silts, clays, and lesser sands associated with this glacial lake.

As the ice retreated and the water levels in the lake fell, sands were deposited west of Lake Rosalind and Marl Lake and across the urban areas of the Town of Hanover (zone 9c on **Figure 2.5**). Other post-glacial sediments mapped in the Study Area include organic sediments (bog deposits), and older and recent alluvium associated with the Saugeen River. Bog deposits in the area include peat and muck, and these deposits are generally less than 2 m in thickness (zone 20 on **Figure 2.5**). Older alluvium deposits consist of sands and gravels occurring at terraces above the modern day Saugeen River floodplain (zone 12 on **Figure 2.5**), and recent alluvium consists of sands, silts and clays occurring on the banks and floodplains of the Saugeen River and its tributaries (zone 19 on **Figure 2.5**).

The marl deposits that were excavated in Lake Rosalind and Marl Lake were formed post-glacially. Marl refers to soft, low density, and low plasticity unconsolidated sediments that have a significant amount of carbonate (i.e., 50% or more calcium or magnesium carbonates). Marl forms in small lakes dominated by groundwater discharge and the amount of calcium bicarbonate is increased through the process of photosynthesis in algae. The calcium bicarbonate partially disassociates into calcium carbonate that precipitates out of solution, sinks, and accumulates forming marl (Guillet 1969). Marl was excavated in the late 1800s and early 1900s, and the original thickness of the marl remains uncertain. The current conceptual model interprets that the marl and fine-grained sediment at surface was excavated; however, a fine-grained unit (**Figure 2.6**) is interpreted to exist and form a barrier between the two lakes and the underlying lower aquifer that the nearby Hanover wells are completed within.

2.4.4 Local-scale Cross-section Interpretations

Quaternary geology mapping provided on **Figure 2.5** represents geological conditions present at surface; to assess the lithological and hydrogeological variability of overburden deposits with depth, geological information stored in the MOECC's Water Well Information System (WWIS) was used.

As part of the Tier Two Assessment, 22 regional and local-scale cross-sections were generated and interpreted to improve on the Tier One Assessment's (AquaResource 2008a, 2008b) representation of subsurface distribution and continuity of the overburden hydrostratigraphic layers. As part of the Tier Three Assessment, the Tier Two hydrostratigraphic layers were further refined near the Lake Rosalind and Hanover municipal wells and areas west of Lake Rosalind and Marl Lake to ensure the model layers were consistent with the observed lithology reported at each of the four municipal wells (**Appendix A**) and the surrounding wells. The hydrostratigraphic layer structure of the Tier Two Assessment was maintained; no hydrostratigraphic layers were removed or added.

The hydrostratigraphic surfaces interpreted for two cross-sections are illustrated on **Figures 2.6** and **2.7** and on both sections, the ground surface elevation is illustrated as a thick line at the top of the cross-section. In some instances, boreholes appear to lie above or below this ground surface topography line. The boreholes illustrate their true elevations; however, they have been projected onto the cross-section line so some deviations are noted. Intersections with rivers, roads, and other features are indicated along the top of the section; reported well screens are also illustrated on the boreholes. Borehole lithologies presented (differentiated by colour) are consistent with the Geological Survey of Canada material codes (Russell et al. 1998). The interpreted geology used to generate the model layers are illustrated on the cross-sections; however, the layers illustrated do not necessarily represent the numerical model layers.

2.4.4.1 Town of Hanover

The Hanover municipal water supply wells are located on the western and eastern sides of Marl Lake (**Figure 1.1**). **Figure 2.6** illustrates an east-west cross-section that cuts through Hanover Wells 1 and 2 and Marl Lake.

Paleozoic bedrock of the Salina Formation lies at the base of the cross-section (**Figure 2.6**). Few boreholes penetrate through the overburden to bedrock in this area, so the bedrock surface elevation and the nature of the deep overburden units in the western portion of the cross-section are not well understood.

Overlying bedrock in this area is a thick unit consisting of clays and clay- and silt-rich diamict, interpreted to be a combination of Catfish Creek Till, fine-grained sediments, and Elma Till (Lower Aquitard on **Figure 2.6**). This unit is interpreted to be regionally extensive and present across the entire Study Area. Overlying this fine-grained unit is a thick package of outwash sand and gravel deposited at the end of the Port Bruce Stadial and the start of the Mackinaw Interstadial period (Lower Aquifer on **Figure 2.6**). This unit is 23 m thick at Hanover Well 1 and 17 m at Hanover Well 2, and most of the wells near the Hanover municipal wells are completed in this unit. As these sands were deposited by glaciofluvial processes, the spatial extent of these units is more limited.

A continuous unit of thin interbeds of fine-grained silt and clay deposited under glaciolacustrine conditions during the Mackinaw Interstadial period overlies the Lower Aquifer (Intermediate Aquitard on **Figure 2.6**). This unit has a limited spatial extent but is present west of Marl Lake and Lake Rosalind near the municipal wells. The Intermediate Aquitard unit is overlain by sands (Upper Aquifer on **Figure 2.6**) that were deposited in a shallow glaciolacustrine environment near the end of the Mackinaw Interstadial period.

2.4.4.2 Community of Lake Rosalind

The Community of Lake Rosalind obtains its water supply from two municipal wells (Lake Rosalind Well 1 and Well 3). The two wells are located within 100 m of one another and within 100 m of the west bank of Lake Rosalind (**Figure 1.1**). **Figure 2.7** presents a north-south cross-section that extends along the western side of Lake Rosalind and Marl Lake and through the Lake Rosalind wells and Hanover Well 1. Due to the proximity of the Lake Rosalind Well Field to the Hanover Wells and the interpreted continuity of the geologic units, the geologic cross-section is similar to that illustrated on **Figure 2.6**, although the thickness of the various units differs from place to place.

Similar to geologic units displayed on **Figure 2.6**, fine-grained diamict (Lower Aquitard) is interpreted to overlie Paleozoic bedrock. Overlying these units is a continuous unit of sand and gravel (Lower Aquifer) that is interpreted to be less than 7 m thick north of the Lake Rosalind wells, to over 20 m thick near Hanover Well 1. This unit is overlain by fine-grained glaciolacustrine silt and clay (Intermediate Aquitard), and a surficial sand unit (Upper Aquifer on **Figure 2.7**). The surficial sand unit (Upper Aquifer on **Figure 2.7**) is interpreted to be much thicker (i.e., 30 m thick) near Lake Rosalind Wells 1 and 3 than the sand thickness observed near Hanover Well 1 (2 m). Lake Rosalind Well 1 and another domestic well are completed within the shallowest portion of this Upper Aquifer unit (12 m thick), while Well 3 is completed within the deeper portion of this unit. A thin (1.5 m), discontinuous layer of clay is described in well logs in the area beneath and surrounding Lake Rosalind Wells 1 and 3, and separates the shallow sands from the deeper sands of this Upper Aquifer unit. Thin beds of finer-grained material within the broader coarse-grained unit are common in glaciolacustrine environments in which these upper sediments were deposited.

2.5 Hydrostratigraphic Setting

Precipitation, ground surface topography, water table elevation and the spatial distribution and connectivity of geologic units largely control groundwater flow within the Study Area. Groundwater recharge is the portion of precipitation that infiltrates to the groundwater system and is not lost to evapotranspiration, interflow, overland flow, or discharge to rivers or creeks. In general, the hydraulic conductivity of surficial sediments, slope of the topography, land use, and soil water content are the primary controls on recharge. Recharge may occur immediately during and after a rainfall/snowmelt event with infiltration at the surface passing through the vadose zone to the underlying water table. Some recharge is delayed by surface-depression storage with recharge occurring for an extended period, supplied by infiltration through the bed of the depression. The following sections discuss the hydrostratigraphy and groundwater flow within the Study Area.

The Study Area contains both overburden and bedrock aquifers that are used for municipal and domestic water supply. Overburden aquifers, which were commonly formed during interstadial periods, tend to be localized in nature and none of those discussed in the previous sections are laterally continuous across the Study Area. Conversely, fractured bedrock aquifers, such as the Salina and Guelph formations are more regional in scale.

Identifying the vertical and horizontal extent of hydrogeologic units throughout the subsurface and their connectivity requires cross-section interpretation (Section 2.4.4) and, subsequently, the creation of three-dimensional (3D) hydrostratigraphic layers. The 3D hydrostratigraphic units are used to form the layers of numerical groundwater flow models that can be applied to simulate groundwater flow directions and fluxes at given points within the model. This is discussed further in Section 6.

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 an approximation; however, the available information is used in conjunction with the regional and local understanding of the spatial distribution of geologic units. Units composed primarily of coarse-grained materials (e.g., sands, gravels) are referred to as aquifers and units composed of lower permeability units (e.g., clay) are referred to as aquitards. Hydrostratigraphic units are not grouped solely on lithology as fracturing or weathering may increase the ability of a low permeability unit to transmit modest amounts of groundwater such that it may be considered a poor aquifer.

Six overburden and six bedrock hydrostratigraphic layers were identified in the Study Area (**Table 2.2**) by grouping units that are texturally and hydrostratigraphically similar. For example, the Lower Aquitard consists of the Elma Till, fine-grained silt and clay, and the Catfish Creek Till as these units act as one aquitard unit in the absence of any intervening units. Aquifer units were defined based solely on the unit's estimated ability to yield groundwater and did not consider water quality or vulnerability to contamination.

TABLE 2.2 Hydrostratigraphic Units within the Study Area

Layer	Geologic Unit	Hydrostratigraphic Unit (Aquifer/ Aquitard)
1	Glaciolacustrine silts and clays	Upper Aquitard
2	Spillway/outwash sand plains	Upper Aquifer
3	Glaciolacustrine silts and clays and Elma Till	Intermediate Aquitard
4	Sands (lesser gravels and silts)	Lower Aquifer
5	Elma Till and Catfish Creek Till	Lower Aquitard
6	Weathered Bedrock (lesser sands and gravels)	Contact Zone Aquifer
7 to 13	Paleozoic limestone, dolostone and shale units of varying thickness	Bedrock aquifers/aquitards of the Salina, Guelph, and deeper bedrock formations

The thickness of overburden hydrostratigraphic layers was determined through interpretation of cross-sections throughout the Study Area whereby the interpreted elevation at each hydrostratigraphic pick was saved to a database and subsequently used to generate aquifer top/ bottom surfaces. The surfaces were created by interpolating the elevations for the tops of each of the hydrostratigraphic units. The bedrock surfaces were not updated from those created in the Tier Two Assessment (AquaResource 2010).

2.5.1 Groundwater Flow

The Study Area contains shallow and deep overburden aquifers and a shallow bedrock aquifer that are used for domestic and municipal water supply.

Interpolated maps of the overburden and bedrock water levels are illustrated on **Figures 2.8** and **2.9**, respectively. Static water levels reported in MOECC water well records were interpolated across the Study Area to create these maps. The water levels in the MOECC water well database correspond to water levels measured and recorded by water well drillers after drilling a well. These static water levels were collected over decades and may represent pre-pumping water level conditions that are not indicative of present day levels, which can be influenced by localized pumping (municipal or otherwise). Despite the limitations, the data used to create the water level maps (**Figures 2.8** and **2.9**) are the best available, and the maps are considered a reasonable representation of regional groundwater flow conditions at the scale applied.

The map of overburden groundwater levels (**Figure 2.8**) was created by kriging all wells in the MOECC WWIS database within the Study Area that are interpreted to be completed within overburden units. The surface was kriged at a 10 m resolution across the model domain, and control points were added along permanent water features and water bodies known to be fed by groundwater discharge. The bedrock water level surface (**Figure 2.9**) was created using wells that are interpreted to be completed within bedrock units and was constrained to the 10 m digital elevation model (DEM) of the Study Area. Constraining the surface in this manner ensures that the kriged water level map does not extend above ground surface. This is particularly useful within river valleys, where a lack of water wells would otherwise create a flat water level surface.

The overburden water levels reach a high of approximately 310 m asl north of Ruhl Lake and in the eastern portions of the Study Area, associated with the ground surface topographic highs. Water levels decline toward the Saugeen River and its tributaries to a low of 245 m asl toward the southwestern extent of the Study Area along the Saugeen River (**Figure 2.8**). Shallow groundwater is interpreted to flow toward and discharge into these incised surface water features. Near the Lake Rosalind municipal wells, water levels decline from the topographic high west of Lake Rosalind toward the lake. Similarly, near the Town of Hanover wells, shallow groundwater levels decline toward Marl Lake, indicating shallow groundwater flow toward the lake. Northwest of the municipal wells, a groundwater flow divide exists beyond where groundwater levels decline toward unnamed surface water features in the northwest corner of the Study Area.

The bedrock water levels show a similar pattern to the overburden water levels with the highest water level elevations occurring in the east and the lowest occurring along the incised surface water features (**Figure 2.9**). While water levels do decline toward the Saugeen River, its tributaries and other water bodies (e.g., Lake Rosalind, Marl Lake, and Ruhl Lake), water level contours are farther apart than the shallower system (**Figure 2.8**), indicating gentler gradients. As with the shallow flow system, a groundwater divide exists in the northwest where deeper flow is interpreted to move toward unnamed tributaries draining to the northwest.

3 MUNICIPAL WATER DEMANDS

The following sections summarize the Hanover Wells 1 and 2, the surface water intake on Ruhl Lake, and the Lake Rosalind Wells 1 and 3 being investigated as part of the Tier Three Assessment. These sections also present the volume of water produced from each municipal production well/intake, as well as non-municipal water demands.

Additional well details (i.e., safe available drawdown) will be collected before performing the risk assessment and will be summarized in the final risk assessment report.

3.1 Municipal Water Systems and Demands

The municipal water supply systems of the Town of Hanover and Community of Lake Rosalind will be characterized as part of this Tier Three Assessment. While the Community of Lake Rosalind relies solely on groundwater for their potable water supply, the Town of Hanover uses a mix of surface water and groundwater to meet their municipal demands.

3.1.1 Town of Hanover Water Supply

The Town of Hanover is located along the southwestern boundary of Grey County, between the Township of West Grey to the east and the Municipality of Brockton of Bruce County to the west (**Figure 1.1**)**.** As of 2011, the Town of Hanover had an estimated population of approximately 7,500 (Statistics Canada 2012a) and relies on surface water from Ruhl Lake, as well as groundwater from two wells (Hanover Wells 1 and 2) for its municipal water supply demands (**Table 3.1**).

TABLE 3.1 Town of Hanover Water Supply Wells/Intakes

Well/Intake Name	Permit Number	Permitted Capacity (m^3/day)	2013 Average Taking (m^3/day)	Hydrostratigraphic Unit
Hanover Well 1	2087-92FRS6 (exp. 11/30/2022)	4,546	829	Lower Aquifer
Hanover Well 2		4,582	1,052	Lower Aquifer
Ruhl Lake Intake	Grandfathered		1,518	n/a
Total		**9,128 + Ruhl Lake takings**	**3,399**	

The total permitted capacity of the two groundwater wells is 9,128 m^3/day under Permit to Take Water (PTTW) 2087-92FRS6, which expires in 2022. Each well is permitted to pump at a rate of approximately 4,500 m^3/day. The Ruhl Lake Intake is not part of the PTTW registry, as it is grandfathered as it was used before the beginning of the PTTW system regulations (Cooper 2014). The total average withdrawal from the two wells in 2013 was 1,881 m^3/day, representing 21% of the permitted amount. In 2013, approximately 55% of the water demand for the Town of Hanover was supplied by Wells 1 and 2, while 45% was supplied by the Ruhl Lake intake.

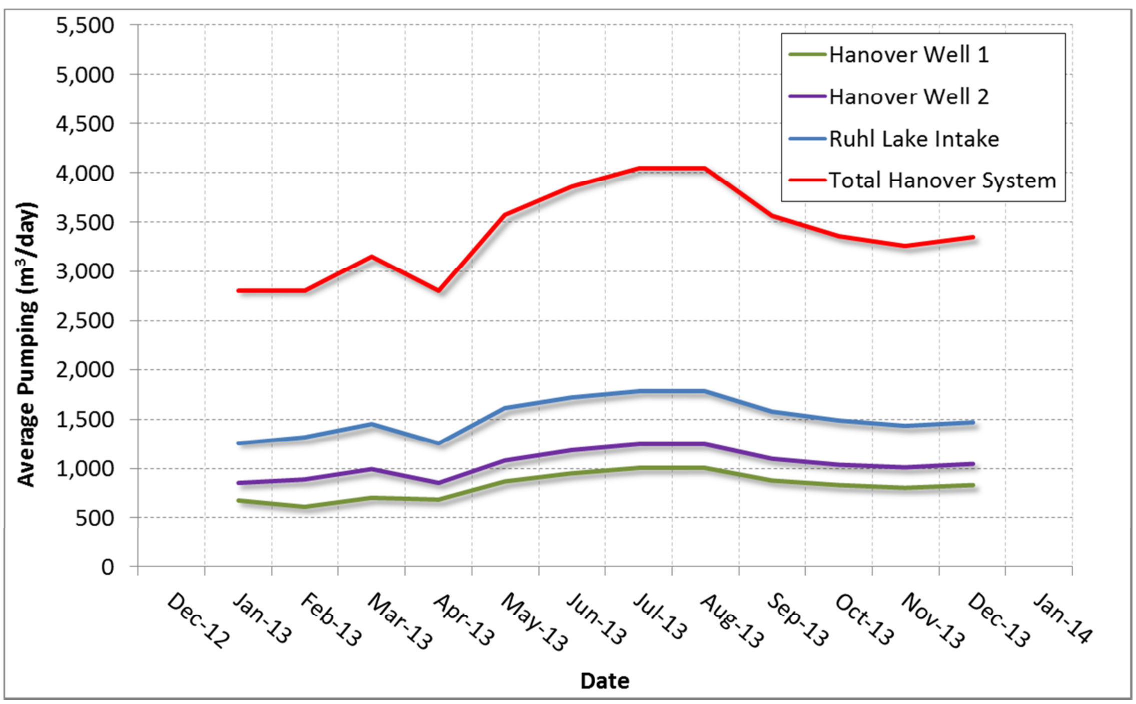
Only one groundwater monitoring well is present within the Study Area; it is located adjacent to Hanover Well 2 and is completed within the same aquifer as Hanover Well 2. Water levels are recorded in the municipal wells and also from the monitoring well every 15 minutes; no monitoring wells are present near Hanover Well 1. Details regarding water levels in the municipal wells and the Hanover Well 2 monitoring well will be presented in the risk assessment report.

As is shown on **Chart 3.1**, total pumping for the Hanover system and each individual well and intake in 2013 follows a seasonal pattern of relatively low demands during fall and winter (total system minimum of 2,800 m^3/day), followed by elevated demands (total system maximum of 4,100 m^3/day) during the late spring and summer months due to various warm weather activities (e.g., lawn/garden watering, car washing, etc.).

3.1.1.1 Groundwater Supply Wells

Hanover Wells 1 and 2 are located approximately 500 m from one another, on the west and east shores of Marl Lake, respectively. Well 1 is located at 34 Airport Road, west of Marl Lake, and east of the Saugeen Municipality Airport. Well 2 is located at 835 Marl Lake Road 8, on the east side of Marl Lake. The wells are located in primarily agricultural land. Hanover Well 1 is located within 100 m of the lake, which is located within the 50-day capture zone of the well. Based on this, Hanover Well 1 is considered Groundwater Under Direct Influence (GUDI) of surface water with effective in-situ filtration (MOE 2014a). Hanover Well 2 is not identified as GUDI (MOE 2014a).

CHART 3.1 Hanover Monthly Pumping (2013)



Hanover Well 1 was completed in 1961 to a total depth of 34 m, and Hanover Well 2 was constructed in 1986 to a total depth 55 m. Borehole logs for these wells are provided in **Appendix A**. Hanover Wells 1 and 2 are completed in a lower confined sand and gravel aquifer (Lower Aquifer; **Figure 2.6**), which has a transmissivity of approximately 450 m^2/day (IWS 1986).

3.1.1.2 Surface Water Intake

As noted, the Town of Hanover relies upon the surface water intake from the relatively small and shallow Ruhl Lake for approximately 45% of its water supply. The surface water intake is located approximately 60 m from the eastern shore of Ruhl Lake, approximately 6 m below the water's surface and 1.5 m above the lake bed (Hanover Waterworks 1924). The intake pipe is 355 mm in diameter and leads to a pump house on the eastern shore of the lake, where a 305 mm diameter pipe then conveys water to the reservoir. As noted in Section 3.1.1., average daily takings (2013) from the lake are approximately 1,500 m^3/day, with greater demand during summer months.

3.1.2 Community of Lake Rosalind Water Supply Wells

The Community of Lake Rosalind has 58 residences (MOE 2014b) and, assuming 2.6 people per residence, which was the average for the Municipality of Brockton (Statistics Canada 2012b), a population of 151 was estimated for this study. The community relies on groundwater from two potential GUDI wells (Lake Rosalind Wells 1 and 3) for their municipal water supply demands (**Table 3.2**).

TABLE 3.2 Community of Lake Rosalind Water Supply Wells

Well Name	Permit Number	Permitted Capacity (m^3/day)	2013 Average Taking (m^3/day)	Hydrostratigraphic Unit
Lake Rosalind Well 1	8774-9M9QY (exp.7/31/2024)	30	7	Upper Aquifer
Lake Rosalind Well 3		110	20	Upper Aquifer
Total		**141**	**27**	

Wells 1 and 3 are located within 80 m of each other (**Figure 1.1**). They are approximately 100 m west of Lake Rosalind and 1 km north of Hanover Well 1. Lake Rosalind Well 1 is a dug well that is 4 m deep, while Lake Rosalind Well 3 is a drilled well that is completed to a depth of approximately 23 m bgs. The borehole log for Lake Rosalind Well 3 is provided in **Appendix A**. A borehole log was not available for Lake Rosalind Well 1.

There is no groundwater monitoring of either of the Lake Rosalind municipal production wells; however, water levels are recorded in the municipal wells. Details regarding water levels in the municipal wells will be presented in the Risk Assessment Report.

The two wells are permitted to pump (8774-9M9QW) 141 m^3/day; this is higher than the 2013 average annual combined taking of 27 m^3/day. Monthly pumping rates for both wells and the combined Lake Rosalind system are shown on **Chart 3.2** for 2013. Pumping rates over this period are relatively low compared to those of the Town of Hanover, with a maximum total system demand of 34 m^3/day during the month of August.

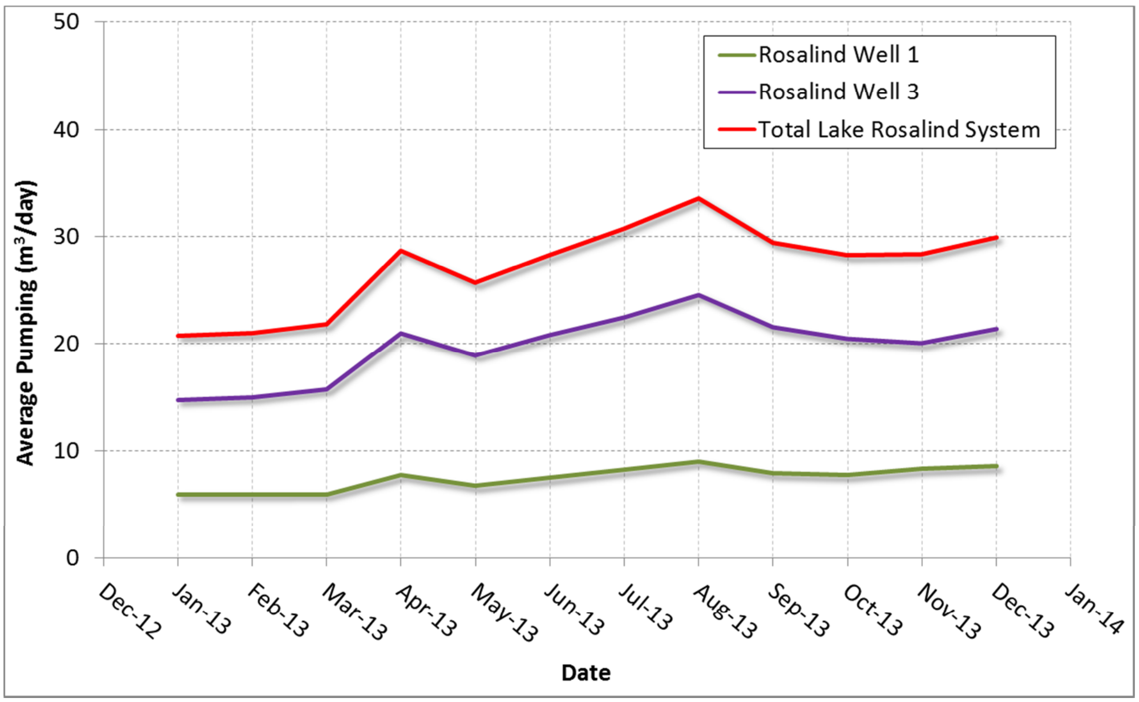
3.2 Non-Municipal Water Demands

Municipal water demands for the Town of Hanover and Community of Lake Rosalind were described in Section 3.1. The following section summarizes the estimation of the non-municipal water demands for the permitted water takers within the Study Area.

3.2.1 Data Sources

Two main data sources were used to estimate non-municipal permitted water demands; the PTTW database and the Provincial Water Taking and Reporting System (WTRS) database (2011). The databases and the methods used to develop estimates of consumptive water use are described in the following sections. The definition of consumptive water use is the amount of water withdrawn from a particular source (e.g., watercourse or aquifer) and not returned to that same source in a reasonable period.

CHART 3.2 Lake Rosalind Average Monthly Pumping Rates (2013)



3.2.1.1 Water Taking and Reporting System

In January 2005, the Water Taking Regulation came into effect. This regulation modified the PTTW program by requiring, among other things, mandatory monitoring and reporting of water takings by all permit holders. The monitoring and reporting requirements were phased in over a 3-year period, with all water users captured under this requirement in 2008. A database was provided by the MOECC to the conservation authorities in 2011 for use in the Tier Three Assessment; however, the data is no longer being distributed so the 2010-2011 datasets represent the most recent data that is currently publically available.

In the Study Area, 3 out of 13 water takings had reported pumping rates contained within the 2010-2011 WTRS that were used in the Tier Three Assessment. The daily reported rates were averaged over the month to obtain monthly pumping rates, and those were averaged over the year to obtain annual average pumping rates. Both datasets will be used in the Tier Three Assessment modelling efforts.

Data contained within the WTRS database are reported directly by permit holders and, as such, data entry errors associated with incorrect units (e.g., gallons per day versus litres per day), inaccurate measurement practices, or number keying issues are common. To identify sources of error, the maximum daily reported rate was queried from the WTRS dataset and compared to the maximum daily permitted rate. If the maximum daily reported rate was significantly larger than the maximum daily permitted rate, the reported data for that source was manually inspected and corrected.

The WTRS dataset contains actual daily pumping volumes; however, not all water withdrawn from an aquifer is consumed. The Water Budget Framework as part of the *Clean Water Act* considers the consumptive demand at each water taking, which is the volume of water withdrawn that is not returned to its original source. To calculate the consumptive use of WTRS reported takings, a consumptive factor related to the purpose of the taking was applied. The consumptive use factors applied were obtained from a document prepared for the MNRF (Kinkead Consulting and AquaResource 2009).

3.2.1.2 Permit to Take Water Database

With some exceptions, persons or organizations withdrawing water at a rate greater than 50,000 L/day, must apply for, and be granted, a PTTW from the MOECC. Information regarding each PTTW is stored within the PTTW database, including such information as name of the person/organization; maximum amount of water that can be withdrawn; coordinates of taking; and the purpose of the water withdrawal.

From a water management perspective, a major shortcoming of this database is that it does not contain data on actual pumping volumes. Typically, actual pumping is significantly less than the maximum amount of withdrawals permitted. The PTTW database used in this study was downloaded from the MOECC (2015) website in June 2015 for use in this study and the permits are considered up-to-date to May 7, 2015.

Water demand estimates were developed to represent consumptive water demands for all permits that did not have reported values (discussed in Section 3.2.1.3). This was done by combining maximum permitted pumping rates with the number of days each taking was permitted to withdrawn for. This volume was distributed across the months in which the taking would be active, and resulted in an estimate of the amount of water withdrawn. Consumptive use factors were then applied to the volume withdrawn to generate consumptive estimates. The same process applied in the Tier Two Assessment was used in this study with the most current version of the PTTW database.

3.2.1.3 Estimated Consumptive Demands

Figure 3.1 illustrates the location of the permitted takings that were included in the groundwater flow model, and their estimated consumptive water takings. **Tables 3.3** and **3.4** provide a summary of this information and includes the maximum permitted rate and average annual consumptive demand by specific purpose for groundwater and surface water takings, respectively. This summary lists the consumptive use estimates using values listed in the WTRS and those derived from the PTTW database where reported rates were not available.

TABLE 3.3 Summary of Groundwater Permitted and Consumptive Demands in the Study Area

Specific Purpose	Number of Sources (Wells, Ponds, etc.)	Maximum Daily Permitted Rate (m^3/day)	Average Annual Consumptive Rate (m^3/day)
Municipal	4	9,269	1,908[1]
Golf Course Irrigation	1	1,023	20.1
Aggregate Washing	2	6,409	579.5
Campgrounds	1	177	1.1
Manufacturing	1	160	20.8
Total	9	17,038	2,530

[1] Based on average annual municipal demand for 2013

TABLE 3.4 Summary of Surface Water Permitted and Consumptive Demands in the Study Area

Specific Purpose	No. of Sources (Streams, Ponds, etc.)	Maximum Daily Permitted Rate (m^3/day)	Average Annual Consumptive Rate (m^3/day)
Aggregate Washing	3	2,045	185
Wildlife Conservation	1	3,240	0
Total	4	5,285	185

Consumptive use estimates are lower than the maximum permitted pumping rates listed in the PTTW database, as they represent more realistic estimates than those estimated by simply summing the permitted volumes. This highlights the need for effective understanding and assessment of demand volumes and rates.

4 WATER BUDGET ASSESSMENT TOOLS

The objective of the Tier Three Assessment is to evaluate the risk that a municipality will not be able to meet its future water quantity requirements considering increased municipal water demand, future land development, drought conditions, and other water uses. The Tier Three Assessment relies on water budget assessment tools that are developed based on the physical conceptual characterization at both regional and local scales and it uses those tools to make predictions on the long-term sustainability of the municipal supplies. For this study, these tools include hydrologic and groundwater water budget tools. For assessment of the Ruhl Lake intake, a surface water spreadsheet-based water budget model was used, and it relied on output from the Guelph All-Weather Storm Event Runoff (GAWSER) watershed-based flow generation model (Schroeter and Associates

2004) developed and applied for the Tier One and Tier Two assessments. It also relied upon groundwater discharge output data from a groundwater flow model, which was developed for the Tier One Assessment, and refined and updated for the Tier Two Assessment and refined again for this study.

4.1 Hydrologic Water Budget Tool

GAWSER is a deterministic watershed-based flow generation model used to simulate major hydrologic processes resulting from precipitation and has been applied widely across Ontario for planning, designing, and evaluating the effects of physical changes in drainage basins (Schroeter and Associates 2004). Precipitation (rainfall and snowfall), after allowance for interception, is input to snow storage at the ground surface (if a snowpack is present) and gives rise to subsequent surface inputs of liquid water (rain and/or snowmelt). Precipitation is then partitioned into evapotranspiration, overland runoff, and infiltration. In a further step, infiltration is allocated to either the increase in soil water storage or groundwater recharge. GAWSER considers multiple influencing factors including climate variability, land use, vegetation cover, surficial soil/sediment, physiography, and topography. During simulation, drainage basins are divided into a series of linked elements representing watersheds, channels, and reservoirs. The physical effects of each element are simulated using numerical algorithms representing tested hydrologic models.

A peer reviewed GAWSER model was developed, calibrated, and applied in the Tier One and Tier Two assessments. During the Tier Two Assessment, the watershed-based flow generation model was linked to a groundwater model through the groundwater recharge component, whereby estimates of groundwater recharge made by the GAWSER model were input into the groundwater flow model. Key outputs from the watershed-based flow generation model (e.g., surface water inflows, direct precipitation) were used in the spreadsheet-based water budget model for the current Tier Three Assessment (Section 5).

4.1.1 GAWSER Model Development

The GAWSER watershed-based flow generation model was originally developed for five significant river systems: Saugeen, Pine, Sauble, Beaver, and Bighead rivers. The study period was from 1950 to 2005 to estimate long-term average conditions. With climate data varying over the Tier One Study Area, the Saugeen River watershed was divided into 21 Zones of Uniform Meterology (ZUMs). Each ZUM had an assigned climate station assumed to be representative of the climate throughout the ZUM. Climate data used for model input included daily rainfall, daily snowfall, daily minimum and maximum temperature, and hourly rainfall data. Data gaps in the climate data were infilled with data from adjacent stations.

The five river systems of the GAWSER model were further divided into water catchments, which represent the smallest spatial area for which the model can output a hydrograph. Catchment geology, land cover, topography, and hummocky topography were used to generate the hydrologic response of the overall watershed. Routing reaches were developed to route the hydrographs downstream. Cross-sections were approximated using simplified trapezoidal channel geometry and used to develop synthetic channel cross sections. Channel lengths and bed slopes were estimated using a 10 m DEM and a provincial virtual drainage layer.

4.1.2 GAWSER Model Calibration and Verification

Model calibration is the process of adjusting model parameters, variables, and other inputs to reduce the differences between simulated values and observed values. The GAWSER model was calibrated during the Tier One Assessment where calibration focused on the agreement between simulated and observed streamflow. Streamflow data available from 11 Water Survey of Canada (WSC) stream gauges within the Saugeen River watershed were used as calibration targets within the GAWSER model.

Once calibrated, the model was able to simulate the flows at the gauges to a reasonable degree (AquaResource 2008b). The model was subjected to a subsequent validation test, wherein model simulated flow rates were compared to measured flow rates from 1999 to 2005. The verification phase ensured the accuracy of the model, outside of the calibration period.

As the land use characteristics of the Study Area have not been significantly altered since 2005, it is unlikely that extending the GAWSER calibration period to 2015 would necessitate updates to model parameterization or significantly change the model output. As such, the Tier One and Tier Two assessments GAWSER model was applied in the Tier Three Assessment to guide the Ruhl Lake surface water intake evaluation and provide the recharge distribution for the Tier Three Assessment groundwater flow model (Section 6).

The uncertainties associated with the GAWSER model inputs (i.e., climate, topography, and land cover data), and calibration data (i.e., stream gauge data) are discussed in detail in the AquaResource (2008b) report.

4.2 Groundwater Water Budget Tool

A FEFLOW (Finite Element subsurface FLOW simulation system) steady-state groundwater flow model was developed, calibrated, and applied as a tool to assess groundwater flow at the regional-scale for the Tier One Assessment. The hydrogeological characterization reflected by the model included regional-scale groundwater aquifers and aquitards. Refinements were made to the hydrogeologic conceptual understanding of the assessment areas, and to the numerical FEFLOW groundwater flow model as part of the Tier Two Assessment.

4.2.1 FEFLOW Model Development

The development of the regional-scale FEFLOW model for the Tier One Assessment is described in the AquaResource (2008a) report. Updates to this model were carried out for the Tier Two Assessment (AquaResource 2010) and those updates included refinements to the overburden model layer structure, hydraulic conductivity values, and boundary conditions (including recharge from the calibrated GAWSER model and the update of pumping wells with information from the PTTW database). Additional refinements to the groundwater flow model structure, properties, and boundary conditions were conducted as part of the Tier Three Assessment and are summarized in Section 6.

4.2.2 FEFLOW Model Calibration

FEFLOW model calibration during the Tier Two Assessment focused on the agreement between simulated and observed groundwater hydraulic head elevations and baseflow. Hydraulic head values were obtained from the MOECC water well database. Baseflow targets were developed by applying a baseflow separation technique (BFLOW) to published WSC streamflow estimates associated with stream gauges within the Saugeen/Grey Sauble Conservation Authorities. Model calibration carried out for the Tier Three Assessment is summarized in Section 6.

The uncertainties associated with the Tier Two Assessment groundwater flow model input parameters, boundary conditions, and layer structure are outlined in detail in the AquaResource (2008a) report.

5 RUHL LAKE SURFACE WATER INTAKE EVALUATION

During the Tier Two Assessment, the “Lake Rosalind Groundwater Assessment Area” was classified as having a Moderate potential for hydrologic stress. As a result, a Tier Three Assessment for the groundwater supply sources was initiated to examine the long-term sustainability of the Hanover and Lake Rosalind water supply sources. The Ruhl Lake surface water intake also lies within this assessment area and supplies approximately 45% (2013) of the Hanover water demand. As Ruhl Lake is interpreted to be hydraulically connected to the groundwater system, the assessment of the Ruhl Lake intake was included as part of this Tier Three Assessment.

5.1 Conceptual Overview

To evaluate the risk associated with the reliability of the Ruhl Lake intake to supply existing and future demands, a spreadsheet-based water budget model was developed to estimate lake discharges and water levels. This water budget model is based on the output from the calibrated Tier Two Assessment GAWSER model and output from the calibrated FEFLOW groundwater flow model (Section 6). The objective of the water budget model is to predict lake water level fluctuations by incorporating all significant inflows and outflows into a mass balance calculation, which considers hydraulic characteristics (e.g., storage and outlet channel characteristics) of the lake.

5.1.1 Water Budget Approach

The water budget model considers the following hydrologic and hydrogeologic inputs:

- Precipitation: Depth of water that falls on Ruhl Lake via rainfall or snowmelt. This value was determined from the Hanover climate data used for the Tier One and Two Assessments.

- Evapotranspiration: Depth of water that is estimated to be removed from the surface of Ruhl Lake via direct evaporation. This value is obtained from the calibrated GAWSER watershed-based flow generation model.

- Surface Water Inflow**:** Volume of surface water that enters Ruhl Lake from the upstream contributing area. This may include streamflow from tributaries, or direct overland flow that enters the lake. This volume was obtained from the simulated hydrograph produced by the calibrated GAWSER model for the subcatchment that contains Ruhl Lake. Due to the Ruhl Lake drainage area only being a portion of the subcatchment that is represented in the GAWSER model, the hydrograph was area-prorated to Ruhl Lake's drainage area.

- Surface Water Outflow: Estimated volume of water that discharges from Ruhl Lake, and is the estimated Ruhl Lake streamflow. This value is predicted by the water budget model, by considering changes in lake level and volume, along with the estimated discharge characteristics of the lake outlet (note: streamflow or spot flow measurements of outflow were unavailable to calibrate the reasonableness of this assessment; however, anecdotal information provided by the Town of Hanover indicates that there has always been outflow into Ruhl Creek (Cooper 2015, Pers. Comm.).

- Groundwater Inflow: Volume of groundwater discharge that enters Ruhl Lake, as estimated by the calibrated Tier Three Assessment FEFLOW groundwater flow model (Section 6). This discharge was predicted transiently to account for the seasonality of groundwater seepage.

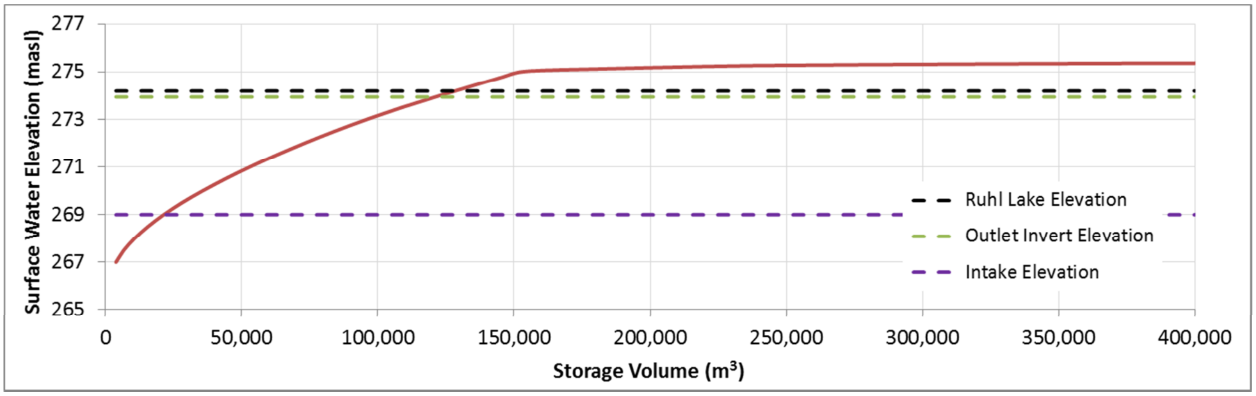
- Water Withdrawals: Volume of water withdrawn from Ruhl Lake from the Town of Hanover intake. The municipal source water withdrawal estimates were generated based on historical municipal withdrawals from the 2013 calendar year.

To predict lake levels and discharge from Ruhl Lake, two components of Ruhl Lake's hydraulics must be understood. These components describe how lake storage varies with lake level, and how lake discharge varies with lake level.

Storage-elevation characteristics of Ruhl Lake are obtained by combining lake bathymetry data, for levels below normal lake levels, with DEM information for levels above normal lake levels. Bathymetry data was provided by the SVCA (Hanover Waterworks 1924). This bathymetric data is approximately 90 years old. It is likely that sedimentation has occurred in that period, thereby reducing the volume of water held within the lake. While not having recent bathymetry data is an uncertainty, it is not expected to have a material impact on the study findings, as the active operation of the municipal intake would limit the accumulation of sediment to the intake elevation.

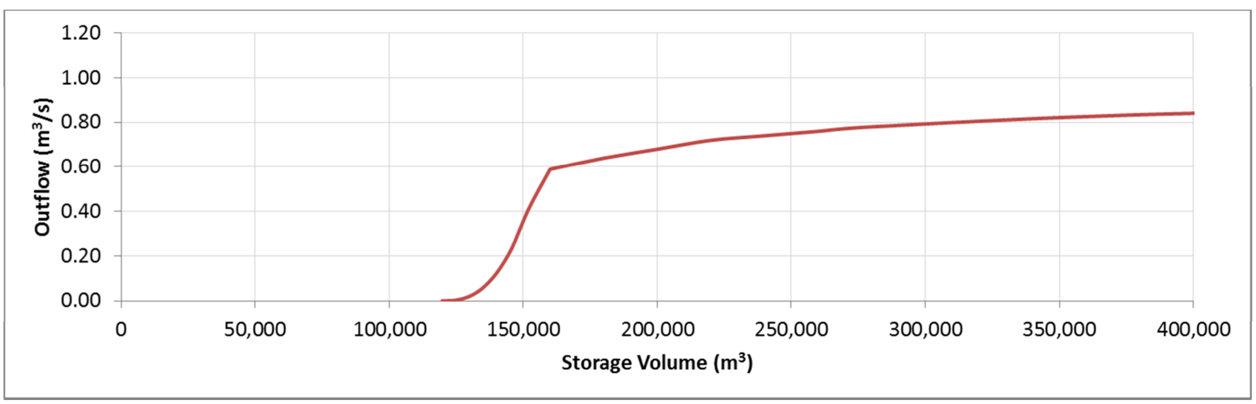
The bathymetry was digitized and combined with a 0.5 m DEM of the local drainage area. Using the estimated storage volume, a rating curve was developed for the relationship between storage volume and surface water level elevation (**Chart 5.1**).

CHART 5.1 Storage-Elevation Rating Curve for Ruhl Lake



Field data collected in October 2015 includes a measured width (1.55 m) and depth (average 0.25) of Ruhl Creek just downstream of Ruhl Lake. To develop a rating curve for the storage-outflow (**Chart 5.2**), a cross-section of the lake's outlet was approximated and guided by the field data collected and an assumed simplified trapezoidal channel geometry similar to the approach used to estimate GAWSER's channel routing (Annable 1996). The channel slope (0.1%) was estimated based on a 0.5 m DEM and a Manning's *n* of 0.05 indicative of a natural stream that is clean, winding, with some pools, weeds, and stones (Bedient et al. 2008).

CHART 5.2 Storage-Outflow Rating Curve for Ruhl Lake



Using the two rating curves and the available information for Ruhl Lake (e.g., 2013 municipal takings and results from GAWSER and FEFLOW), a hydrologic water budget model, which incorporated a mass balance equation on a daily time step, was developed to estimate Ruhl Lake's hydrograph, and a simple water budget.

5.2 Results

Using the developed spreadsheet water budget model, a long-term (1950 to 2005) mean annual water budget for Ruhl Lake was estimated and is summarized in **Table 5.1**. The results of the model indicate that the majority (56%) of the inflow to Ruhl Lake is from direct groundwater discharge to the lake, with the remainder predominantly being streamflow. Direct precipitation is not a significant contributor to the water balance. Municipal withdrawals are less than half of the estimated groundwater discharge inflow to Ruhl Lake.

TABLE 5.1 Mean Annual Water Budget of Ruhl Lake

Time Period	Precipitation (mm/year)[A]	Potential Evapotranspiration (mm/year)[A]	Stream Inflow (mm/year)[A]	Stream Outflow (mm/year)[D]	Groundwater Inflow (mm/year)[B]	Municipal Withdrawals (mm/year)[C]
1950 to 2005	989 (71 m^3/day)	612 (44 m^3/day)	39,952 (2,877 m^3/day)	70,852 (5,101 m^3/day)	51,663 (3,720 m^3/day)	21,138 (1,522 m^3/day)

Notes:
[A] Based on results from calibrated GAWSER model, scaled to the Ruhl Lake drainage area or reservoir area. Actual ET depends on vegetation, soil moisture and other parameters and is expected to be lower than 612 mm/yr.
[B] Based on result from refined and calibrated FEFLOW model (groundwater discharge varies from 3,250 to 4,504 m^3/day over the simulated 55 year period)
[C] Based on 2013 average daily municipal water withdrawals from Ruhl Lake
[D] Based on the water budget model and associated rating curve

As shown on **Chart 5.3**, Ruhl Lake stream inflows, outflows, and average annual precipitation volumes increase over the 55-year assessment period, with average daily flows positively correlating to the annual precipitation. Higher flows observed in 1985 are due to record rainfall in April and generally higher precipitation values over the year. With the exception of the spring freshet (mid-February to April), the major inflow to Ruhl Lake is predominately from groundwater seepage (**Chart 5.4**). The total annual municipal takings range from 13% to 32% of the total annual estimated outflow from Ruhl Lake. At all times in the simulated period, the municipal takings remain less than the estimated groundwater discharge into Ruhl Lake (**Chart 5.4**).

Over the 55-year period, Ruhl Lake's absolute surface water elevation is estimated to range from 274.1 to 275.4 m asl, maintaining an average water level more than 5.7 m above the municipal water intake elevation (268.7 m asl; **Chart 5.5**). **Chart 5.5** also displays the range of level fluctuations typically experienced by Ruhl Lake. For most months, the 10th to 90th percentile range, which corresponds to the expected levels that would occur 80% of time, remain close to the average monthly elevation. The 0% to 100% range shows greater variability in water levels during the spring freshet. With no control structure to limit outflows from the lake, and due to its small size, Ruhl Lake has limited capacity to store inflows. As a result, outflows closely match inflows and water levels remain relatively constant.

The average annual surface water elevation is variable from year to year; however, a linear trend line through the data shows a general increase in elevation of approximately 3.8 cm over the 55-year monitoring period (**Chart 5.6)**. This increase coincides with an increasing trend in precipitation over the same period.

CHART 5.3 Estimated Stream Inflow, Stream Outflow, and Precipitation at Ruhl Lake

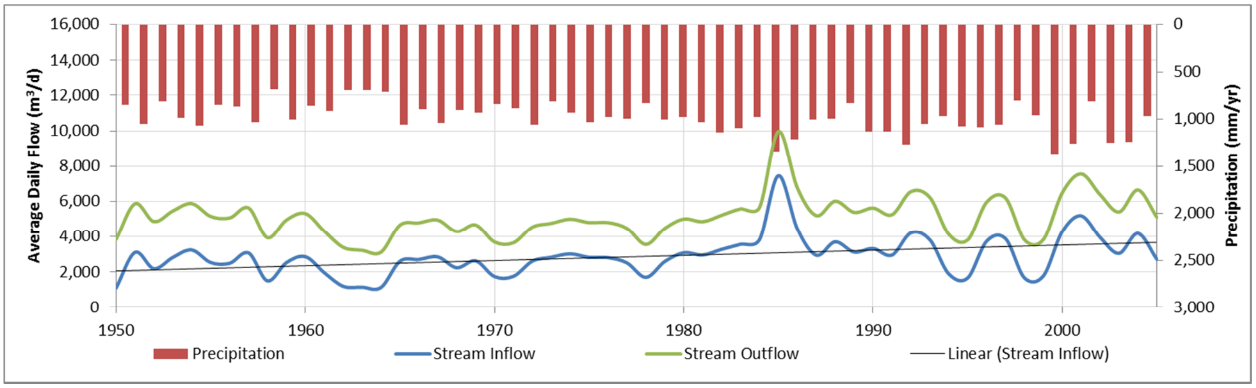


CHART 5.4 Estimated Monthly Stream Inflow, Stream Outflow, Groundwater Seepage and Municipal Withdrawal Rate of Ruhl Lake (Average 1950 to 2005)

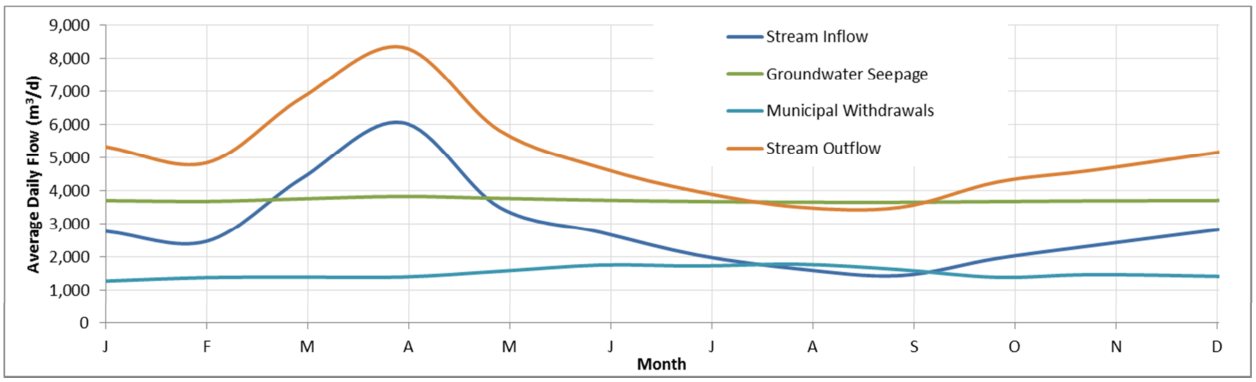


CHART 5.5 Ruhl Lake Water Level Distribution (Average 1950 to 2005)

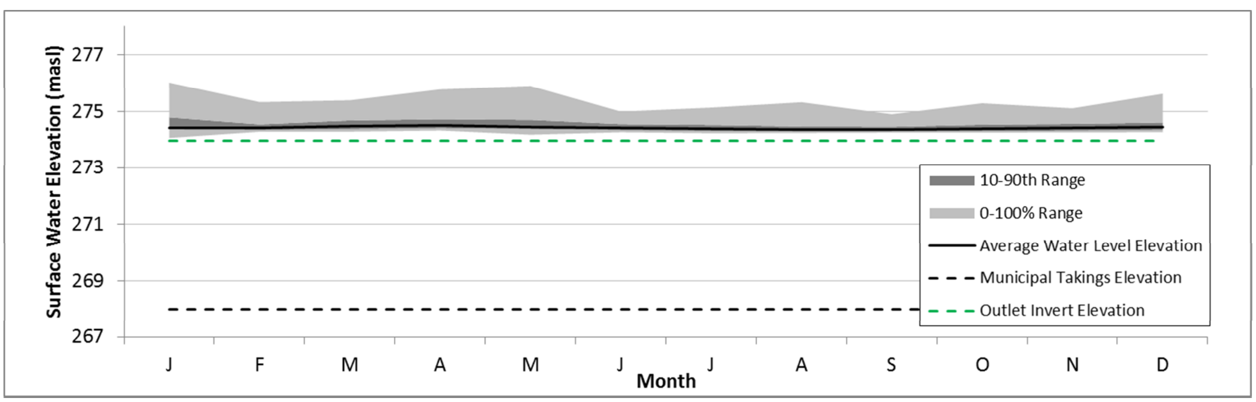
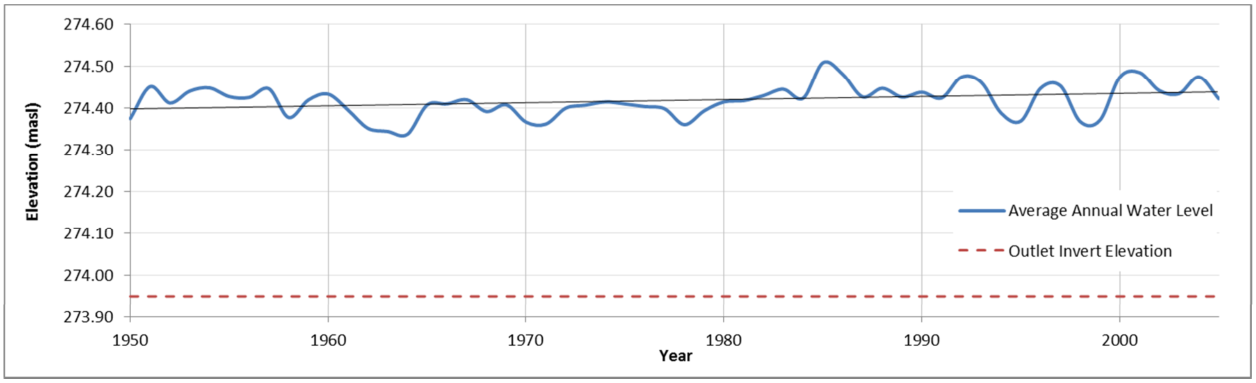


CHART 5.6 Estimated Annual Surface Water Elevation of Ruhl Lake (Average 1950 to 2005)



5.3 Summary

A water budget model was developed for Ruhl Lake using outputs from the existing GAWSER and FEFLOW models, historic municipal takings, Ruhl Lake bathymetry, and assumptions regarding the outlet dimensions of Ruhl Lake. Based on the water budget model developed, groundwater seepage represented more than half of the total lake inflow, with the remaining inflow interpreted to be from streamflow to the lake. Of the total annual outflows from Ruhl Lake, streamflow from the outlet represents the majority of flows (76%), while municipal takings represent 23% of all outflows on an annual basis. Climatic components, including precipitation and evapotranspiration, represented a small fraction of the lake's inflow and outflow and, as a result, are interpreted to have minimal effects on the lake's surface water elevation. Simulated surface water elevations fluctuate annually but maintain a generally consistent elevation of at least 5.7 m above the municipal source water inlet.

5.4 Assessment Limitations and Assumptions

Although any model is a simplification of the movement of water through the environment, the appropriate model should be able to make valid inferences regarding the key hydrologic processes within a watershed. Limitations and assumptions pertaining to the water budget include the following:

- Assumptions regarding the outlet channel dimensions can lead to uncertainties associated with the estimated discharge, and subsequently lake levels. These uncertainties will be focused on lake level ranges which exceed the outlet channel invert (e.g., when the lake is discharging). This uncertainty becomes irrelevant as lake levels fall below the lake outlet invert (e.g., as the lake ceases to discharge). Given that the intake elevation (268.7 m asl) is approximately 5 m below the estimated outlet invert, this uncertainty will not materially affect the assessment of whether the intake is able to withdraw water.

- The bathymetry data used to generate the lake level-storage relationship is approximately 90 years old. The study has assumed that the bathymetry of the lake has remained stable since the data was originally collected. It is likely that some sedimentation has occurred, resulting in a slightly shallower lake. While relying on older bathymetry data is an uncertainty, it is not expected to have a significant impact on the study findings, as the active operation of the municipal intake would limit the maximum accumulation of sediment to the intake elevation.

- There are no local streamflow observations to confirm the appropriateness of the GAWSER results for the Ruhl Lake catchment. This introduces a level of uncertainty into the analysis. However, in the absence of local monitoring data, using a regionally calibrated surface water model to infer local conditions provides reasonable estimates that use all available information.

- There are no lake level observations on Ruhl Lake to confirm the water levels predicted by the water budget model; however, anecdotal information from the Town of Hanover staff indicates that seasonal lake stage elevations are minor, varying historically on the order of 0.3 to 0.6 m (Cooper 2015, Pers. Comm.). This magnitude of variation is comparable with the 10^{th} to 90^{th} percentile range of simulated water levels presented in **Chart 5.5**. Due to the elevation of the intake in relation to the lake outlet invert, this data gap is not expected to affect the results of the Tier Three Assessment.

6 GROUNDWATER ASSESSMENT

This section describes the refinement of the numerical groundwater flow model representing the municipal water supplies and area surrounding the Town of Hanover and the Community of Lake Rosalind. The model layers were based on the conceptual hydrostratigraphic model presented in previous sections. The groundwater flow model was originally developed for the Tier One Assessment and refined in the Tier Two Assessment (AquaResource 2010) and was further refined locally in this study to better represent the conceptual model in each of the well field areas.

6.1 Model Refinements

A number of updates were made to the Tier Two Assessment FEFLOW groundwater flow model within the Study Area to represent the refined hydrostratigraphic conceptualization and to improve the match between the model simulations and observed water level elevations from that achieved in the Tier Two Assessment. No new data points were added relative to the Tier Two Assessment, an enhancement of the groundwater flow directions near the municipal wells was the aim of the model and calibration updates. Refinements to the model include the following:

- the finite element mesh
- the representation of ground surface and the hydrostratigraphic layer structure
- boundary conditions
- model properties (i.e., hydraulic conductivity and storage values)

6.1.1 FEFLOW Model Mesh

The model mesh was refined in areas where it was desirable to improve the representation of drawdown around the municipal wells and other areas of interest. The size of the elements within the model (node spacing) was reduced to less than 5 m in the areas immediately surrounding each of the four active municipal wells, and it was gradually coarsened to the original Tier Two Assessment mesh spacing further away from the well features. The node spacing was also refined from approximately 100 m to 25 m around Ruhl Lake, Lake Rosalind, Marl Lake, and stream features located within 1 km of each of the municipal wells to improve the representation of these features within the model. **Figure 6.1** illustrates the revised model mesh in the Study Area.

6.1.2 Ground Surface and Hydrostratigraphic Layer Elevations

The top surface representing ground surface topography was updated near the municipal wells for the Tier Three Assessment using a 0.5 m DEM provided by Grey Sauble Conservation Authority. This refined DEM better represents the local topography surrounding Ruhl Lake, Marl Lake, and Lake Rosalind and the stage elevation of these lakes. The refined DEM also better approximates the ground elevation at the municipal wells. This surface was merged with the existing regional DEM that covers the remainder of the area.

As the Tier Three Assessment aims to evaluate or quantify potential interactions between the groundwater flow system and nearby surface water features, the shape of the lake bottom of Ruhl Lake, Lake Rosalind, and Marl Lake were incorporated into the FEFLOW model. Bathymetric surveys for Ruhl Lake (Hanover Waterworks 1924) and Lake Rosalind and Marl Lake (Ontario Department of Lands and Forests 1971) were digitized into a GIS and refined in the FEFLOW model. It is not clear if all the surficial marl was extracted from the lake, or if a fine-grained clay or marl is still present at the base of the lakes. The conceptual model assumed a continuous Intermediate Aquitard comprised primarily of glaciolacustrine silts and clays beneath the lake that forms a hydraulic barrier between Marl Lake and Lake Rosalind and the underlying Lower Aquifer (Figure 2.6). This aquitard is interpreted to hydraulically separate the Hanover municipal production wells from the nearby lakes.

The water level elevation in Lake Rosalind and Marl Lake was estimated using the 0.5 m DEM, and both were explicitly represented in the model using the top surface of the model represented by the DEM and the base of Layer 1 represented using the bathymetric survey data.

The numerical model was subdivided into six overburden model layers (**Table 2.2)** based on the hydrostratigraphic layers outlined in Section 2.5. The elevations of model layers 1, 2, 3, and 4 were updated to reflect the hydrostratigraphic layers outlined in Section 2.5. The elevations and properties of the deeper overburden and all bedrock layers represented in the model remained unchanged from the Tier Two Assessment.

6.1.3 Boundary Conditions

Boundary conditions represent the interaction between the numerical model domain and the surrounding areas outside the model domain. They are applied in the groundwater flow model to approximate the regional groundwater flow patterns and major groundwater fluxes within the Study Area. Boundary conditions applied in the model consisted of three types:

- Specified head (Type I) boundary conditions are boundaries where the value of the hydraulic head is assigned a fixed value to specific nodes within the model, and the amount of discharge into or out of the model node fluctuates to satisfy the surrounding head conditions. Physically, these boundary conditions are commonly used to simulate areas where aquifer potentials are expected to remain at a constant level. These boundary conditions can permit flow to and from large rivers, lakes, or represent areas where water enters or exits the model domain.

- Specified flux (Type II) boundary conditions are boundary conditions for which a flux value is assigned to specific model nodes. The hydraulic head at the node is allowed to fluctuate to meet that flux condition. When run to a steady state solution, these boundary conditions are also called constant flux boundaries and are used to represent groundwater extraction or injection wells, or recharge to the groundwater system when applied over an area on Layer 1. No-flow boundaries are one type of specified flux boundary where the rate of lateral flow across the boundary is assumed to be negligible or equal to zero. In general, no flow boundaries are applied to simulate groundwater divides or impermeable geologic units.

- Head dependent boundary conditions (Type III) are boundaries where a flux across a boundary is calculated based on an assigned head value in the specific model nodes. The flux value is dependent on the difference between a specified head and the calculated heads in the surrounding model nodes. These head dependent flow boundary conditions are sometimes used to represent flow into a drain or into or out of a river.

Boundary conditions applied in the model aim to represent groundwater recharge (provided from the GAWSER model), flow into and out of surface water features (streams, rivers, and lakes), groundwater pumping wells, and flow into and out of the model along the outer perimeter.

6.1.3.1 External Regional Flow Boundary Conditions

One advantage of updating the original Tier Two Assessment model is that its external boundary conditions are located over 30 km from the municipal wells in the Study Area and, as such, will not influence model predictions. The groundwater flow model applied in this Tier Three Assessment is bounded by Lake Huron and Georgian Bay to the north and west, respectively, and is represented by fixed head boundary conditions representing the lake elevation. The south and east of the model are bounded by groundwater flow divides that were set in the Tier One and Tier Two assessments.

6.1.3.2 Surface Water Boundary Conditions

Perennial rivers, streams, and lakes were simulated in the model using specified head boundary conditions. The application of boundary conditions in the model to simulate these features is illustrated on **Figure 6.2**. Perennial streams were initially identified using the Strahler class number and were confirmed and modified using aerial photograph analysis and field observations before their representation in the FEFLOW model.

The elevation of Ruhl Lake was set at 274.2 m asl using the 0.5 m DEM, and explicitly represented in the numerical model using a specified head boundary condition. Lake Rosalind and Marl Lake were represented in the same fashion, with specified head boundary conditions set to the lake stage elevation on the top of Layer 1 (270.8 m asl for Lake Rosalind, and 270.5 m asl for Marl Lake). While Lake Rosalind was represented with a specified head boundary condition, the lake will not act as an infinite supply of water to Lake Rosalind Well 1, because the elevation of the lake is below the elevation of the screen bottom for the well. As such, the boundary condition in the model is not able to supply water to the well.

6.1.3.3 Recharge

Groundwater recharge refers to the amount of water that infiltrates and seeps through the unsaturated zone and ultimately reaches the water table. The rate of groundwater recharge is dependent on a number of factors including precipitation, evapotranspiration, land use and vegetation, surficial soil type (geology), and physiography. Recharge is enhanced in areas where the ground surface is hummocky and direct runoff to nearby creeks and rivers is inhibited.

Initial recharge rates used in the groundwater model were obtained from the calibrated surface water GAWSER model (AquaResource 2010) discussed in Section 4.1. The GAWSER model was calibrated to baseflow, or low flow conditions, so the estimated overall average recharge rate across the model are considered reliable for use in the groundwater flow model. The Tier Two Assessment (AquaResource 2010) outlined the GAWSER model construction and calibration process, and the resulting estimated recharge distribution within the Study Area. Recharge rates produced from the GAWSER model were applied in the model to the elements using area-weighted averaging.

Figure 6.3 illustrates the calibrated recharge distribution over the Study Area where recharge ranges from less than 50 mm/year to greater than 550 mm/year. Recharge rates of 550 mm/year were applied to the model in areas where sand deposits are present at surface and hummocky topography exists. In these areas, it is anticipated that recharge is enhanced as runoff is negligible. The areas of enhanced recharge primarily exist in the agricultural areas over 3 km northwest of the Lake Rosalind wells.

6.1.3.4 Pumping Wells

In FEFLOW, groundwater extraction wells are typically represented using a constant flux boundary condition, such that each node intersecting the screen/open borehole of a well is assigned a specified flux. This specified flux of water is either removed from the model (in the case of pumping) or donated to the model (in the case of injection). In all, 13 groundwater wells were simulated within the Study Area, 4 municipal takings and 9 non-municipal permitted water takers (**Figure 3.1; Tables 3.3** and **3.4)**.

6.1.4 Model Properties

Hydraulic conductivity and storage (specific storage and specific yield) values are the two main hydrogeologic properties assigned within elements of a numerical groundwater flow model domain. Hydraulic conductivity plays a role in the calculated hydraulic head distribution within the model domain. In contrast, storage parameters are not used in a steady-state simulation; however, under transient conditions, specific yield, and specific storage control the timing and response of the groundwater system to external stresses.

6.1.4.1 Hydraulic Conductivity Values

Hydraulic conductivity is a property of porous media that describes the relative ease with which water can move through pore spaces or fractures. When developing the numerical groundwater flow model, initial estimates of hydraulic conductivity are specified and subsequently altered through the calibration process to achieve an acceptable fit to observed data. Initial conductivity estimates are generally based on the conceptual understanding of the geologic/ hydrostratigraphic units and their hydrogeologic properties. Field estimates of hydraulic conductivity (e.g., from pumping tests or slug tests) help to constrain the conductivity estimates within particular geologic formations. When such data are not readily available, conductivity values are often estimated from literature values for materials with a similar lithological description, or from past studies that estimate the hydraulic properties of a particular hydrostratigraphic unit. In this study, both site-specific, measured hydraulic conductivities (i.e., from pumping test analysis) and estimates from literature were applied.

Hydraulic conductivity estimates for the overburden units were extrapolated from field-based, local-scale values to other areas within the Study Area. Where available, these field-measured values were used as initial estimates of hydraulic conductivity in the groundwater flow model, and the values were altered within the range of the conceptualized material based on literature values in an effort to better simulate observed water levels. This was the primary focus of the calibration process, along with other qualitative targets, which are discussed in the sections below.

The initial conceptual hydraulic conductivity distribution within the Study Area ranged from 1×10^{-4} m/s for coarse-grained sand units, to 1×10^{-8} m/s for the Intermediate Aquitard. Average initial hydraulic conductivity estimates for each unit and the calibrated values are provided in **Table 6.1**. The initial estimate for vertical hydraulic conductivity was set to be 1/10 of the horizontal hydraulic conductivity to account for horizontal bedding, but was varied as part of the calibration process.

The anisotropy ratio applied to represent the Upper Aquifer and Intermediate Aquitard was assigned a ratio of approximately 100:1 to account for the presence of interbeds within the aquifer and aquitard units. The anisotropy value is interpreted to reduce the vertical flow of groundwater and account for preferential horizontal flow within highly interbedded units. Borehole data throughout the area identify the presence of coarse-grained interbeds within the fine-grained aquitard units and fine-grained sediments within the coarse-grained aquifer units (**Figures 2.6** and **2.7**).

TABLE 6.1 Conceptual and Calibrated Hydraulic Conductivity Estimates

Hydrostratigraphic Unit	Initial Horizontal Hydraulic Conductivity Estimate (m/s)	Source of Estimated K Value (m/s)	Calibrated Horizontal Hydraulic Conductivity (m/s)	Calibrated Anisotropy (K_y/K_z)
Upper Aquitard (Silts and Clays)	1×10^{-7}	Freeze and Cherry (1979)	1×10^{-7} to 1×10^{-6}	10
Upper Aquifer (Sands/ gravels)	1×10^{-4} to 1×10^{-6}	Freeze and Cherry (1979); Luinstra Earth Sciences (2008)	1×10^{-6} to 8×10^{-4}	10 to 100
Intermediate Aquitard (Silts/Clays)	1×10^{-7} to 1×10^{-9}	Freeze and Cherry (1979)	1×10^{-6} to 5×10^{-8}	50 to 100
Lower Aquifer (Sands, lesser gravels, and silts)	5×10^{-4} to 1×10^{-5}	IWS (1986); Luinstra Earth Sciences (2008)	1×10^{-5} to 2×10^{-4}	10
Lower Aquitard (Elma/Catfish Creek Till)	1×10^{-7} to 1×10^{-8}	Freeze and Cherry (1979)	3×10^{-8} to 1×10^{-7}	10 to 100
Contact Zone Aquifer (Lesser sands and gravels)	1×10^{-6}	Freeze and Cherry (1979)	5×10^{-7} to 5×10^{-6}	10

6.1.4.2 Storage

In transient models, specific yield and specific storage values are used to represent the release of water from storage due to dewatering of pores or the reduction in pressure head within aquifers of interest. For the Study Area, estimates of specific yield and specific storage were obtained from literature values (Johnston 1967; Domenico and Mifflin 1965) and are summarized in **Table 6.2**.

TABLE 6.2 Summary of Specific Storage/Yield Values

Hydrostratigraphic Unit	Assigned Specific Storage (m^{-1})	Assigned Specific Yield
Upper Aquitard (Silts and clays)	1.5×10^{-5}	0.18
Upper Aquifer (Sands/ gravels)	1.5×10^{-5}	0.20
Intermediate Aquitard (Silts/Clays)	1.5×10^{-4}	0.05
Lower Aquifer (Sands, lesser gravels, and silts)	6.1×10^{-6}	0.20
Lower Aquitard (Elma/Catfish Creek Till)	1.5×10^{-4}	0.05
Contact Zone Aquifer (Lesser sands and gravels)	1.5×10^{-6}	0.14

6.2 Calibration Approach

Numerical groundwater flow models are typically calibrated by systematically adjusting the model input parameters and boundary conditions to determine the optimum match (within an acceptable margin of error) between the simulated results and field observations. The model's ability to represent observed conditions is assessed qualitatively to assess trends in water levels and distribution of groundwater discharge and quantitatively to achieve acceptable statistical measures of calibration.

The model was calibrated to long-term (steady-state) conditions representing the conditions in the 2013 calendar year. Municipal and non-municipal water users were represented using 2013 pumping rates (**Appendix B**). The model input parameters and boundary conditions were adjusted until a reasonable fit to the observed range of water level elevation values was obtained. This iterative process was repeated until the model was considered calibrated from a quantitative and qualitative perspective.

A transient calibration was not undertaken as observed pumping and water level data is not available. The only known pumping test undertaken on any of the four municipal wells is a 72-hour constant rate pumping test conducted on Hanover Well 2 (IWS 1986). The interpreted results of the test (i.e., estimated transmissivity and hydraulic conductivity) were cited in other water resources reports; however, Matrix was unable to obtain the original IWS (1986) pumping test report or any associated data. The lack of transient calibration data that could be used to refine estimates of storage and hydraulic conductivity values is noted as a data gap.

6.2.1 Calibration Datasets

The steady-state model was calibrated to 285 water level measurements reported in the MOECC water wells, plus an additional three observations from the Ruhl Lake investigation (Luinstra Earth Sciences 2008). Of the 288 data points, 162 wells were completed in overburden, and 126 wells were completed in bedrock. **Figure 6.2** illustrates the locations of the water level observation dataset within the Study Area.

Six boreholes were removed from the dataset due to poor ground surface elevation or location reliability. The remaining wells with water levels were not filtered for a particular period, and the water levels reported are considered representative of the time in which the well was drilled and the water level was collected. Static water level observations offer the benefit of having model calibration targets that extend across the entire model domain; however, there is uncertainty associated with individual observations. These uncertainties arise from errors in the reported location of the wells and the measurement techniques used were not designed to provide scientific information. As there were no higher-quality monitoring data available within the Study Area, the MOECC water well records represent the best data to calibrate the model and to identify regional trends in observations. However, the exact water level elevation at any given point has a degree of uncertainty. Although two bedrock Provincial Groundwater Monitoring Network wells are present in the Hanover area; however, they are located just outside of the Study Area to the south and east.

Streamflow data can be used to estimate baseflow, which is assumed to be almost entirely groundwater discharge but can include anthropogenic sources such as waste water treatment plant flow contributions or other water diversions. When available, baseflow estimates represent a calibration measure for limiting the non-uniqueness associated with a specific model calibration. Baseflow estimates using continuous gauges provide the best available means for estimating baseflow. The previous Tier Two Assessment FEFLOW model was calibrated on a regional scale to the baseflow values in the gauged rivers and streams. Additional surface water calibration was not undertaken as part of the Tier Three Assessment as areas where refinements were made to the model layer structure, properties, and boundary conditions were minimal compared to the gauged catchment areas.

6.3 Calibration Results

In general, a model is considered calibrated if there is a reasonable fit between the observed head contours and the model-predicted contours, and quantitatively if the model-predicted heads and groundwater discharge estimates fall within the range of reported values. The aim is to achieve calibration results that are "as good as possible" using reasonable parameter estimates that are supported (where available) by field data or literature values.

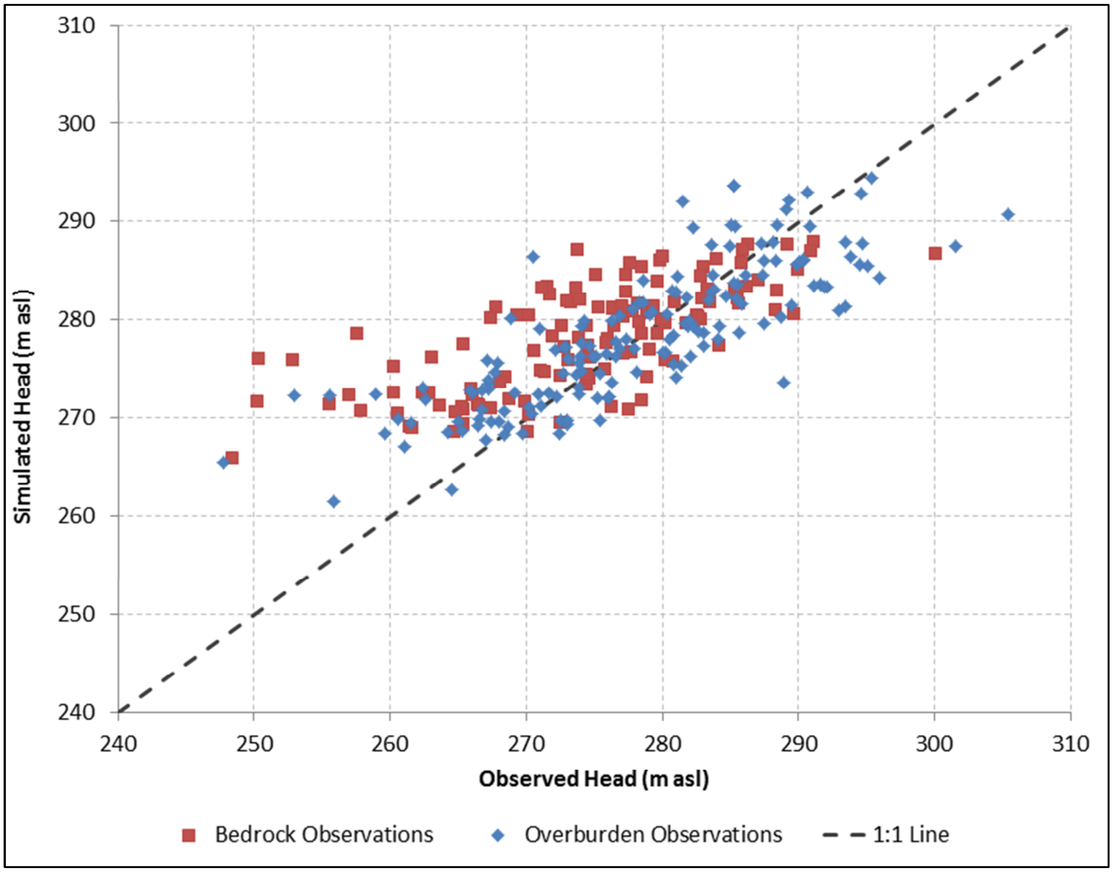
6.3.1 Quantitative Assessment

The following paragraphs outline the calibration of the model from a quantitative perspective. In general, the model-predicted water levels fall within a reasonable margin of error from the observed water levels.

6.3.1.1 Steady-State Calibration to Water Level Elevations

Chart 6.1 provides a scatter plot of observed and simulated water level elevations for the calibration targets. Good agreement was achieved between simulated and observed water levels with the majority of the targets having a model simulated value within 5 m of the observed value, consistent with the measurement uncertainty of MOECC wells and the variation during periods of the observations. The slope of scatter plots follows the trend of a one-to-one match indicating a good model representation of the observed regional gradient in the central portion of the model. The model simulated water level elevations in the bedrock and overburden near the Saugeen River are higher than the observed water level elevations. A buried bedrock valley underlies the modern day Saugeen River; however, the sediment infilling this valley and it's depth into the bedrock formations are not well understood due to the lack of data. As such, it is possible the bedrock valley simulated in the model is shallower and infilled with more fine-grained material than reality, which would lead to a greater hydraulic connection between the bedrock aquifer system and the overlying Saugeen River. Modifying this connection would reduce the heads in the overburden and bedrock in this area and improve the calibration. This discrepancy was not considered crucial to address during calibration as the fit within the municipal well field area is very good. Calibration statistics for the hydraulic head calibration measures are provided below. A plan view map of calibration residuals is illustrated on **Figure 6.4**.

CHART 6.1 Scatterplot of Observed and Simulated Water Level Elevations



The calibration statistics for the wells are as follows:

- Normalized root mean squared (NRMS) error = 9.7%. 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; Lutz et al. 2007; Gallardo et al. 2005); however, the NRMS error is dependent on the range of observed water levels. In the Hanover area, the range of water level observations is approximately 76 m and as such an error band of 7.6 m represents a NRMS of approximately 10%.

- Root mean squared (RMS) error = 7.4 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 7.4 m of the observed value. Water levels associated with the MOECC WWIS are collected over decades and are reflective of the snapshot in time when they were collected. Water levels may vary seasonally by 2 m, depending on the geologic environment, and the location and elevation reliability of these wells and their water levels is another added level of uncertainty. Given these uncertainties with the data, an error of +/- 7.4 m is considered acceptable in this area.

- Mean Error = 2.0 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 higher than the observed values by 2 m.

- Mean Absolute Error = 5.3 m. The mean absolute error is a measure of the average deviation between observed and simulated water levels. The value of 5.3 m is less than the population statistic (RMS) and within the range of the expected level of error when using water levels from well records.

Near the Lake Rosalind well field, an effort was made to ensure the simulated water levels in the shallow aquifer between Ruhl Lake and Lake Rosalind were as close as possible to the observed water levels. The topographic rise west of Lake Rosalind contains a number of domestic water wells with an observed depth to water table that ranges from 3 to 5 m, equating to a water table elevation of approximately 290 m asl. In comparison, the static water table elevation at Lake Rosalind, approximately 200 m away is approximately 271 m asl. Efforts were made to ensure this gradient was simulated in the model.

The simulated water level elevations for domestic water wells near Hanover Wells 1 and 2 closely matched those observed. The hydraulic conductivity of the Lower Aquifer within which the Hanover production wells are completed was calibrated to range from 5×10^{-5} to 1×10^{-4} m/s, which closely matches the field-estimated hydraulic conductivity of 1.7×10^{-4} m/s (Luinstra Earth Sciences 2008) and the transmissivity estimate of 450 m^2/d (IWS 1986).

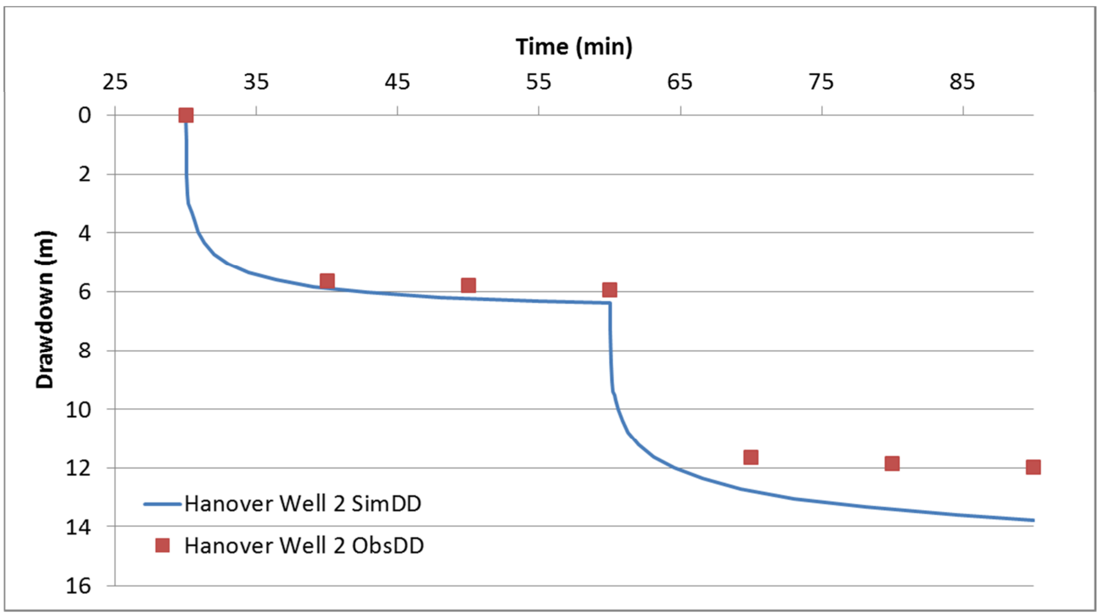
At the time of model calibration, the pumped water level elevations in the Town of Hanover and the Community of Lake Rosalind municipal wells were unavailable, as all water level data was provided as depths above a reference point within each well. Despite best efforts to attain the data at the onset of the project, the reference points for the Town of Hanover wells were determined in consultation with the Town after the model calibration and risk assessment scenarios were complete. The observed pumped water levels in Hanover Wells 1 and 2 are approximately 265 and 268 m asl, respectively, and the model simulated water levels in the production aquifer are approximately 259 m asl at each of the wells. The absolute water levels at the wells are under-simulated in the model relative to the field observations; however, the simulated magnitude of the drawdown in the municipal wells (see Section 6.3.1.2) is very good. As the Tier Three Assessment is concerned with simulated drawdown as compared to available drawdown, the model is considered well calibrated in this area.

Two monitoring wells were drilled on the eastern side of Ruhl Lake as part of a hydrogeologic study of Ruhl Lake (Luinstra Earth Sciences 2008). One well was drilled into the Upper Aquifer and the other in the Lower Aquifer, with the two wells approximately 1.5 m apart. A pumping test was performed on the Lower Aquifer and no response was observed in the Upper Aquifer. Higher water levels observed in the monitoring wells relative to the lake level lead to the conclusion that Ruhl Lake is supplied primarily by the shallow aquifer in the immediate vicinity of the lake. The model simulated difference in water level elevation between the two observation points was approximately 5 m, and the observed water levels in the shallow aquifer were 5 m higher than the lower aquifer. The hydraulic separation in this area was also interpreted to exist 500 m west of this area near the Lake Rosalind municipal water supply wells.

6.3.1.2 Transient Calibration to Water Level Elevations

A step test was conducted in Hanover Well 2 in January 2015, as part of the Town of Hanover's ongoing well and pump maintenance. The test was short-term in duration but provided valuable information on the response of the Lower Aquifer at Well 2 in response to pumping. The step test pumping schedule was applied in the groundwater flow model to attempt to replicate the drawdown observed in the field. **Chart 6.2** illustrates the simulated and observed drawdown in the well during the test, and shows an excellent fit to the observed data. The results of this test increases the confidence in the model's ability to replicate pumping conditions at the well under pumping conditions. Similar step test data was unavailable for Hanover Well 1, and the Lake Rosalind Wells.

CHART 6.2 Transient Model Calibration: Observed and Simulated Water Levels



6.3.1.3 Steady-State Calibration to Baseflow

Baseflow targets were developed by applying a baseflow separation technique (BFLOW) to published WSC streamflow data associated with stream gauges in the broader Saugeen and Grey Sauble Conservation Authorities from 1996 to 2005. Recognizing the uncertainty associated with baseflow separation techniques, the BFLOW techniques produced three baseflow estimates. For the purpose of calibrating the FEFLOW model, the maximum and minimum of these values was used for the calibration.

When comparing the simulated groundwater discharge values to the observed baseflow values (estimated by BFLOW), there is an implicit assumption that baseflow is representative of groundwater discharge. Streamflow estimates in the winter months are highly impacted by backwater when ice in the river channel constricts the channels and water levels rise. As the stream gauges measure river stage (level) and use a stage-discharge relationship to estimate streamflow, higher baseflow are often reported in the winter months. Despite this uncertainty, the simulated results match well with the observed estimates at the three closest WSC stream gauge stations. The Saugeen River near Walkerton gauge is located approximately 7 km southwest of the Hanover municipal wells. The Carrick Creek near Carlshrue gauge and South Saugeen River near Neustadt gauge are located approximately 6 km and 9 km, respectively, southeast of the Hanover wells.

As outlined in Table 6.3, the simulated baseflow at Saugeen River near Walkerton is slightly lower than observed and this may be due to backwater ice effects noted above. The simulated baseflow at “Carrick Creek near Carlshrue” and “South Saugeen River near Neustadt” are comparable to, or slightly higher than, the observed range of expected baseflows. The flow contributing to these latter two stream gauges originates from the south, away from the Tier Three Assessment Study Area.

TABLE 6.3 Summary of Baseflow Calibration

Gauge Name	Gauge ID	Low Estimate of Observed Baseflow (m^3/s)	High Estimate of Observed Baseflow (m^3/s)	Simulated Baseflow (m^3/s)
Saugeen River near Walkerton	02FC002	16.49	18.63	16.0
Carrick Creek near Carlshrue	02FC011	0.96	1.13	1.5
South Saugeen River near Neustadt	02FC012	3.58	4.33	3.9

The long-term sustainability of the Ruhl Lake intake will be evaluated using the water budget spreadsheet model and inputs to that spreadsheet model will be derived from the groundwater flow model. Marl Lake and Marl Creek were both simulated as groundwater discharge features in the groundwater flow model with water simulated to move from the shallow groundwater flow system into the surface water features. No measured surface water flow values were available to calibrate the groundwater flow model.

6.3.2 Qualitative Assessment

The following sections outline the qualitative measures used to assess the model calibration. Models are non-unique and as such, qualitative checks are beneficial to assess the reasonableness of the model’s predictions.

6.3.2.1 Simulated Upper Aquifer Equipotential Contours

Figure 6.5 illustrates the water level contours simulated by the steady-state groundwater flow model in the Upper Aquifer. As illustrated on the figure, water table contours generally mimic the ground surface topography and show flow regionally toward the Saugeen River and southwest. In the northwest, shallow groundwater is predicted to flow and discharge toward streams that flow toward the north. In the area of the municipal wells, local shallow groundwater flows converge on Lake Rosalind, Marl Lake, and Ruhl Lake following the local ground surface topography.

The largest gradients are observed at regional discharge locations, which include the Saugeen River, and Marl Lake, Ruhl Lake, and Lake Rosalind.

6.3.2.2 Simulated Lower Aquifer Equipotential Contours

Figure 6.6 illustrates the Lower Aquifer simulated water level elevation contours within the Study Area when the municipal wells are pumping at their current average annual rates (average of 2013 demands). Groundwater flow in the Lower Aquifer originates in the east, flows to the west, and converges on the Saugeen River in the southwest. There is also localized drawdown and radial flow simulated toward Hanover Wells 1 and 2 due to municipal pumping from the Lower Aquifer. The Intermediate Aquitard separating the Upper and Lower aquifers is generally interpreted to be continuous and competent, which hydraulically disconnects the two aquifers. As noted above, this interpretation is supported by pumping test data conducted in the area east of Ruhl Lake where the Lower Aquifer was pumped and no response was seen in the Upper Aquifer in a monitoring well only 1.5 m away. The only exception is at the Saugeen River, where the river has eroded the confining unit and groundwater from both units is conceptualized, and simulated, to discharge into the Saugeen River. The extent of the erosion of the confining unit at the Saugeen River is poorly understood and may not be well represented in the model due to a lack of data in this area.

6.3.2.3 Groundwater Discharge to Surface Water

Part of the Tier Three Assessment involves examining the potential impact of increased municipal pumping on other water uses such as streams or rivers that host coldwater fish communities. Within the Hanover area, there are several surface water bodies that are interpreted to receive groundwater discharge to varying degrees, including Ruhl Lake, Lake Rosalind, Marl Lake, and the Saugeen River and its tributaries (**Figure 2.3**).

Figure 6.7 shows areas of observed cold, cool, and warm water streams and lakes as defined by the MNRF (2015). Also illustrated are the surface water features that are noted to be gaining and losing water to the underlying groundwater flow system in the calibrated groundwater flow model. A close match was observed between features known to receive groundwater discharge (e.g., coldwater streams and lakes) and simulated groundwater discharge conditions.

6.3.3 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 shallow and deep groundwater levels are consistent with those observed and flow conceptualization; simulated groundwater discharge is consistent with thermal regime mapping in the creeks and rivers. Quantitatively, simulated hydraulic head measurements closely match observed values within the acceptable statistical range, while reproducing observed flow directions. Regionally, the error based on the difference between observed and simulated water levels is minimized and no significant spatial trends that may impact the model predictions were noted. Locally, the simulated heads near the municipal wells are close to observed values.

The calibration was achieved using input parameter values (i.e., conductivity and storage) that are within the expected range or measured range for the groundwater system in the area. Local and regional understanding of the hydrostratigraphy in the Study Area helped guide the calibration effort. Overall, the calibration results suggest that the groundwater flow model is suitably calibrated to steady-state conditions.

6.4 Groundwater Flow Model Limitations

All models developed to represent natural systems are simplifications of the natural environment and the hydrologic processes within that environment. It is not possible to represent all the complexities of the physical system and incorporate all details into a numerical context. Most of the scientific approach involves representing physical conditions observed using approximations of larger-scale functionality; hydraulic conductivity of representative elemental volumes 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; however, the limitations of such tools when interpreting model results needs to be recognized.

Regardless of the level of refinement of the groundwater modelling analysis, there remains a significant source of uncertainty that cannot be eliminated. Numerical models are approximations of the real world environment and generalizations are necessary to take a complex hydrogeologic system and bring it into the numerical environment. The distribution of data points and the poor quality of some data (e.g., geological descriptors in water well records) means that a number of simplifying assumptions need to be made regarding the geology or the hydrostratigraphy of the system. In the Hanover area, the Upper (surficial) Aquifer, and Intermediate Aquitard were deposited in a dynamic glacial environment and the stratigraphy can vary greatly from place to place. The number of boreholes available to characterize the geologic and hydrogeologic conditions in the Study Area is limited, and consequently, there is a level of uncertainty associated with the layer structure and properties applied in the model, especially between data points.

Despite the limitations noted above, well calibrated groundwater flow models are tools that can be used to understand water levels, groundwater flow directions, and hydraulic gradients under current and future scenarios.

7 SUMMARY AND CONCLUSIONS

The Study Area containing the Town of Hanover and Community of Lake Rosalind wells is covered by a thick blanket of Quaternary-aged sediments deposited during the Late Wisconsinan as glacial ice lobes advanced and retreated across southern Ontario. The glacial history of the area was examined in detail to help refine the hydrostratigraphy in the local Study Area from that originally developed during the Tier One and Tier Two Assessments. This refined conceptualization was used to update the model layers and properties in a 3D numerical groundwater flow model of the Study Area, especially near the municipal wells and intake.

The groundwater flow model consists of a sequence of aquifers and aquitards, and this structure forms the basis for the groundwater flow model.

A FEFLOW groundwater flow model was developed during the Tier One Assessment and was later updated and refined as part of the Tier Two Assessment. For the Tier Three Assessment, additional refinements were made to the Tier Two Assessment model to represent hydrogeologic conditions local to the Lake Rosalind and Hanover municipal wells. In particular, a higher resolution DEM was incorporated, additional hydrostratigraphic interpretation at the municipal wells was performed, and updates to parameter values were made as part of the refined model calibration. The groundwater flow model was calibrated using the recharge estimates provided by the GAWSER watershed-based flow generation model from the Tier Two Assessment. The groundwater flow model was calibrated both quantitatively and qualitatively to available MOECC water well observation data. The model is well calibrated to steady-state conditions, considering the quality of the available calibration data. Data and knowledge gaps noted in the model construction and calibration processes will be applied in an uncertainty assessment within the context of the predictive scenarios as part of the Tier Three Risk Assessment.

Due to the interpreted hydraulic connection between the groundwater system and Ruhl Lake, the intake at Ruhl Lake has been included in the Tier Three Assessment. To assess the reliability of the surface water intake to supply current and future demands, a spreadsheet-based water budget model was developed for Ruhl Lake using intake pumping data, bathymetry data, output from the existing Tier Two Assessment GAWSER model, groundwater discharge predictions from the Tier Three FEFLOW model, and by making assumptions about the Ruhl Lake outlet.

In the next phase of the Tier Three Assessment process, the spreadsheet-based water budget model and the calibrated groundwater flow model will be used to complete a water budget and Local Area Risk Assessment. The water budget provides improved estimates for various components of the hydrologic cycle in the Study Area. The Local Area Risk Assessment develops and assesses a set of scenarios that represent the municipal Allocated Quantity of Water, as well as the current and future land uses. Ultimately, the changes in water levels in the municipal supply aquifer and Ruhl Lake, and the impacts to baseflow under average and drought climate conditions, will be estimated and used to assign a level of risk to the municipal systems.

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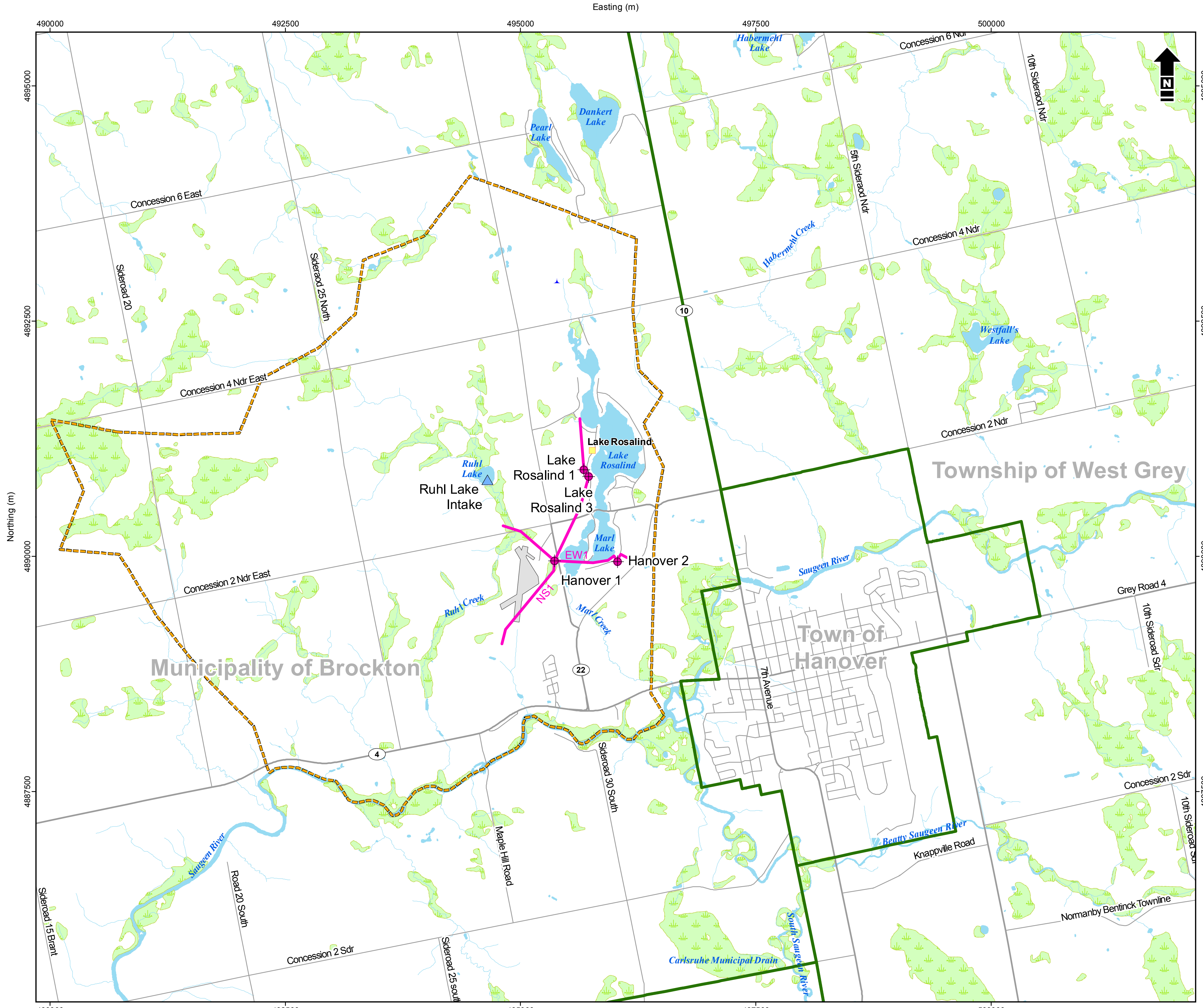

Lake Rosalind Groundwater Assessment Area (Tier Two Assessment)
Airport
Municipality
Wetland
Water Body
Watercourse
Highway
Road
Cross Section
Municipal Well
Municipal Surface Water Intake
Community

1:42,000
430 0 430 860 m
NAD 1983 UTM Zone 17N

Reference: Data obtained from GeoBase®, Ontario Ministry of Natural Resources and SVCA used under license. Produced using information provided by the Ministry of Natural Resources, Copyright © Queen's Printer, 2015.

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Physical Characterization and Water Budget Report

Study Area

Date:	Project:	Technical:	Reviewer:	Drawn:
27 Aug 2015	21581-527	D. Van Vliet	P. Meyer	C. Curry

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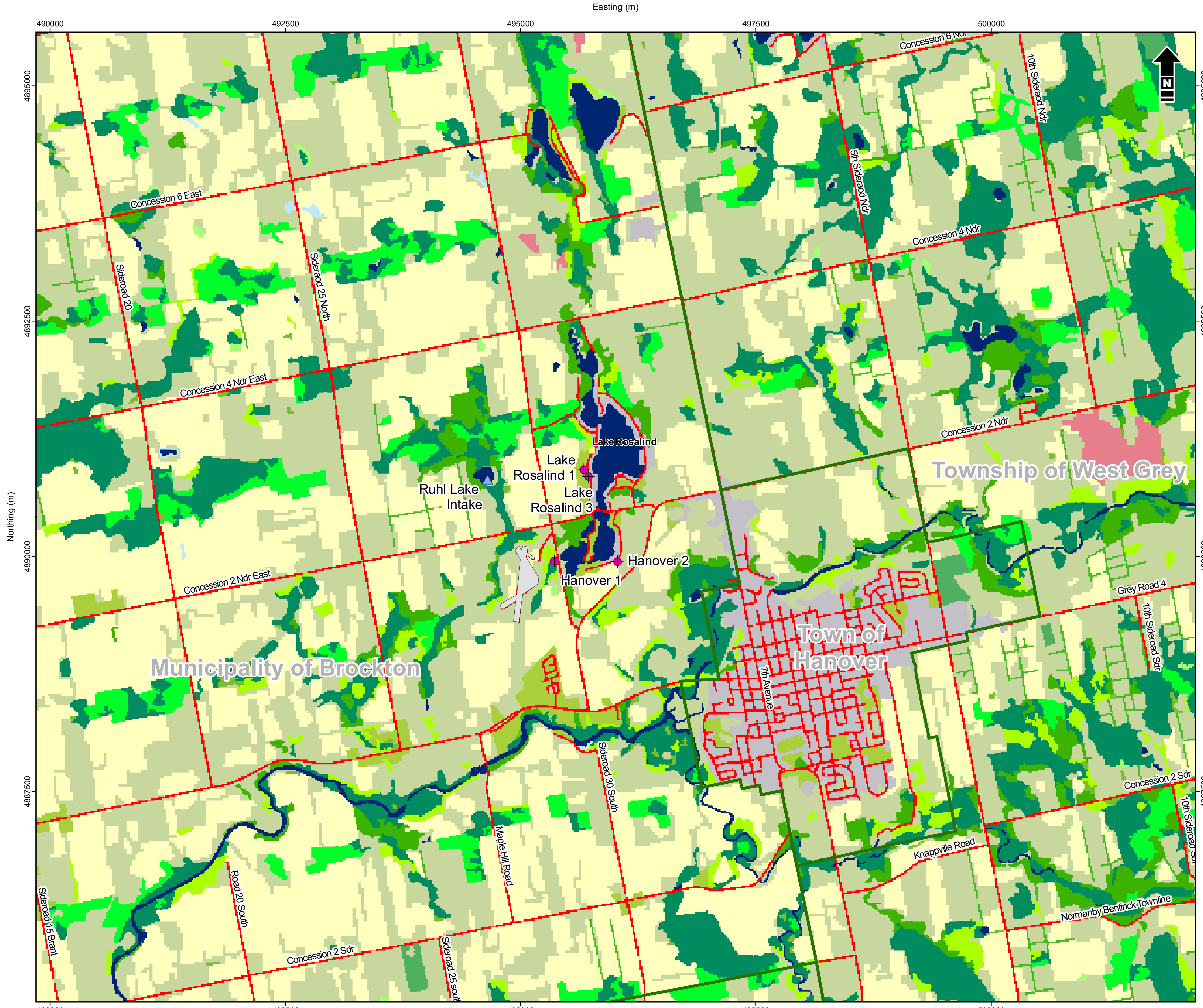
Figure 1.1



Airport
Municipality
Municipal Well
Municipal Surface Water Intake
Community

Land Cover

- 90. Forest
- 91. Coniferous Forest
- 92. Mixed Forest
- 93. Deciduous Forest
- 131. Treed Swamp
- 135. Thicket Swamp
- 160. Marsh
- 170. Open Water
- 191. Plantation
- 192. Hedge Row
- 193. Tilled
- 201. Transportation
- 202. Built Up Area - Pervious
- 203. Built Up Area - Impervious
- 204. Extraction - Aggregate
- 250. Undifferentiated

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Land Cover data provided by the Southern Ontario Land Resource Information System (SOLRIS) Land Use Data version 2. Toronto, Ontario: The Ontario Ministry of Natural Resources, 2015
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1:42,000
430 0 430 860 m
NAD 1983 UTM Zone 17N

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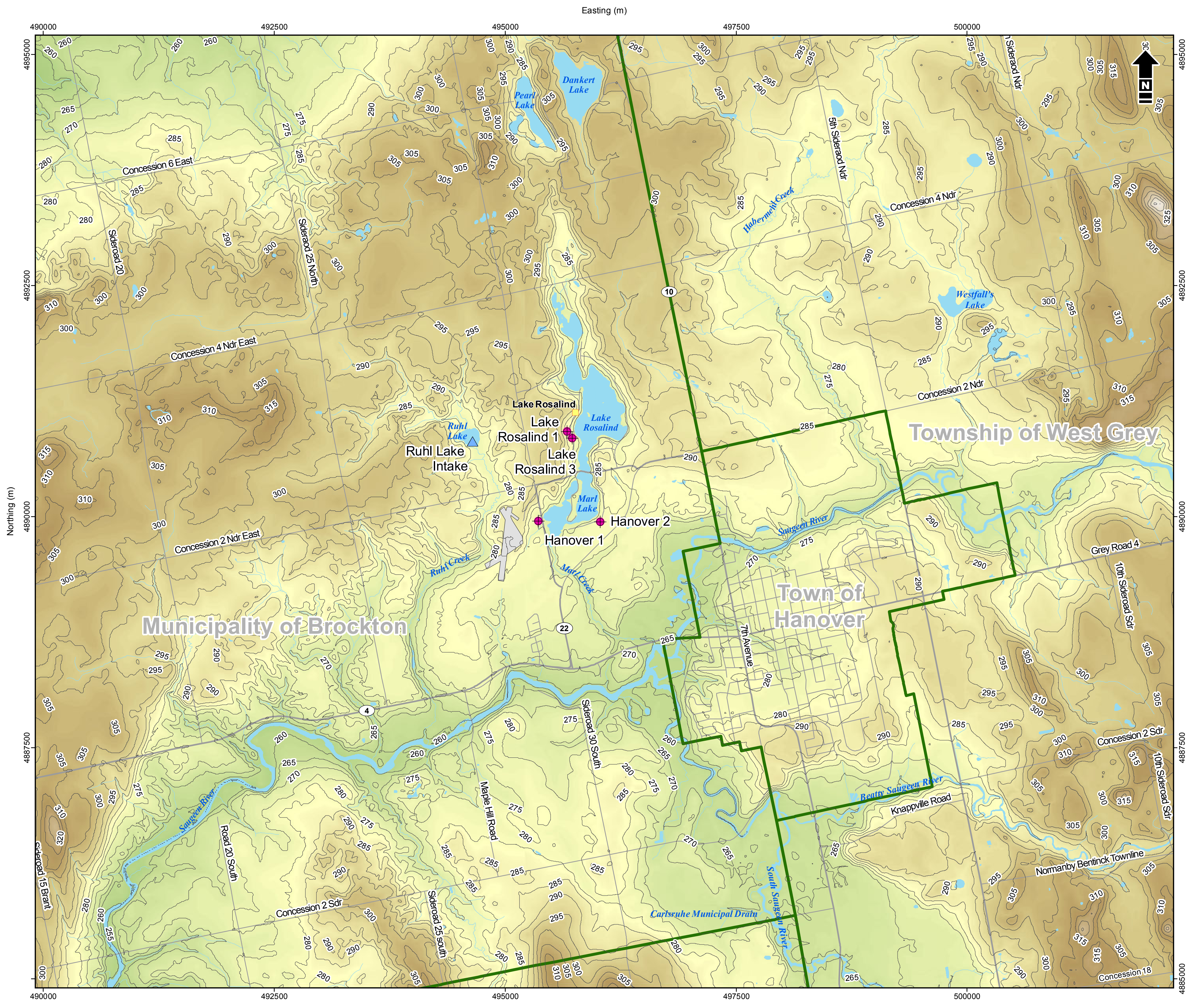
Physical Characterization and Water Budget Report

Land Cover (SOLRIS)

Date:	Project:	Technical:	Reviewer:	Drawn:
27 Aug 2015	21581-527	D. Van Vliet	P. Meyer	C. Curry

Figure 1.2



Airport
Municipality
Water Body
Watercourse
Highway
Road
Elevation Contour (5m)
Municipal Well
Municipal Surface Water Intake
Community

Elevation (m asl)
High : 345
Low : 250

Reference: Data obtained from GeoBase® and Ontario Ministry of Natural Resources and SVCA used under license.
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1:42,000
430 0 430 860 m
NAD 1983 UTM Zone 17N

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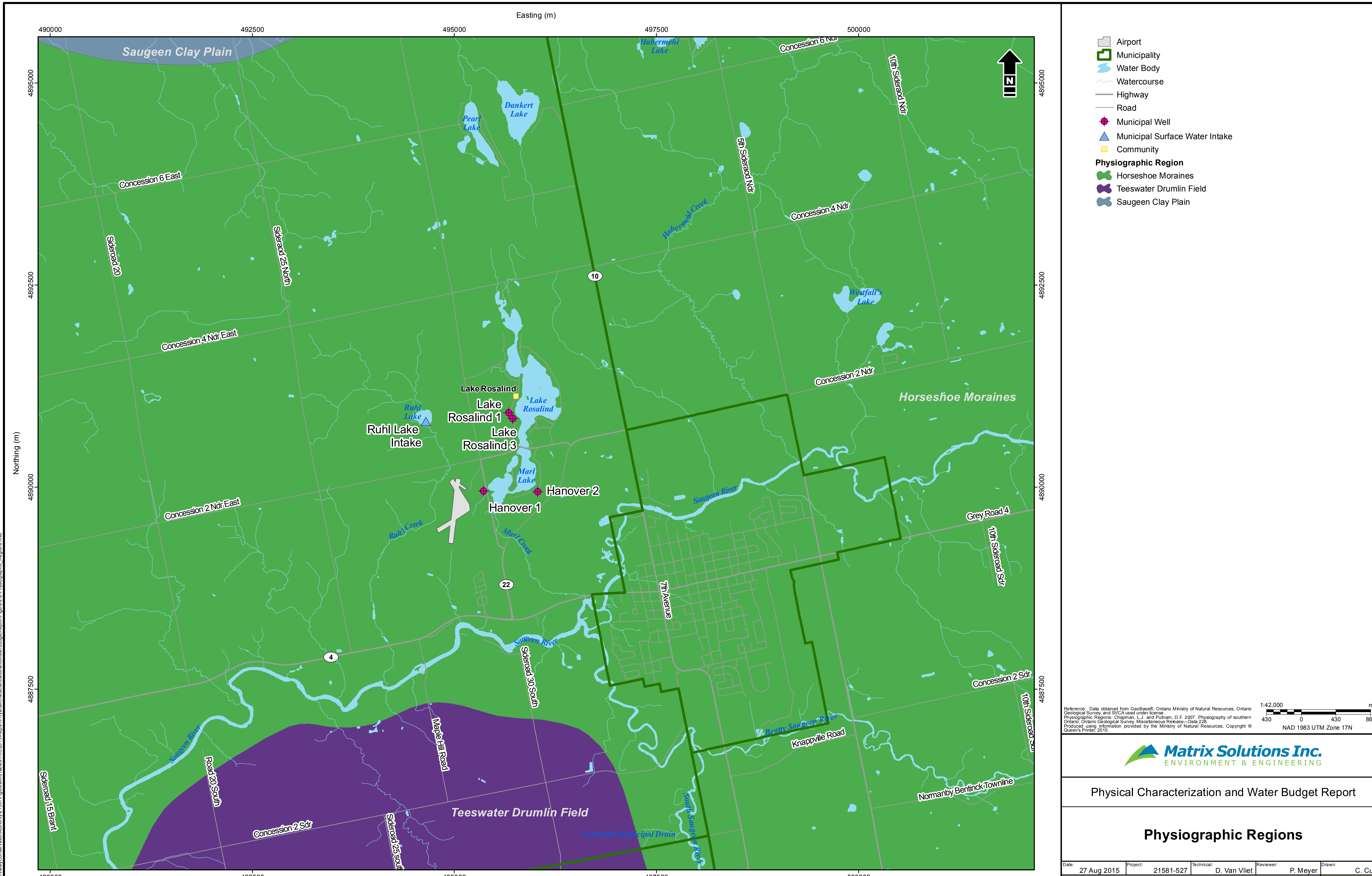
Physical Characterization and Water Budget Report

Ground Surface Topography

Date:	Project:	Technical:	Reviewer:	Drawn:
27 Aug 2015	21581-527	D. Van Vliet	P. Meyer	C. Curry

Figure 2.1



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Physiographic Regions: Chapman, L.J. and Putnam, D.F. 2007. Physiography of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 228.
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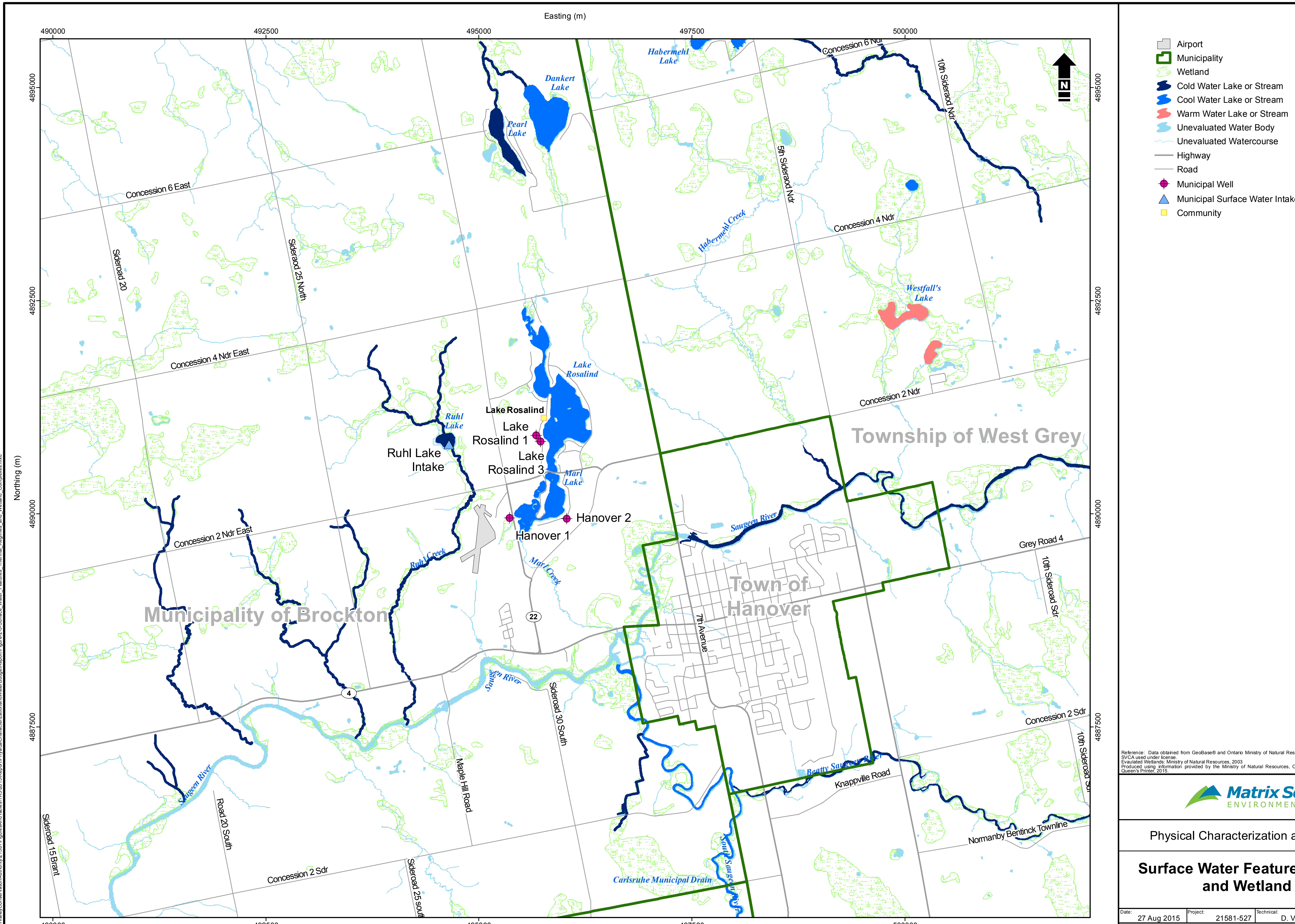
Physical Characterization and Water Budget Report

Physiographic Regions

Date:	Project:	Technical:	Reviewer:	Drawn:
27 Aug 2015	21581-527	D. Van Vliet	P. Meyer	C. Curry

Figure 2.2



Reference: Data obtained from GeoBase® and Ontario Ministry of Natural Resources and SVCA used under license.
Evaulated Wetlands: Ministry of Natural Resources, 2003
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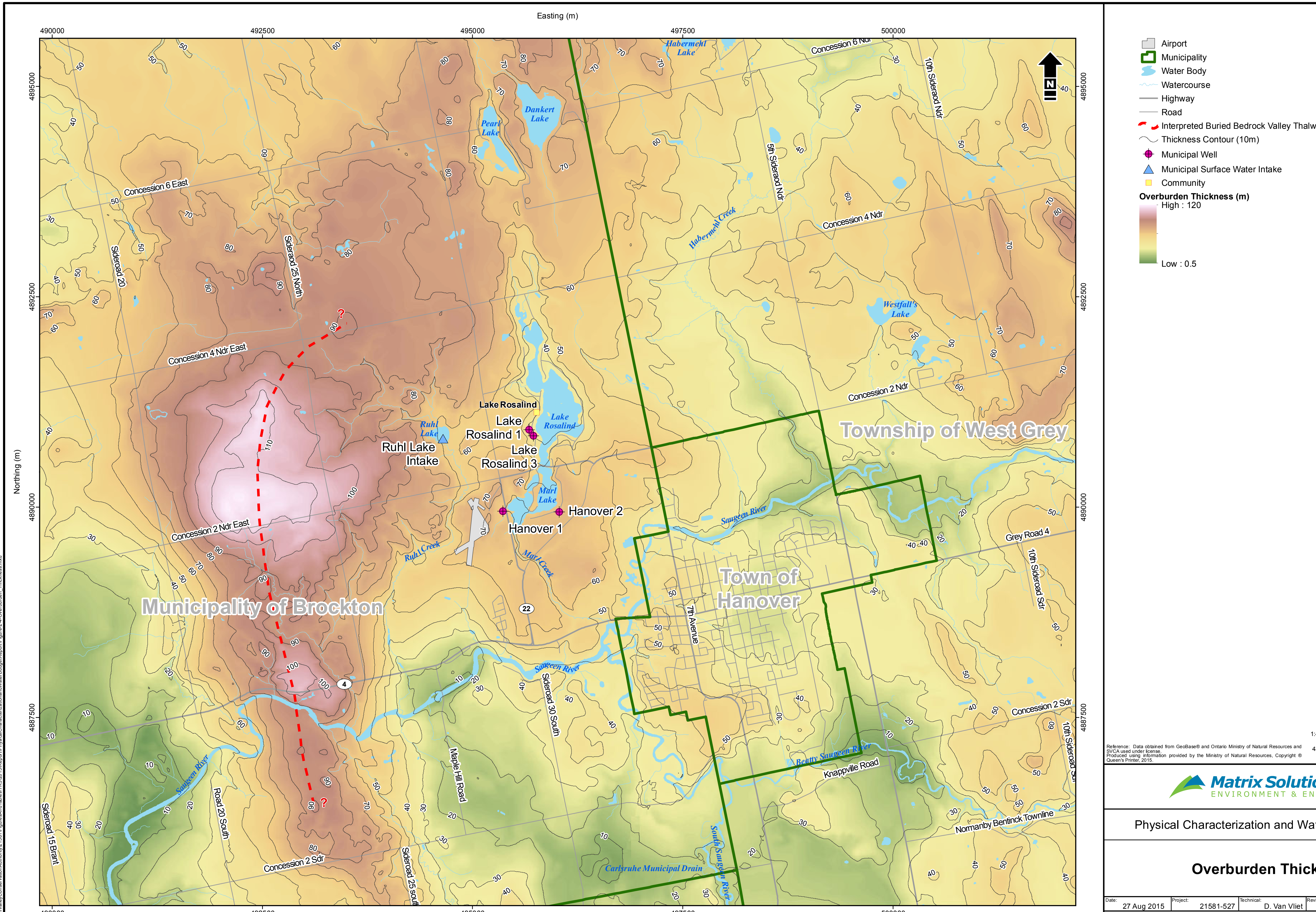
Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Physical Characterization and Water Budget Report

Surface Water Features, Thermal Regimes and Wetland Complexes

Date:	Project:	Technical:	Reviewer:	Drawn:
27 Aug 2015	21581-527	D. Van Vliet	P. Meyer	C. Curry

Figure 2.3



Reference: Data obtained from GeoBase® and Ontario Ministry of Natural Resources and SVCA used under license.
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1:42,000
430 0 430 860 m
NAD 1983 UTM Zone 17N

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Physical Characterization and Water Budget Report

Overburden Thickness

Date:	Project:	Technical:	Reviewer:	Drawn:
27 Aug 2015	21581-527	D. Van Vliet	P. Meyer	C. Curry

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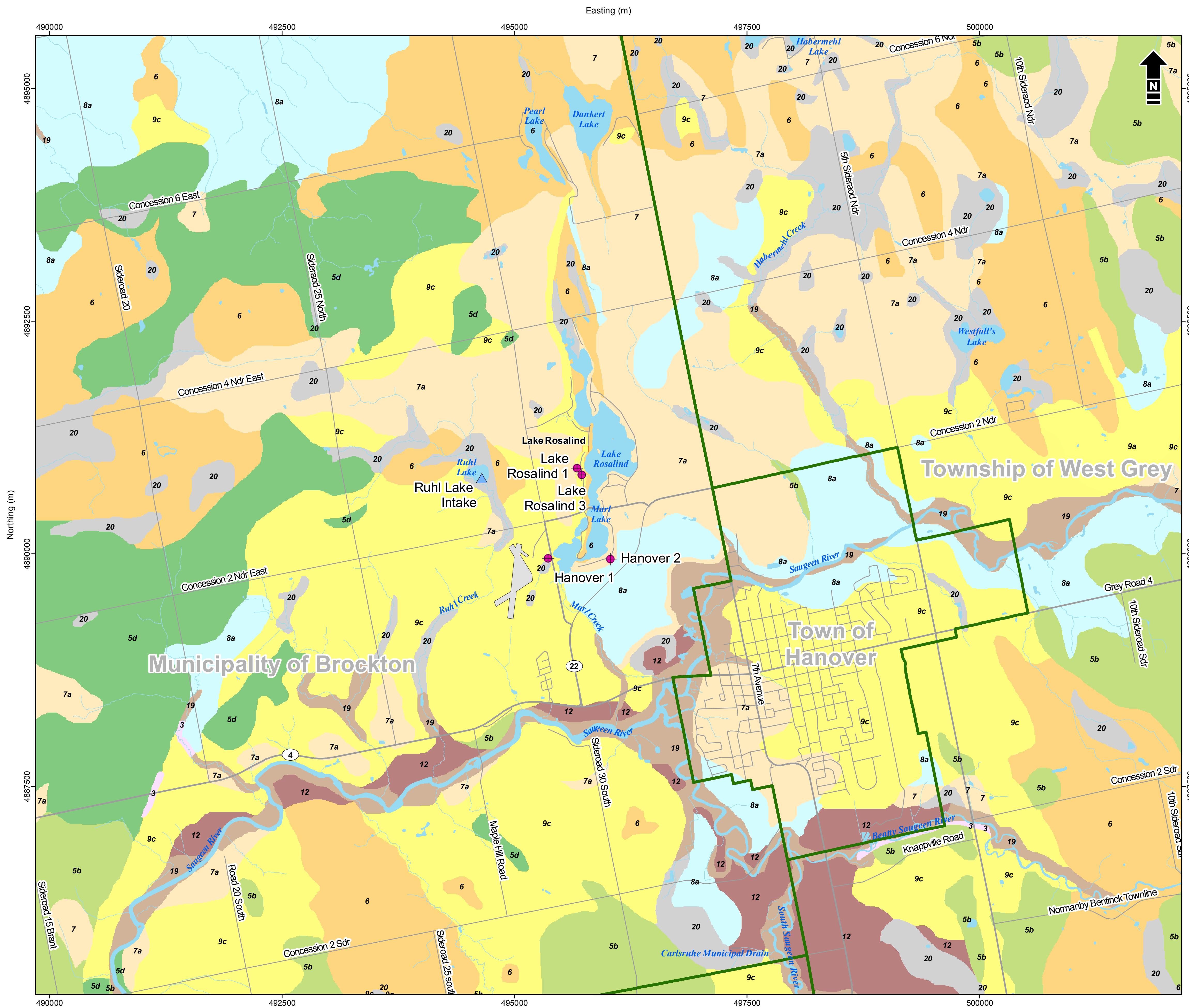
Figure 2.4



Airport
Municipality
Water Body
Watercourse
Highway
Road
Municipal Well
Municipal Surface Water Intake
Community

Surficial Geology

- 3: Paleozoic bedrock
- 5b: Stone-poor, carbonate-derived silty to sandy till
- 5d: Glaciolacustrine-derived silty to clayey till
- 6: Ice-contact stratified deposits
- 7: Glaciofluvial deposits
- 7a: Sandy deposits
- 8a: Massive-well laminated
- 9a: Deltaic deposits
- 9c: Foreshore-basinal deposits
- 12: Older alluvial deposits
- 19: Modern alluvial deposits
- 20: Organic deposits

Reference: Data obtained from GeoBase® and Ontario Ministry of Natural Resources and SVCA used under license.
Surficial Geology: Ontario Geological Survey 2010. Surficial geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 128 – Revised.
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1:42,000 m
430 0 430 860
NAD 1983 UTM Zone 17N

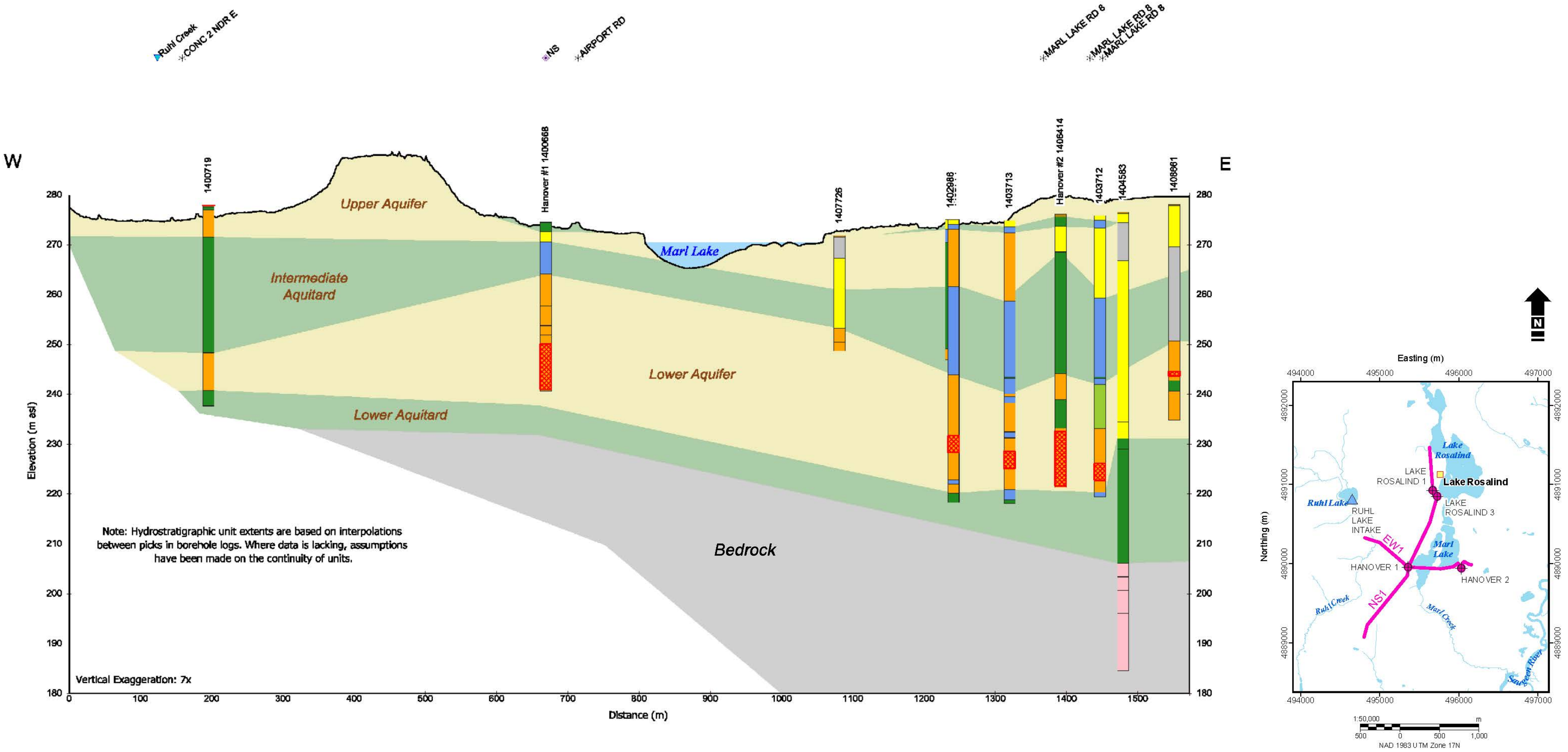
Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Physical Characterization and Water Budget Report

Surficial Geology

Date:	Project:	Technical:	Reviewer:	Drawn:
27 Aug 2015	21581-527	D. Van Vliet	P. Meyer	C. Curry

Figure 2.5



Water Body
Watercourse
Cross Section
Municipal Well
Municipal Surface Water Intake
Community

LEGEND

Profile Intersection
- Road
- Drainage
- Cross-section

Ground Surface, Lake Bathymetry

Screened Interval

Borehole Lithology
- Clay, silty clay
- Silt
- Fine-grained diamict (cl, si)
- Gravel, Medium sand, Clay
- Fine/silty sand
- Gravel
- Organic
- Fill, Topsoil
- Limestone
- Unknown

Interpreted Unit
- Lake
- Sandy aquifer (variably saturated)
- Clay-rich aquitard
- Paleozoic Bedrock

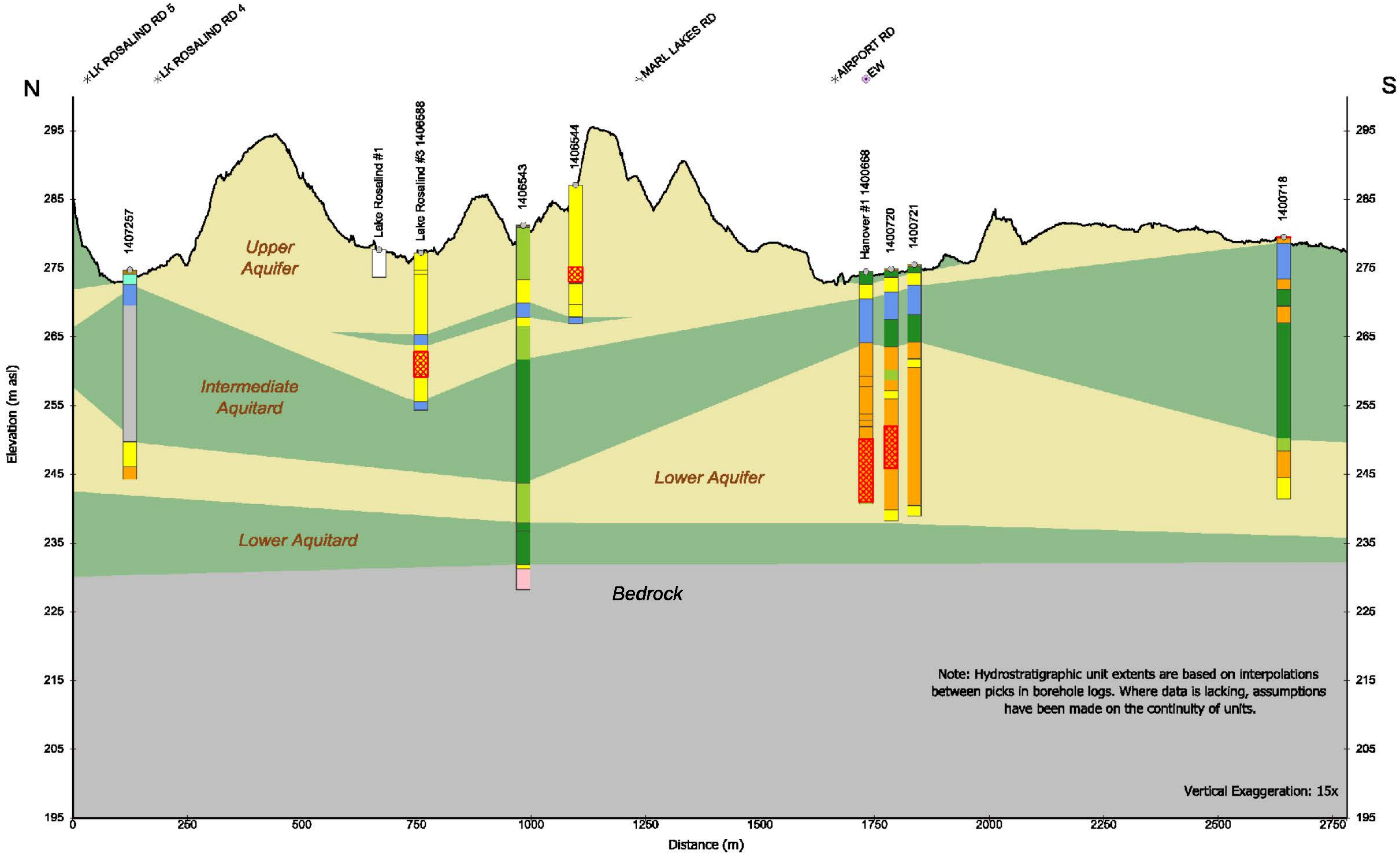
Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

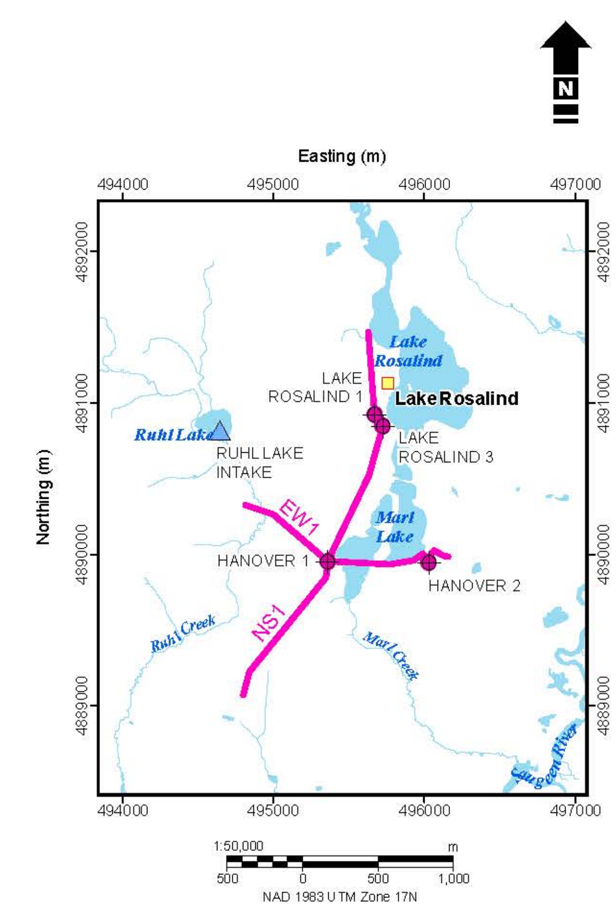
Physical Characterization and Water Budget Report

Hydrostratigraphic Cross Section E-W

Date: 11 Sep 2015	Project: 21581-527	Technical: D. Van Vliet	Reviewer: P. Meyer	Drawn: M. Pfeifer

Figure 2.6





- Water Body
- Watercourse
- Cross Section
- Municipal Well
- Municipal Surface Water Intake
- Community

LEGEND

Profile Intersection		Borehole Lithology		Interpreted Unit
Road	Ground Surface, Lake Bathymetry	Clay, silty clay	Gravel	Sandy aquifer (variably saturated)
Cross-section	Screened Interval	Silt	Organic	Clay-rich aquitard
		Fine-grained diamict (cl, si)	Fill, Topsoil	Paleozoic Bedrock
		Gravel, Medium sand, Clay	Limestone	
		Fine/silty sand	Unknown	

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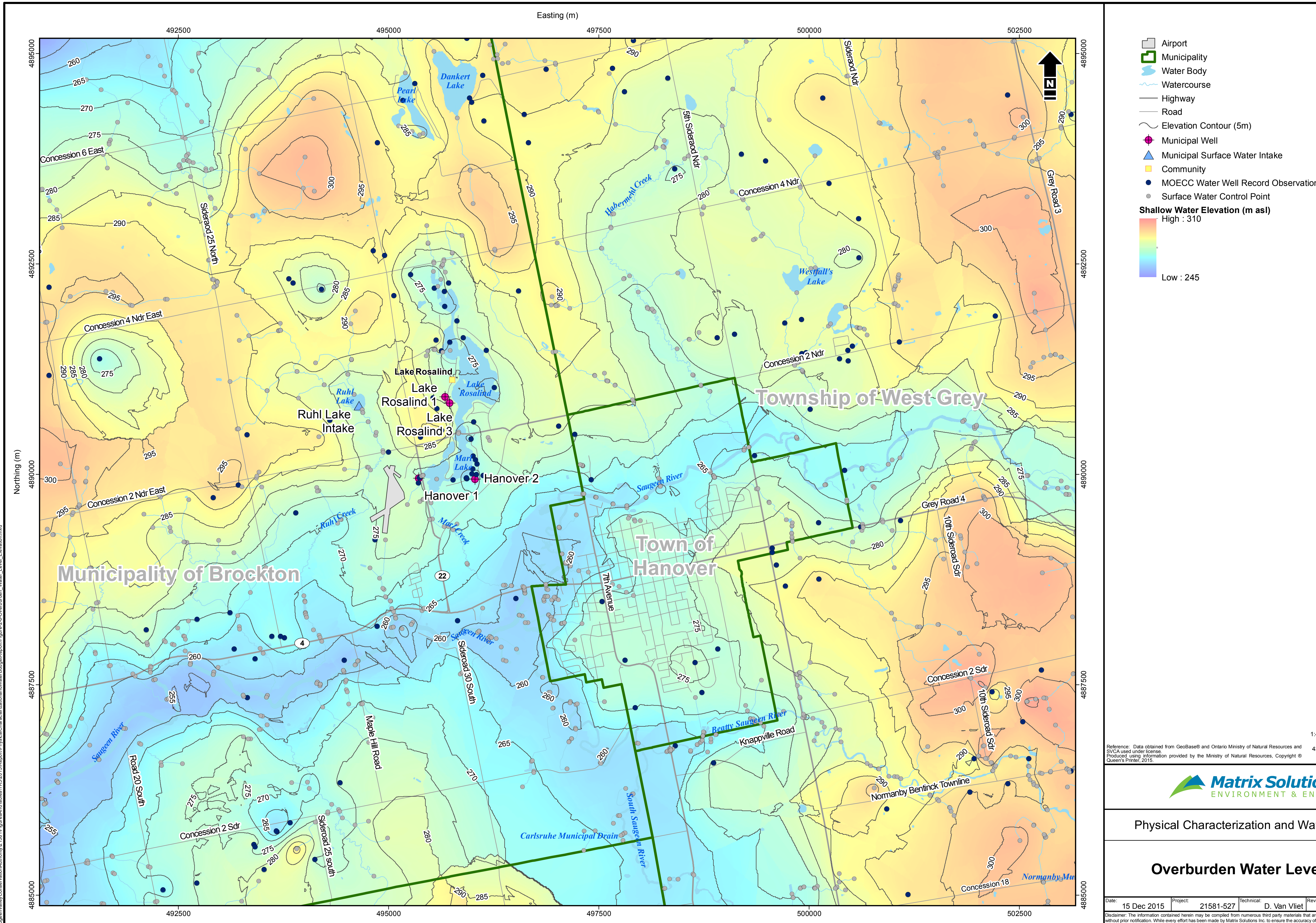
ENVIRONMENT & ENGINEERING

Physical Characterization and Water Budget Report

Hydrostratigraphic Cross Section N-S

Date:	Project:	Technical:	Reviewer:	Drawn:
28 Aug 2015	21581-527	D. Van Vliet	P. Meyer	M. Pfeifer

Figure 2.7



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ENVIRONMENT & ENGINEERING

Physical Characterization and Water Budget Report

Overburden Water Level Elevation

Date:	Project:	Technical:	Reviewer:	Drawn:
15 Dec 2015	21581-527	D. Van Vliet	P. Meyer	C. Curry

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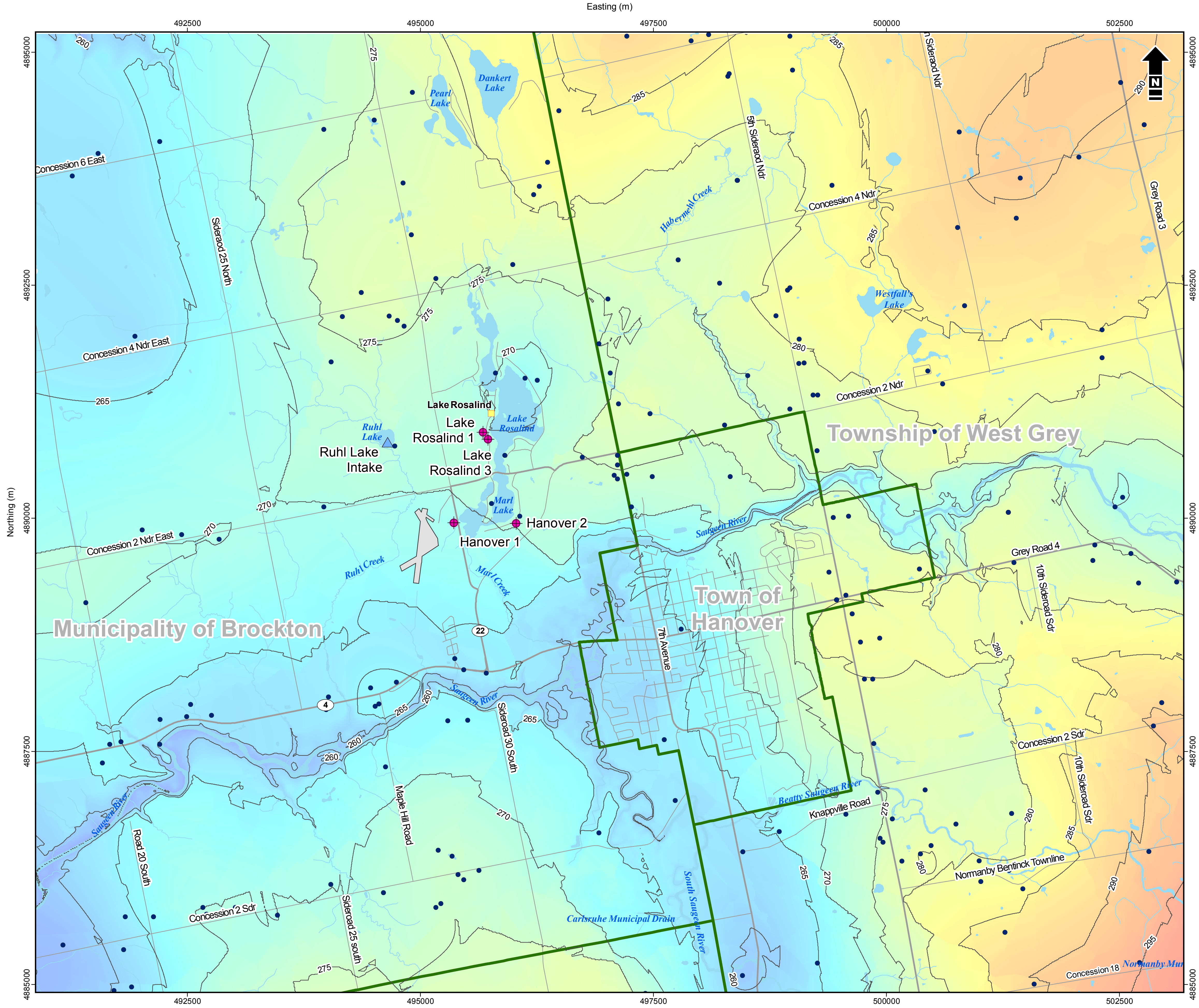
Figure 2.8



Airport
Municipality
Water Body
Watercourse
Highway
Road
Elevation Contour (5m)
Municipal Well
Municipal Surface Water Intake
Community
MOECC Water Well Record Observation

Deep Water Elevation (m asl)
High : 300
Low : 250

1:42,000
430 0 430 860 m
NAD 1983 UTM Zone 17N

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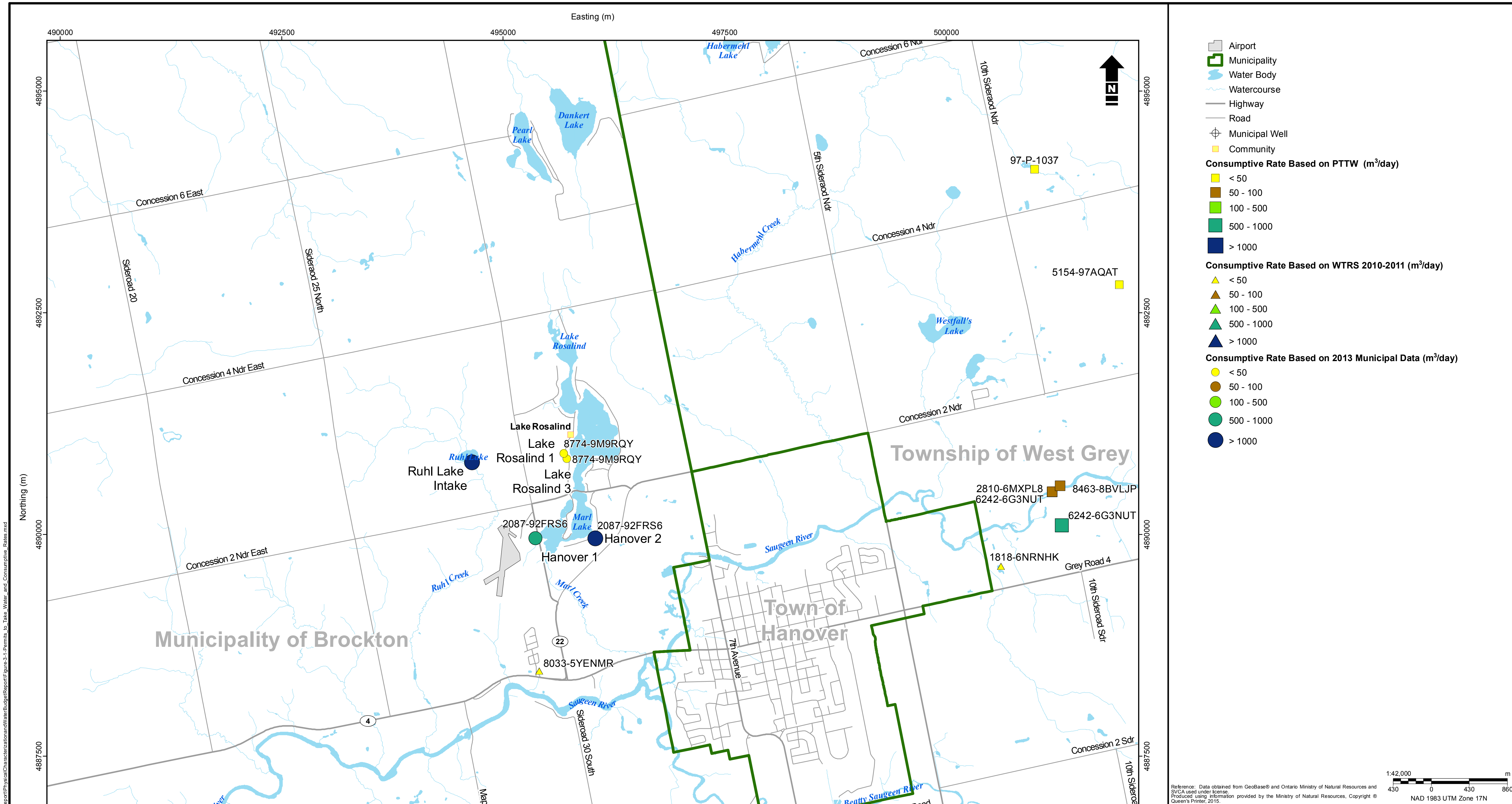
Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Physical Characterization and Water Budget Report

Bedrock Water Level Elevation

Date:	Project:	Technical:	Reviewer:	Drawn:
15 Dec 2015	21581-527	D. Van Vliet	P. Meyer	C. Curry

Figure 2.9



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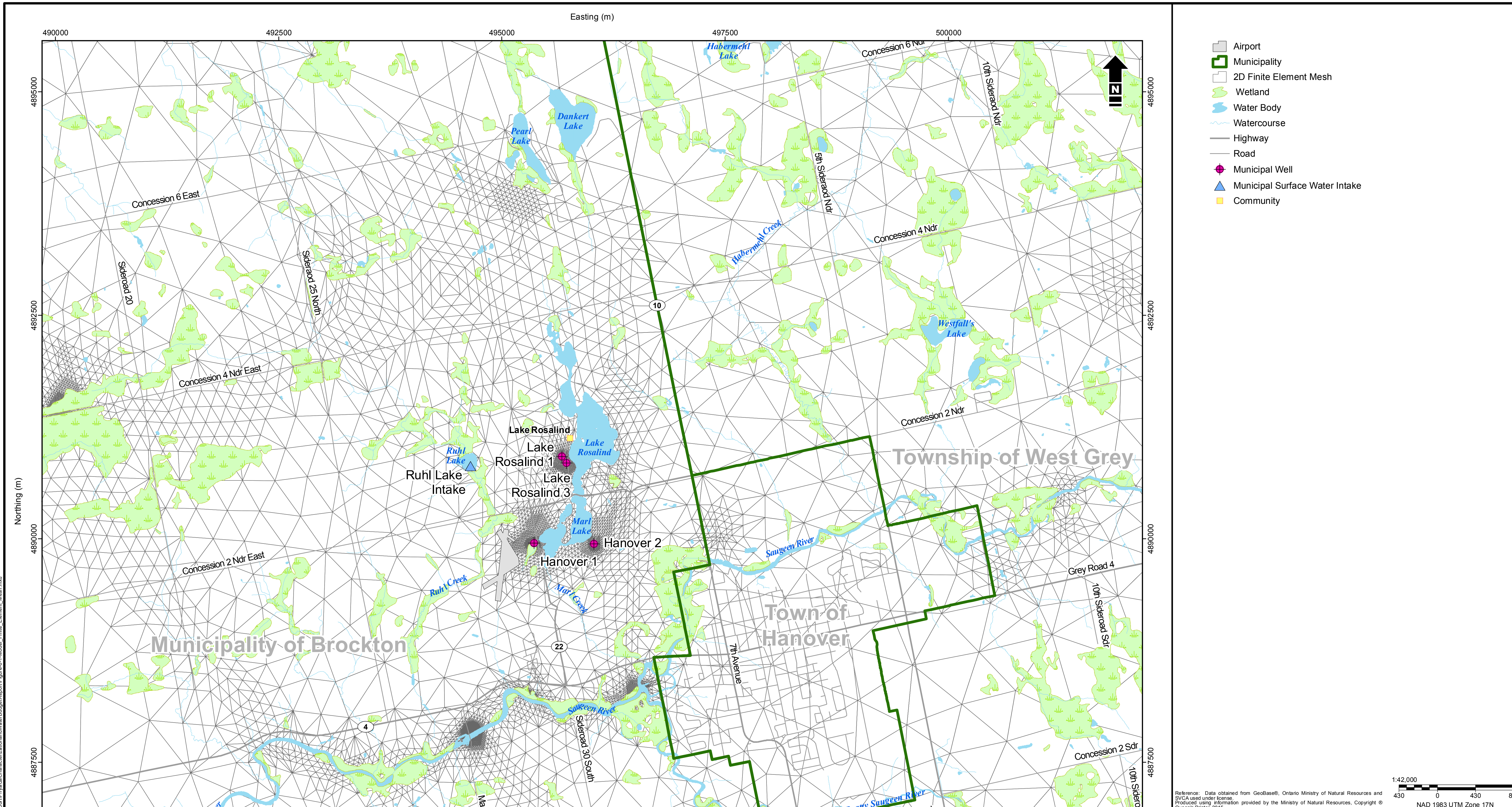
Matrix Solutions Inc. ENVIRONMENT & ENGINEERING

Physical Characterization and Water Budget Report

Permits to Take Water and Consumptive Rates

Date:	Project:	Technical:	Reviewer:	Drawn:
04 Dec 2015	21581-527	D. Van Vliet	P. Meyer	C. Curry

Figure 3.1



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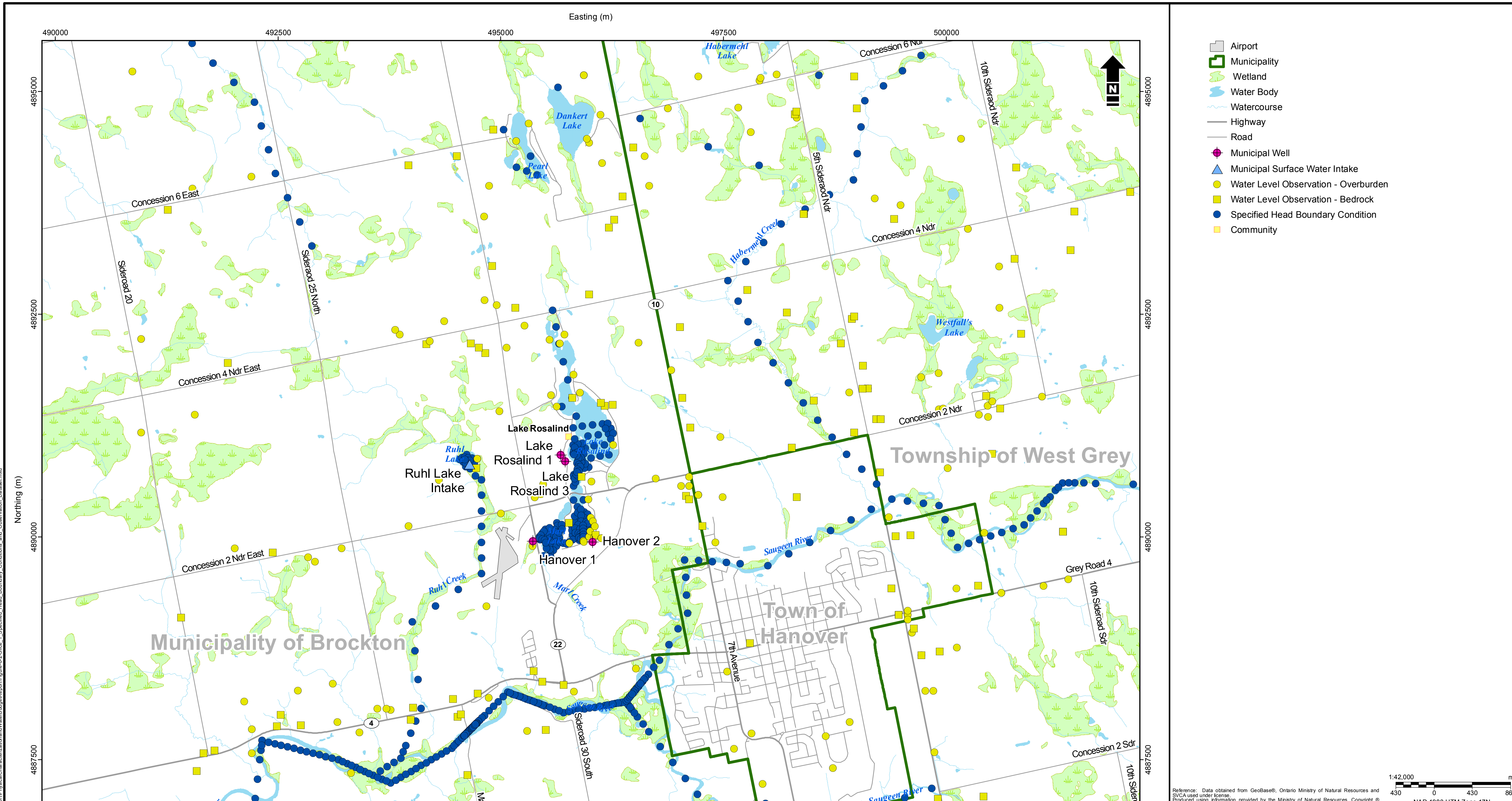
Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Physical Characterization and Water Budget Report

Model Finite Element Mesh

Date:	Project:	Technical:	Reviewer:	Drawn:
11 Sep 2015	21581-527	D. Van Vliet	P. Meyer	M. Pfeifer

Figure 6.1



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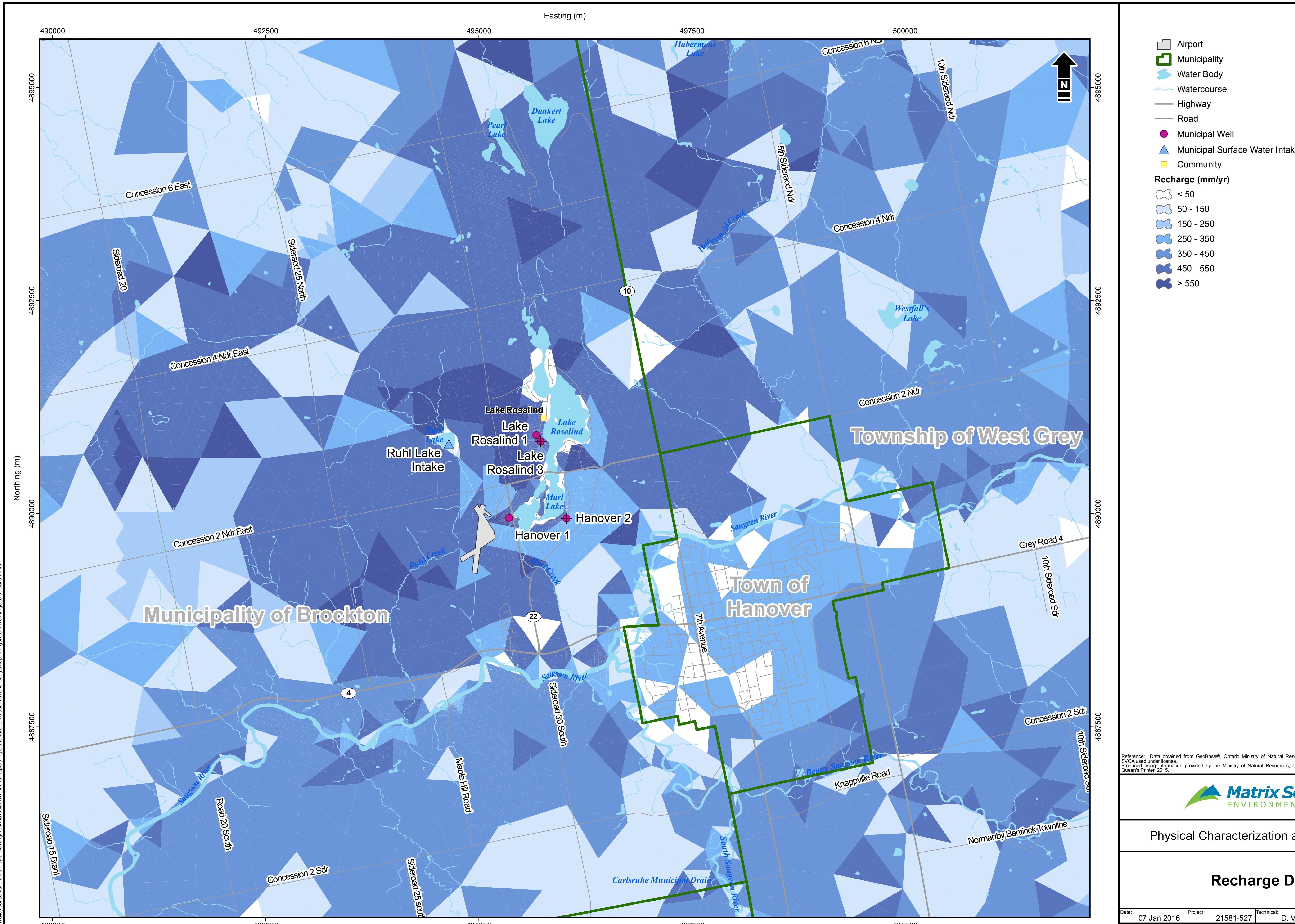
ENVIRONMENT & ENGINEERING

Physical Characterization and Water Budget Report

Slice 1 Specified Head Boundary Conditions and Observation Dataset

Date:	Project:	Technical:	Reviewer:	Drawn:
14 Sep 2015	21581-527	D. Van Vliet	P. Meyer	M. Pfeifer

Figure 6.2



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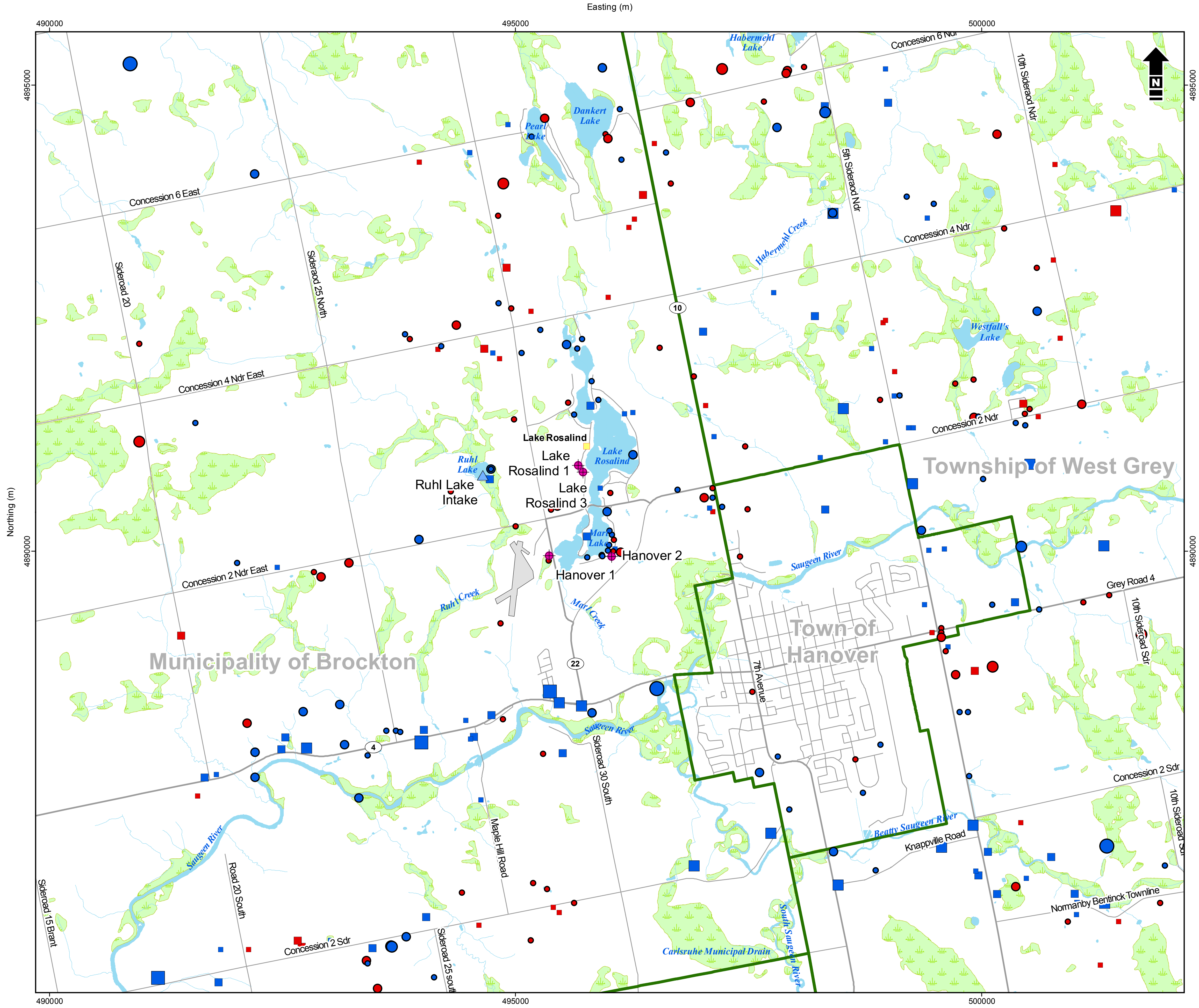
Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Physical Characterization and Water Budget Report

Recharge Distribution

Date:	Project:	Technical:	Reviewer:	Drawn:
07 Jan 2016	21581-527	D. Van Vliet	P. Meyer	M. Pfeifer

Figure 6.3



Airport
Municipality
Wetland
Water Body
Watercourse
Highway
Road
Municipal Well
Municipal Surface Water Intake
Community

Overburden Hydraulic Head Residual (Simulated - Observed) (m)

- > 15
- 10 to 15
- 5 to 10
- 0 to 5
- 0 to -5
- -5 to -10
- -10 to -15
- < -15

Bedrock Hydraulic Head Residual (Simulated - Observed) (m)

- > 15
- 10 to 15
- 5 to 10
- 0 to 5
- 0 to -5
- -5 to -10
- -10 to -15
- < -15

1:42,000
430 0 430 860 m
NAD 1983 UTM Zone 17N

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Matrix Solutions Inc.
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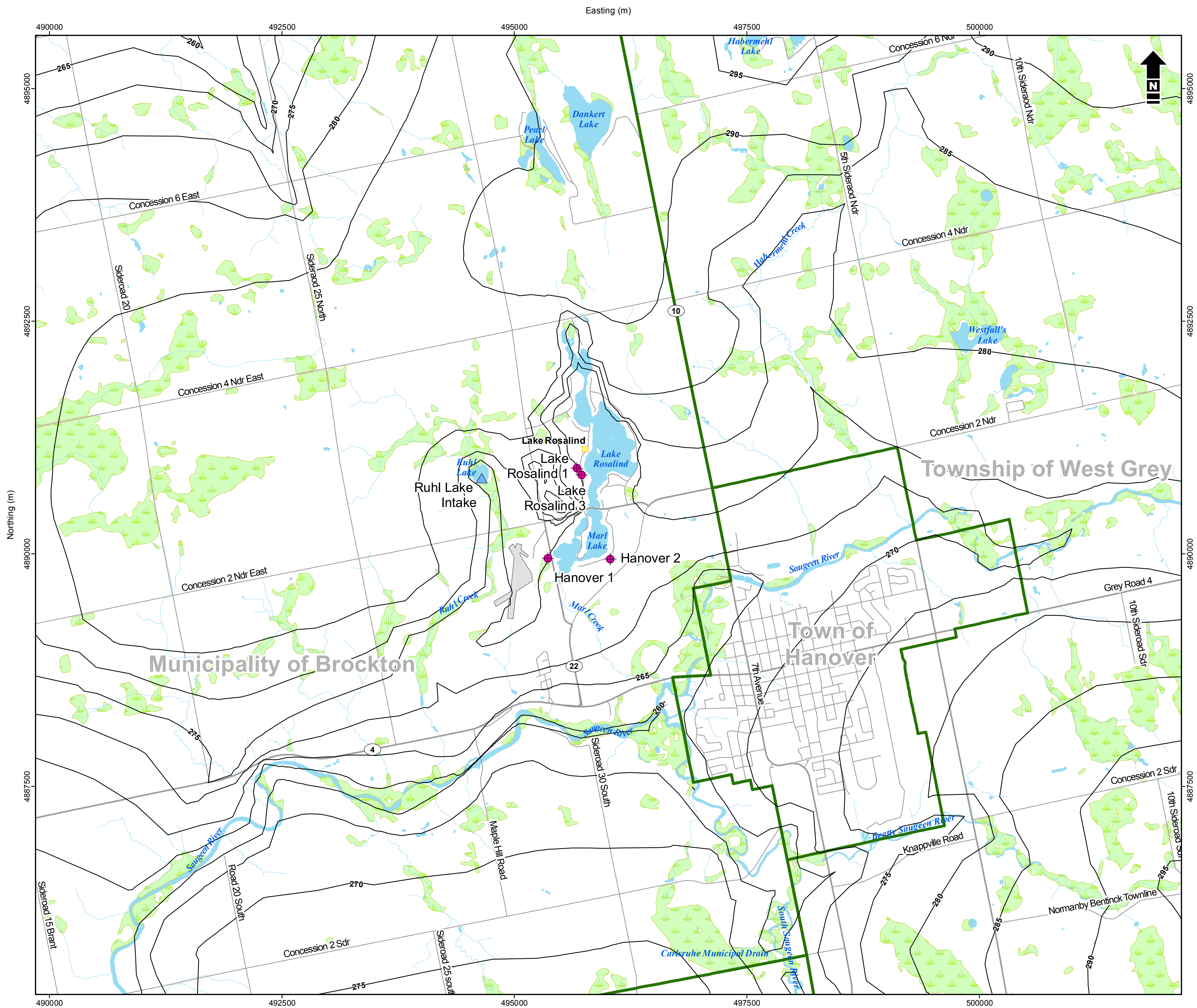
Physical Characterization and Water Budget Report

Plan View of Calibration Residuals

Date:	Project:	Technical:	Reviewer:	Drawn:
16 Sep 2015	21581-527	D. Van Vliet	P. Meyer	M. Pfeifer

Figure 6.4



Airport
Municipality
Wetland
Water Body
Watercourse
Highway
Road
Model Predicted Water Level Elevation Contour (m asl) (5m interval)
Municipal Well
Municipal Surface Water Intake
Community

1:42,000
430 0 430 860 m
NAD 1983 UTM Zone 17N

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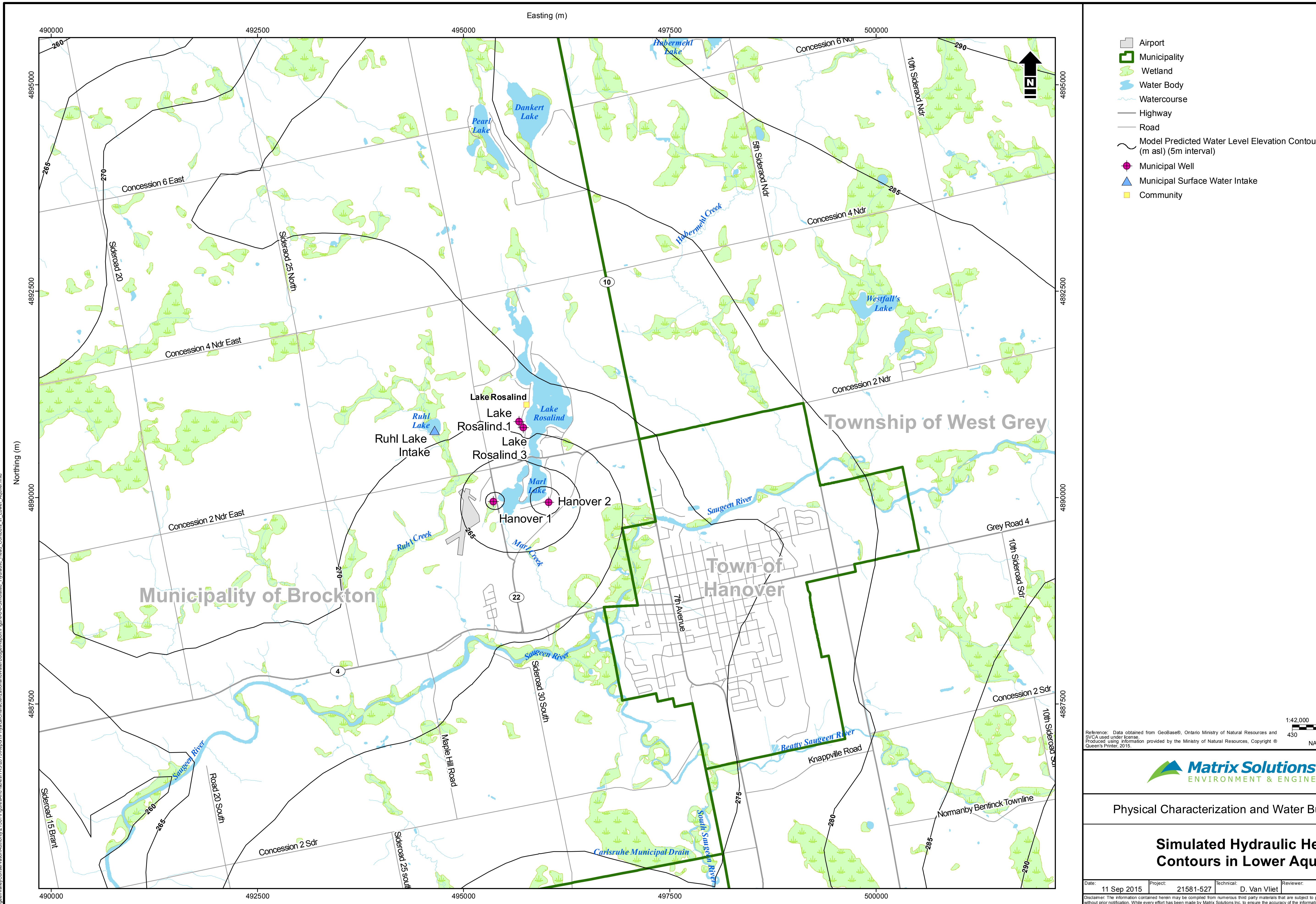
ENVIRONMENT & ENGINEERING

Physical Characterization and Water Budget Report

Simulated Hydraulic Head Contours in Upper Aquifer

Date:	Project:	Technical:	Reviewer:	Drawn:
11 Sep 2015	21581-527	D. Van Vliet	P. Meyer	M. Pfeifer

Figure 6.5



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Physical Characterization and Water Budget Report

Simulated Hydraulic Head Contours in Lower Aquifer

Date:	Project:	Technical:	Reviewer:	Drawn:
11 Sep 2015	21581-527	D. Van Vliet	P. Meyer	M. Pfeifer

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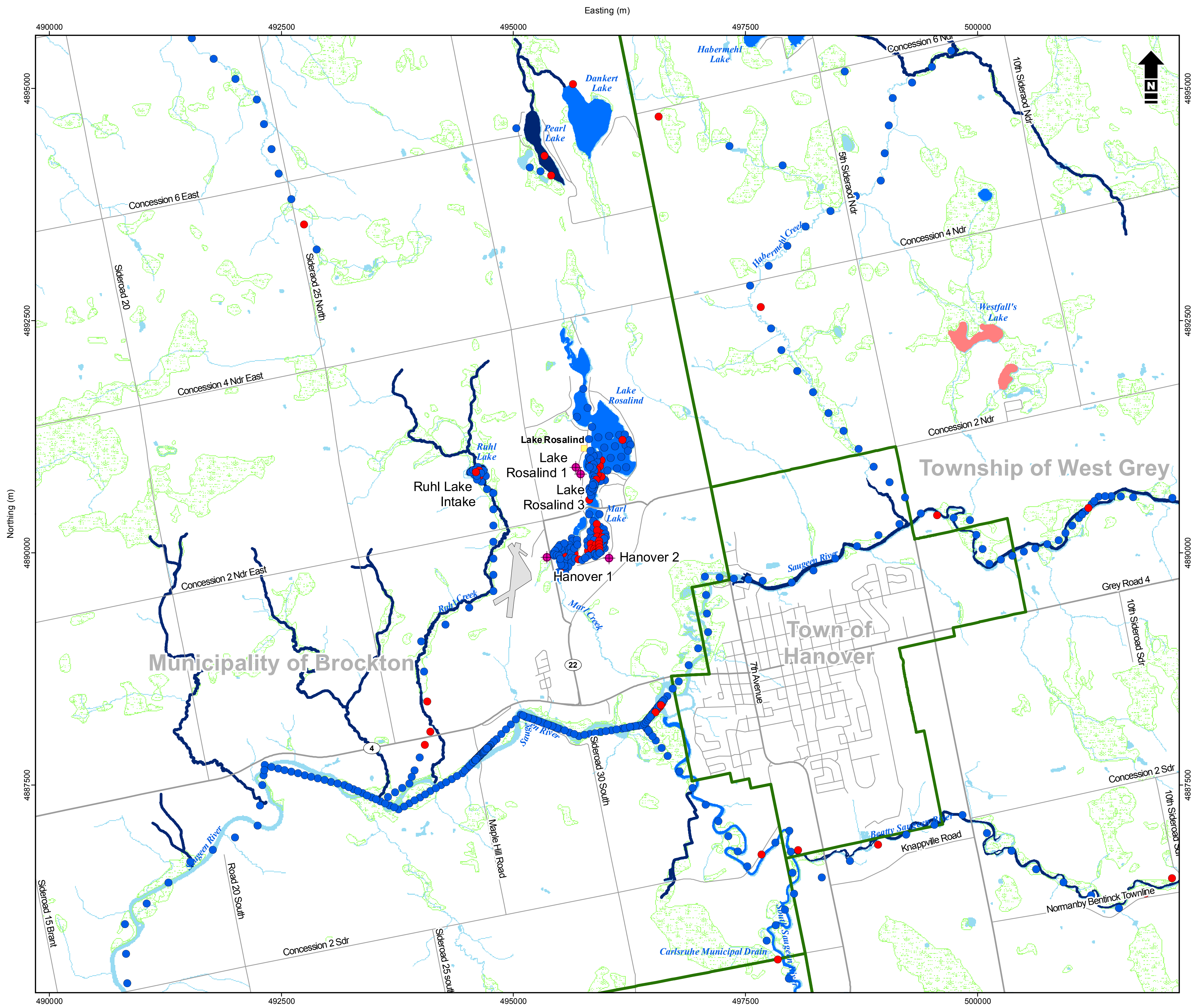
Figure 6.6



Airport
Municipality
Wetland
Cold Water Lake or Stream
Cool Water Lake or Stream
Warm Water Lake or Stream
Unevaluated Water Body
Unevaluated Watercourse
Highway
Road
Municipal Well
Municipal Surface Water Intake
Simulated Gaining Stream or Groundwater Discharge
Simulated Losing Stream or Groundwater Recharge
Community

Reference: Data obtained from GeoBase® and Ontario Ministry of Natural Resources and SVCA used under license.
Evaulated Wetlands: Ministry of Natural Resources, 2003
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1:42,000
430 0 430 860 m
NAD 1983 UTM Zone 17N

Matrix Solutions Inc.
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Physical Characterization and Water Budget Report

Qualitative Baseflow Calibration

Date:	Project:	Technical:	Reviewer:	Drawn:
11 Sep 2015	21581-527	D. Van Vliet	P. Meyer	M. Pfeifer

Figure 6.7

APPENDIX A

Municipal Production Well Logs

17 Z 4 9 5 3 5 0 E

5 R 4 8 8 9 7 3 5 N

E5 R 4 8 9 0

The Ontario Water Resources Commission Act

WATER WELL RECORD

GROUND WATER BRANCH
14 Nº 668
MAY 18 1962
ONTARIO WATER RESOURCES COMMISSION

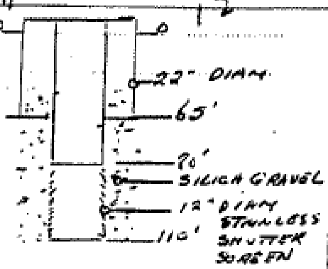
County or District: BRUCE — Township, Village, Town or City: BRANT

Con. II NORTH — Lot 65 — Date completed 29 (day) AUG (month) 196[illegible] (year)

Owner: PUC HANOVER (print in block letters) — Address

Casing and Screen Record

- Inside diameter of casing: 22"
- Total length of casing: 80' of 12"
- Type of screen: 4½ NC
- Length of screen: 30'
- Depth to top of screen: 80'
- Diameter of finished hole: 13"



Pumping Test

- Static level: 8.51'
- Test-pumping rate: 700 G.P.M.
- Pumping level: 41.83'
- Duration of test pumping: 72 HRS.
- Water clear or cloudy at end of test: CLEAR
- Recommended pumping rate: 700 G.P.M.
- with pump setting of 65' feet below ground surface

Well Log

Overburden and Bedrock Record	From ft.	To ft.	Depth(s) at which water(s) found	Kind of water (fresh, salty, sulphur)
CLAY & SAND	0'	6'		
SAND	6'	13'	6'	
CLAY & SILT	13'	25'		
CLAY	25'	34'		
SAND & GRAVEL	34'	50'	34'	FRESH
GRAVEL & SAND	50'	55'		
SAND & GRAVEL	55'	68'		
GRAVEL, SAND & BOULDERS	68'	71'		
GRAVEL & SAND	71'	74'		
PACKED SAND	74'	78'		
SAND & GRAVEL & BOULDERS SAND GRAVEL CLAY	78'	110'		

For what purpose(s) is the water to be used? Municipal Supply

Is well on upland, in valley, or on hillside?

Drilling or Boring Firm: INTERNATIONAL WATER SUPPLY LTD.

Address: 12 MAITLAND ST. LONDON, ONT. (Box 816)

Licence Number

Name of Driller or Borer: L. E. C[illegible]

Address

(Signature of Licensed Drilling or Boring Contractor)

7 5M-61-3852

RC COPY

Location of Well #1

In diagram below show distances of well from road and lot line. Indicate north by arrow.

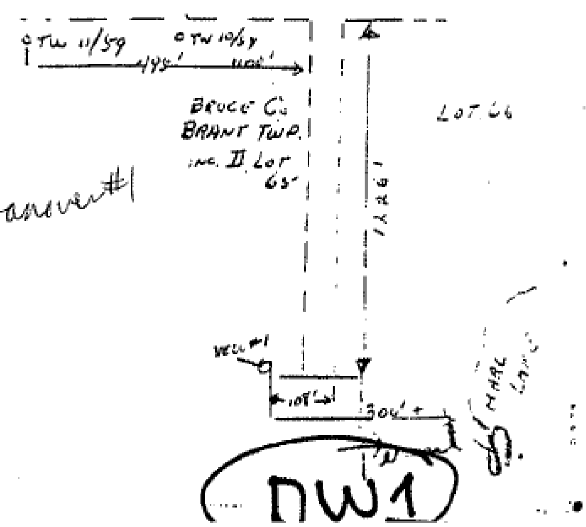


FIGURE A.1 Hanover Well 1

Ministry of the Environment
Ontario

The Ontario Water Resources Act

WATER WELL RECORD

1. PRINT ONLY IN SPACES PROVIDED
2. CHECK ☒ CORRECT BOX WHERE APPLICABLE

11 1406414

County or District	Township/Borough, City, Town, Village	Con., Block, Tract, Survey etc.	Lot
BRUCE	BRANT	II North Durham Rd	69

Owner (Surname First)	Address	Date Completed
Town of Hanover	Hanover Ontario	Day 26 Mo. 5 Yr. 86

LOG OF OVERBURDEN AND BEDROCK MATERIALS (SEE INSTRUCTIONS)

General Colour	Most Common Material	Other Materials	General Description	Depth - Feet From	To
	topsoil			0	2
Brown	clay	sandy		2	8
	Sand fn			8	25
Brown	clay	sandy, strks of sand		25	69
Grey	clay	sandy, strks of sand		69	105
	Sand, Gravel	Boulders, some clay,		105	122
	clay	sandy & Gravel		122	141
	Gravel Sand	MC		141	180

41 WATER RECORD

Water Found at - Feet	Kind of Water
140-180	☑ Fresh

51 CASING & OPEN HOLE RECORD

Inside Diam. Inches	Material	Wall Thickness Inches	Depth - Feet From	To
24	Steel	.375	+2.5	142
12		.375	+2.5	144

SCREEN

Slot No.	Diameter	Length
20 slot	12	36

Material and Type: stainless steel — Depth to Top of Screen: 143 feet

61 PLUGGING & SEALING RECORD

Depth Set at - Feet From	To	Material and Type
4	137	Cement Grout.

71 PUMPING TEST

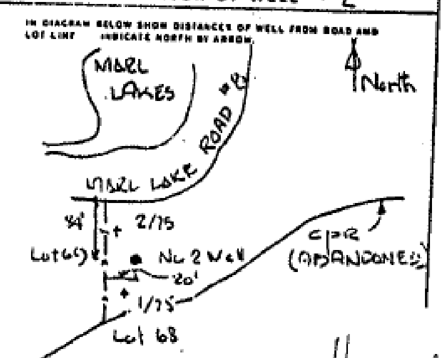
Pumping Test Method	Pumping Rate	Duration of Pumping
☑ Pump	702 GPM	72 Hours

Static Level	Water Level End of Pumping	15 Minutes	30 Minutes	45 Minutes	60 Minutes
31.53	90.91	80.7	84.15	86.35	95.66

Water at end of test: ☑ Clear

LOCATION OF WELL #2

In diagram below show distances of well from road and lot line. Indicate north by arrow.



Hanover #2

FINAL STATUS OF WELL	☑ Water Supply
WATER USE	☑ Public Supply
METHOD OF DRILLING	☑ Rotary (Conventional)

CONTRACTOR

Name of Well Contractor: International Water Supply — Licence Number: 2801

Address: P.O. Box 310 Barrie Ont.

Name of Well Driller or Boxer: K. McAgee

Signature of Contractor: D. Wall — Submission Date: Day 14 Mo. 7 Yr. 86

OFFICE USE ONLY — DW2

MINISTRY OF THE ENVIRONMENT COPY

FIGURE A.2 Hanover Well 2

WATER WELL ᴅ. .A SYSTEM Aug 13 1998 PAGE: 139 COUNTY: ᴣRUCE GROUND .TER BULLETIN REPORT

MUNICIPALITY CONCESSION ETC	LOT	WELL NO	UTM EASTING NORTHING	ELEV FEET	DATE	DRILLER	CSG DIA INS	KIND OF WATER	WATER FOUND FEET	STAT LVL FEET	PUMP LVL FEET	TEST RATE GPM	TEST TIME HR:MN	WATER USE	SCREEN DEPTH FEET	SCREEN LENGTH FEET	OWNER / DEPTHS IN FEET TO WHICH FORMATIONS EXTEND
CONTINUING... BRANT TOWNSHIP																	
DR N 03	066	14- 08781	999999 9999999		1995/06		36	FR	0030	4			:	DO			WEDOW, BREN BRWN LOAM 0001 BRWN CLAY SNDY 0004 BRWN CSND 0008 BLUE CLAY SILT LYRD 0035
DR N 03	067	14- 06589	495550 4890690	950	1987/04	1737							:	NU			TOWNSHIP OF BRANT BRWN FILL SOFT 0002 BRWN SAND SILT SOFT 0011 GREY FSND SOFT 0016 GREY CLAY SAND LYRD 0048 GREY CLAY SILT SOFT 0080
DR N 03	067	14- 06542	495525 4890520	950	1987/02	1737	01	FR	0141				1 :0	NU	0136	03	TOWNSHIP OF BRANT BRWN SILT CLAY 0012 BRWN SAND SILT FGRD 0018 GREY CLAY SILT MARL 0061 GREY SAND SILT FGRD 0076 GREY CLAY SILT FGRD 0099 GREY SAND CLAY FGRD 0136 GREY HPAN STNS GRVL 0171 GREY SHLE LMSN SOFT 0181
DR N 03	067	14- 06543	495650 4890410	950	1987/02	1737							:	NU			TOWNSHIP OF BRANT LOAM 0001 BRWN SAND CLAY SILT 0026 BRWN FSND SOFT 0037 BRWN CLAY SILT SOFT 0044 BRWN MSND CSND SOFT 0048 BRWN SAND CLAY FGRD 0064 GREY CLAY SILT SAND 0123 GREY SAND CLAY FGRD 0142 GREY HPAN GRVL STNS 0146 GREY HPAN SAND MGRD 0162 GREY MSND SOFT 0164 GREY LMSN SHLE MGRD 0174
DR N 03	067	14- 06544	495620 4890300	950	1987/03	1737	06	FR	0057	3	37	30	24:0	MN	0046 0046	07 07	TOWNSHIP OF BRANT BRWN SAND SILT FGRD 0047 BRWN FSND CSND 0057 BRWN SAND SILT FGRD 0063 GREY CLAY SILT SOFT 0066
DR N 03	067	14- 06588	495560 4890555	950	1987/04	1737	08	FR	0060	3		70	48:0	MN	0047 0047	12 12	TOWNSHIP OF BRANT BRWN FSND SILT SOFT 0008 BRWN MSND SOFT 0010 BRWN FSND SILT SOFT 0023 BRWN MSND SOFT 0039 BRWN CLAY SILT SOFT 0044 BRWN MSND SOFT 0058 BRWN MSND SILT SOFT 0071 GREY CLAY SILT SOFT 0075 ← TW 5
DR N 03	068	14- 06304	495700 4890450	875	1985/10	1804	06	FR	0193	32	33	20	7 :0	DO			SHENCK JACK GREY CLAY STNS 0022 GREY CLAY MARL 0066 GREY HPAN STNS GRVL 0173 GREY ROCK 0193
DR N 03	069	14- 04092	495890 4890450	900	1976/03	1804	05	FR	0170	15	30	15	3 :30	DO			GRYGAS WINNIFRED BRWN FILL 0002 BRWN CLAY STNS SAND 0020 BRWN CLAY 0090 GREY SAND 0168 BRWN CGVL 0172
DR N 03	069	14- 06303	496000 4890400	850	1985/10	1804	06	FR	0185	16	18	20	7 :0	DO			KOENIG LORNE BRWN SAND CLAY 0012 BRWN CLAY CLAY 0122 BRWN STNS GRVL 0180 GREY ROCK 0185
DR N 03	069	14- 07258	495966 4890197	930	1989/09	1804	05	FR	0160	44	94	6	2 :20	DO	0156	04	CHARRON RON BRWN SAND 0040 BRWN SAND CLAY 0148 BRWN GRVL 0160
DR N 03	069	14- 00730	496040 4890300	926	1967/04	2801	06						:				HANOVER PUC LOAM 0001 FSND LOAM 0014 SNDS CLAY MSND 0025 FSND SILT 0041 CLAY SILT 0143 CLAY GRVL 0147 GRVL CLAY MSND 0190 LMSN 0191
DR N 03	071	14- 02191	496240 4891260	940	1968/12	1804	04	FR	0152	30	65	15	2 :0	DO			HARTMAN BERNIE MSND 0030 GREY CLAY 0060 CLAY MSND 0100 QSND 0120 CLAY MSND 0146 GREY LMSN 0159
DR N 03	071	14- 03604	496109 4891281	900	1974/09	1804	06	SU	0220	150	200	4	2 :0	DO			COSTIC D RED CLAY 0130 BLUE SHLE 0200 BRWN ROCK 0226
DR N 03	071	14- 04091	496240 4890850	900	1976/04	1804	05	FR	0140	FLW		25	2 :20	DO			MULLEN LORNE BRWN FILL 0002 BRWN SAND MARL 0050 BRWN SAND GRVL CLAY 0120 BLUE SHLE SOFT 0128 BLCK ROCK 0148
DR N 03	071	14- 05247	496150 4891250	950	1979/10	1804	05	FR	0134	10	50	8	3 :30	ST DO			OSTHOFF P GREY MARL 0081 BRWN SAND 0128 GREY STNS SOFT 0134

FIGURE A.3 Lake Rosalind Well 3 (Circled as TW5; BMROSS 2000)

APPENDIX B

Permitted Water Takings in Study Area

Permit #	Client	Easting	Northing	Interpreted Bottom of Screen Elevation (m)	Interpreted Geologic Unit	Purpose	Specific Purpose	Maximum Permitted Taking (m^3/d)	Maximum Permitted Taking Days/Year	Maximum Permitted Average Annual Rate (m^3/d)	Consumptive Rate Factor	Source	Tier Three Applied Rate (m^3/d)	Tier 3 Data Source
1818-6NRNHK	1293426 Ontario Limited	500616	4889640	252.02	Contact zone	Commercial	Golf Course Irrigation	1,023.3	120	336.4	0.85	GW	20.1	WTRS Values from 2010-2011 database
6242-6G3NUT	Georgian Aggregates and Construction Ltd.	501305	4890101	274.98	Upper Aquifer	Industrial	Aggregate Washing	5,727.9	220	3,452.5	0.15	GW	517.9	Consumptive use rate multiplied by maximum annual average taking
6242-6G3NUT	Georgian Aggregates and Construction Ltd.	501193	4890480	265.94	Upper Aquifer	Industrial	Aggregate Washing	681.9	220	411.0	0.15	GW	61.7	Consumptive use rate multiplied by maximum annual average taking
5154-97AQAT	E.C. King Contracting a Division of Miller Paving Limited	501951	4892817	281.12	Upper Aquifer	Industrial	Manufacturing	160	365	160.0	0.13	GW	20.8	Consumptive use rate multiplied by maximum annual average taking
2810-6MXPL8	Cedarwell Excavating Ltd.	501193	4890480	N/A	N/A	Industrial	Aggregate Washing	681.9	220	411.0	0.15	SW	61.7	Consumptive use rate multiplied by maximum annual average taking
6242-6G3NUT	Georgian Aggregates and Construction Ltd.	501193	4890480	N/A	N/A	Industrial	Aggregate Washing	681.9	220	411.0	0.15	SW	61.7	Consumptive use rate multiplied by maximum annual average taking
8463-8BVLJP	Cedarwell Excavating Ltd.	501283	4890551	267.89	Upper Aquifer	Industrial	Aggregate Washing	681.9	220	411.0	0.15	SW	61.7	Consumptive use rate multiplied by maximum annual average taking
97-P-1037	Ducks Unlimited Canada	500995	4894117	N/A	N/A	Miscellaneous	Wildlife Conservation	3,240	365	3,240.0	0	SW	0.0	Consumptive use rate multiplied by maximum annual average taking
8033-5YENMR	Country Village Mobile Home Park	495405	4888459	251.41	Upper / Lower Aquifer	Water Supply	Campgrounds	177.1	365	177.1	0.12	GW	6.3	WTRS Values from 2010-2011 database
2087-92FRS6	The Corporation of the Town of Hanover	495357	4889953	241.47	Lower Aquifer	Water Supply	Municipal	4,546	365	4,546.0	1	GW	1,034.5	WTRS Values from 2010-2011 database
2087-92FRS6	The Corporation of the Town of Hanover	496027	4889944	225.24	Lower Aquifer	Water Supply	Municipal	4,582.3	365	4,582.4	1	GW	1,169.9	WTRS Values from 2010-2011 database
8774-9M9RQY	The Corporation of the Municipality of Brockton	495724	4890848	274.03	Upper Aquifer	Water Supply	Municipal	110.6	365	110.6	1	GW	6.2	WTRS Values from 2010-2011 database
8774-9M9RQY	The Corporation of the Municipality of Brockton	495670	4890922	260.72	Upper Aquifer	Water Supply	Municipal	30.2	365	30.2	1	GW	20.3	WTRS Values from 2010-2011 database

APPENDIX B
Selection of Appropriate WHPA-Q1 Drawdown Contour

APPENDIX B

SELECTION OF APPROPRIATE WHPA-Q1 DRAWDOWN CONTOUR

The municipal drinking water wells in the communities of Hanover and Lake Rosalind are completed within overburden aquifers. To select an appropriate drawdown contour for delineation of the WHPA-Q1, water level fluctuations were estimated through review of long-term hydrographs from monitoring wells completed within the shallow to intermediate overburden. The overburden wells are part of the monitoring well network that lie upgradient of the Hanover-Walkerton Landfill site located 1 km south-southeast of the municipal wells. These wells were chosen as the observed water level fluctuations are interpreted to not be impacted by the cycling on and off of municipal wells, and the hydrostratigraphy in the Landfill area is comparable to that at the municipal wells. Water level data from 12 monitoring wells were plotted and reviewed (**Chart B1** through **Chart B12**).

The average annual water level fluctuation for the 12 wells was 1.8 m, and ranged from 0.9 m at OW22-5 to 3.8 m at OW27-69. Based on this a representative natural water level fluctuation of 2.0 m was selected for use in the delineation of the WHPA-Q1 area.

CHART B1 Water Level Fluctuations at well OW10-16

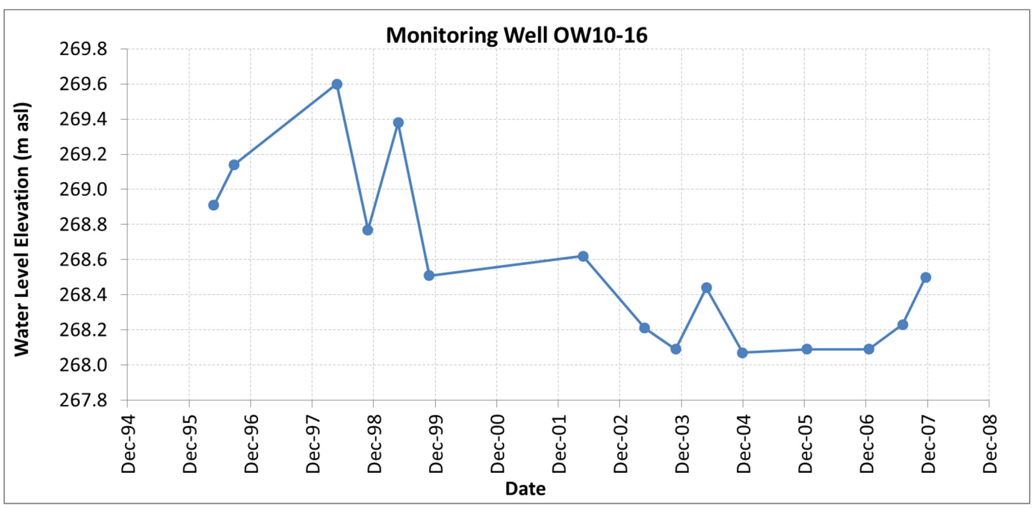


CHART B2 Water Level Fluctuations at well OW11-9

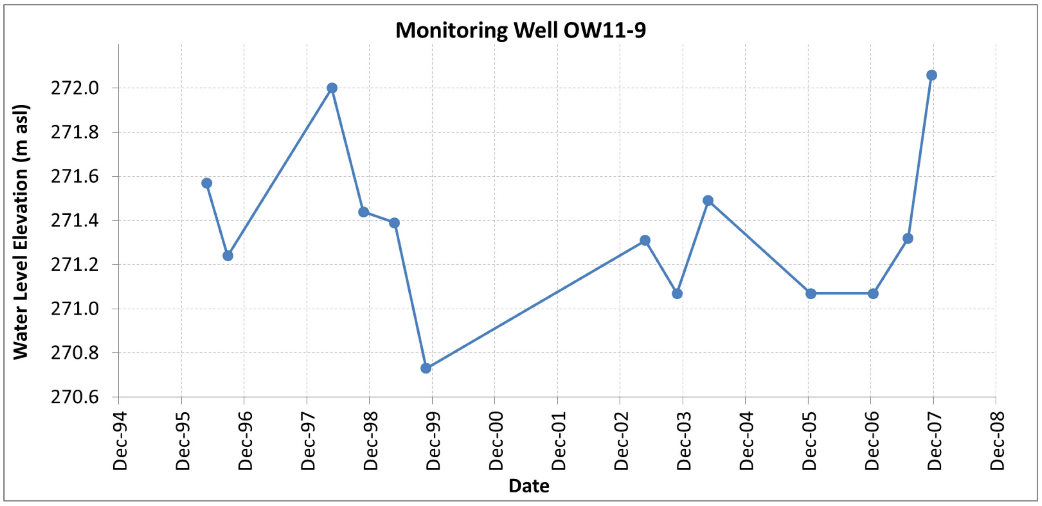


CHART B3 Water Level Fluctuations at well OW12-12

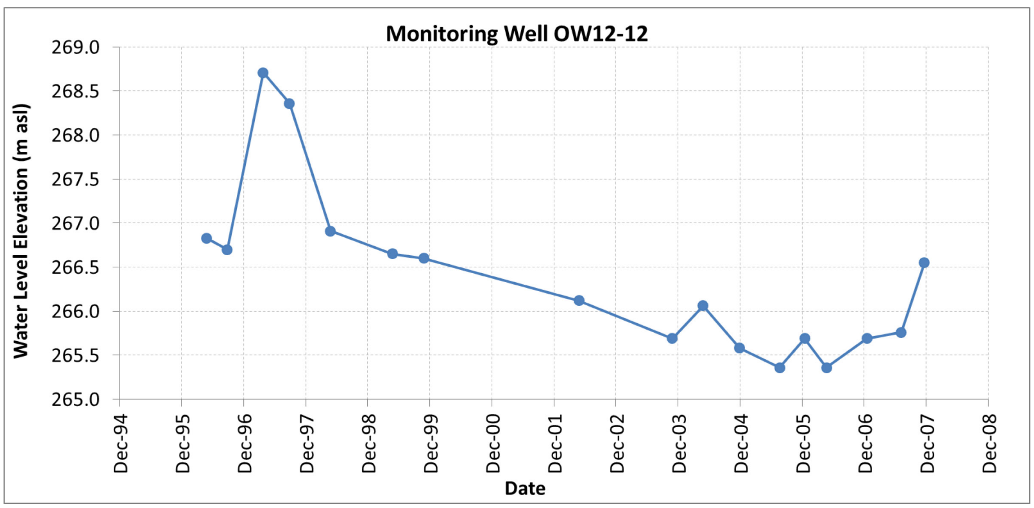


CHART B4 Water Level Fluctuations at well OW13-8

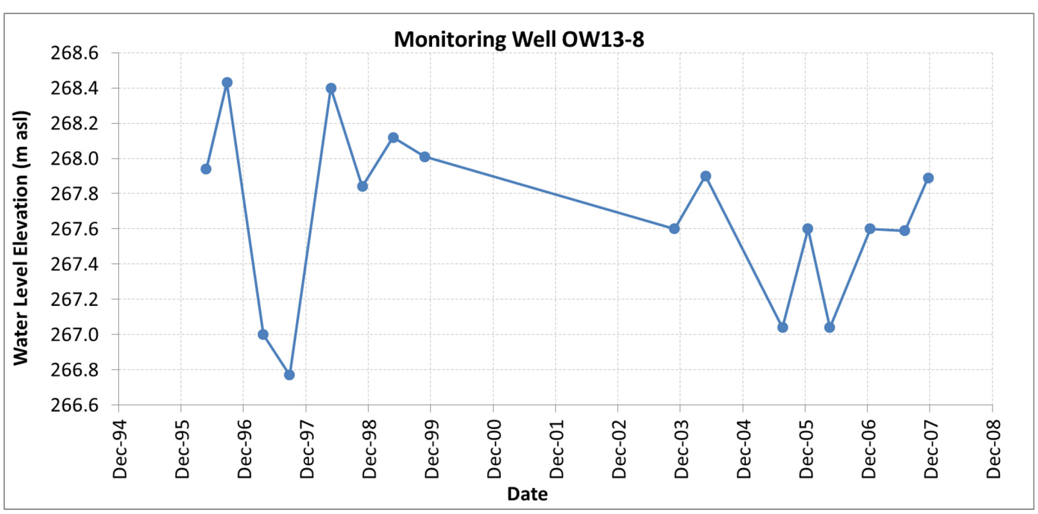


CHART B5 Water Level Fluctuations at well OW16-12

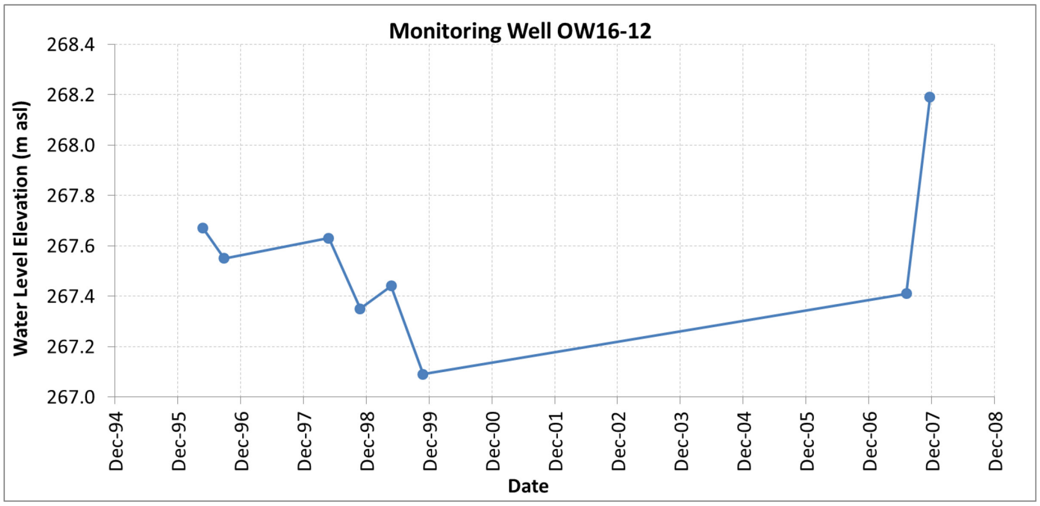


CHART B6 Water Level Fluctuations at well OW22-5

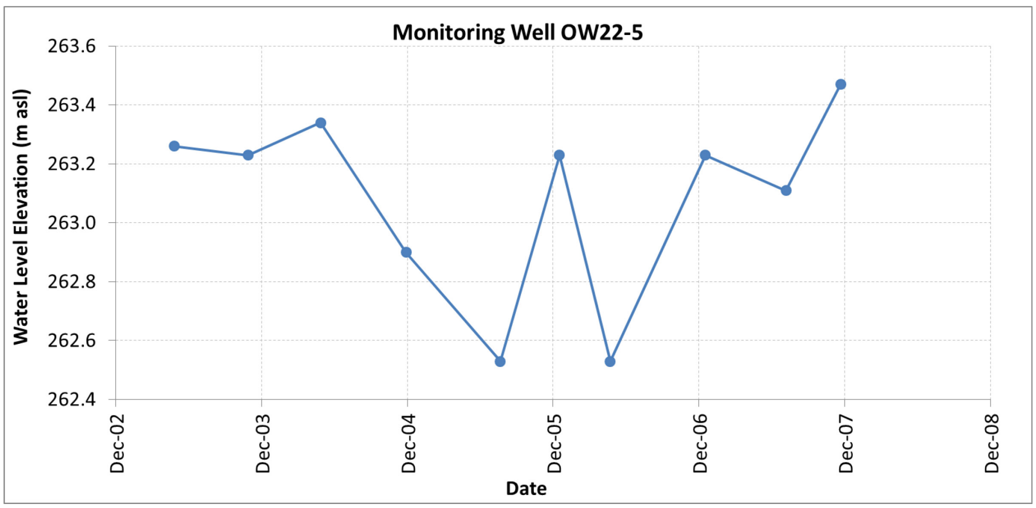


CHART B7 Water Level Fluctuations at well OW22-9

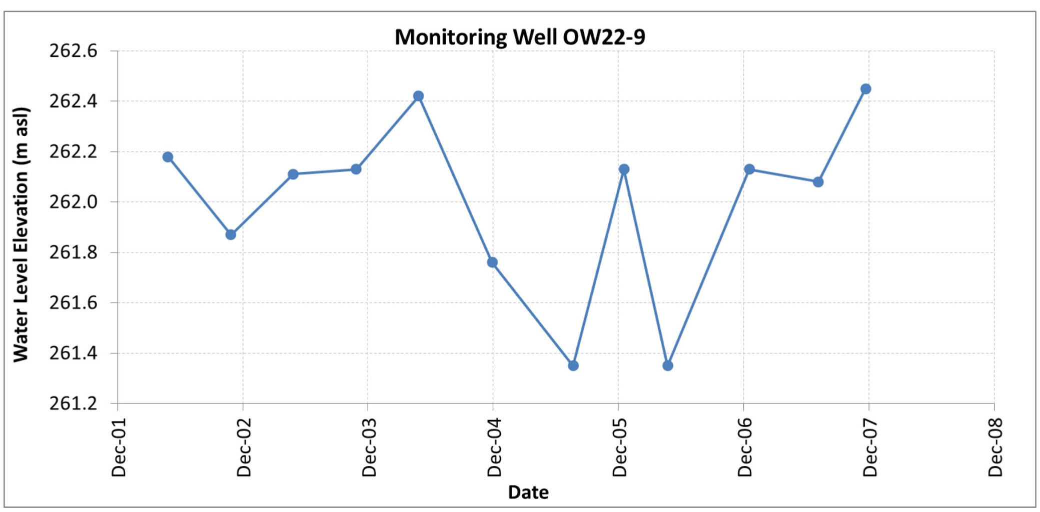


CHART B8 **Water Level Fluctuations at well OW26-11**

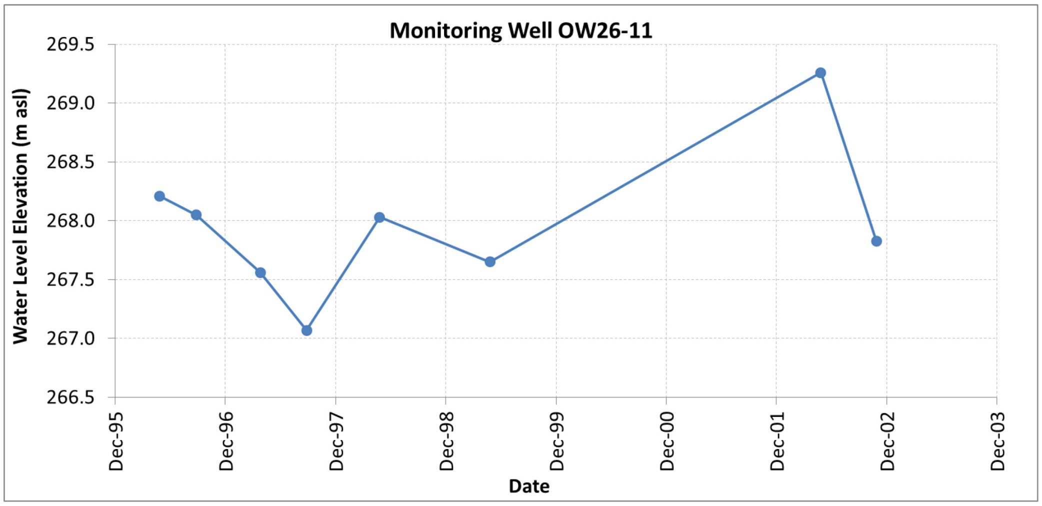


CHART B9 **Water Level Fluctuations at well OW26-14**

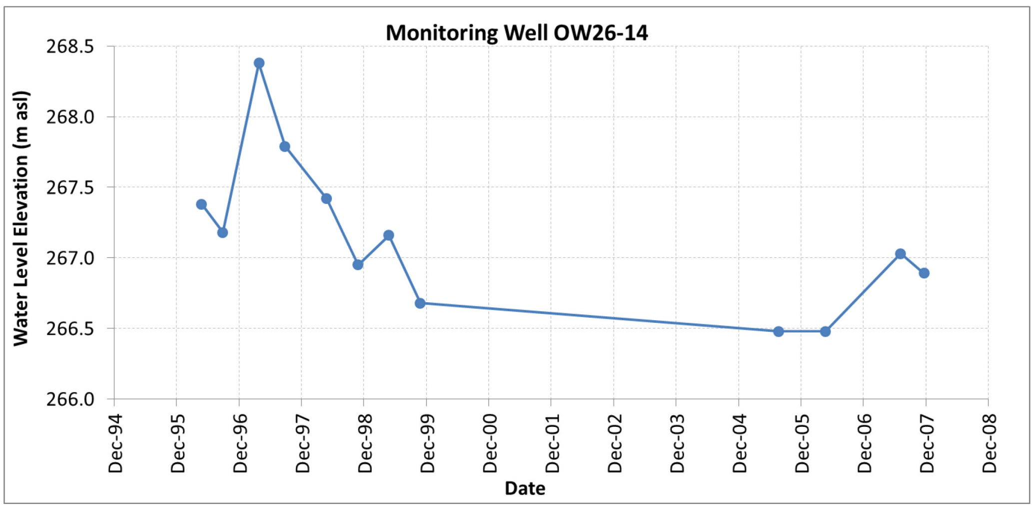


CHART B10 **Water Level Fluctuations at well OW27-69**

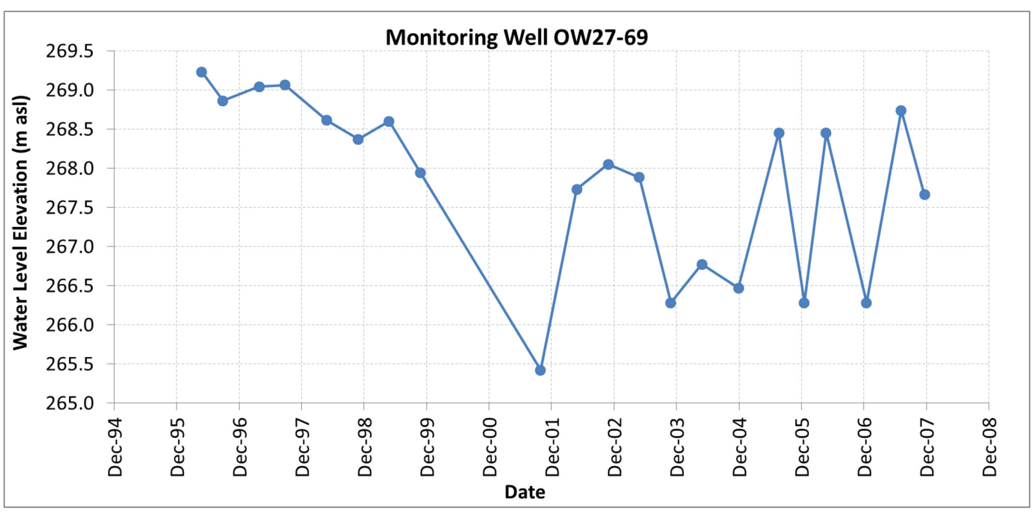


CHART B11 Water Level Fluctuations at well OW28-8

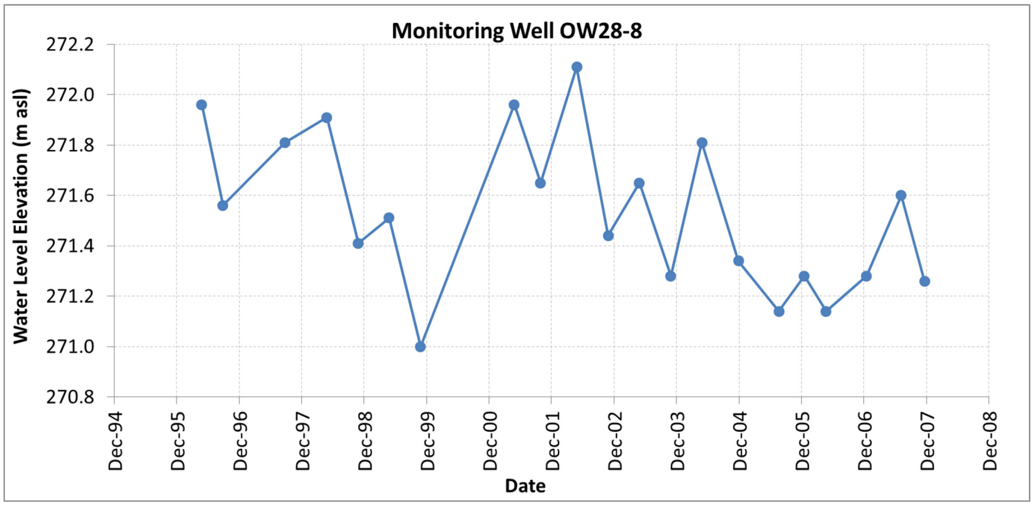
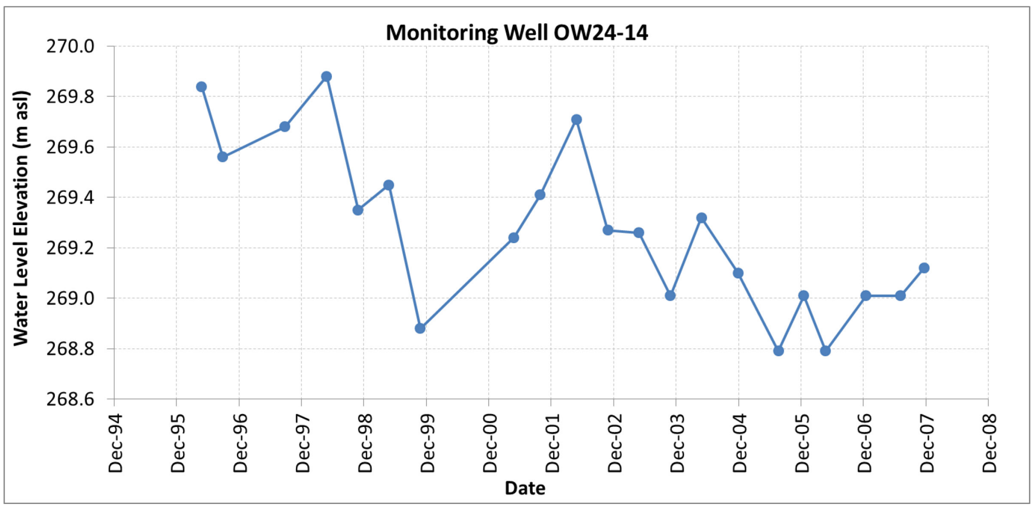
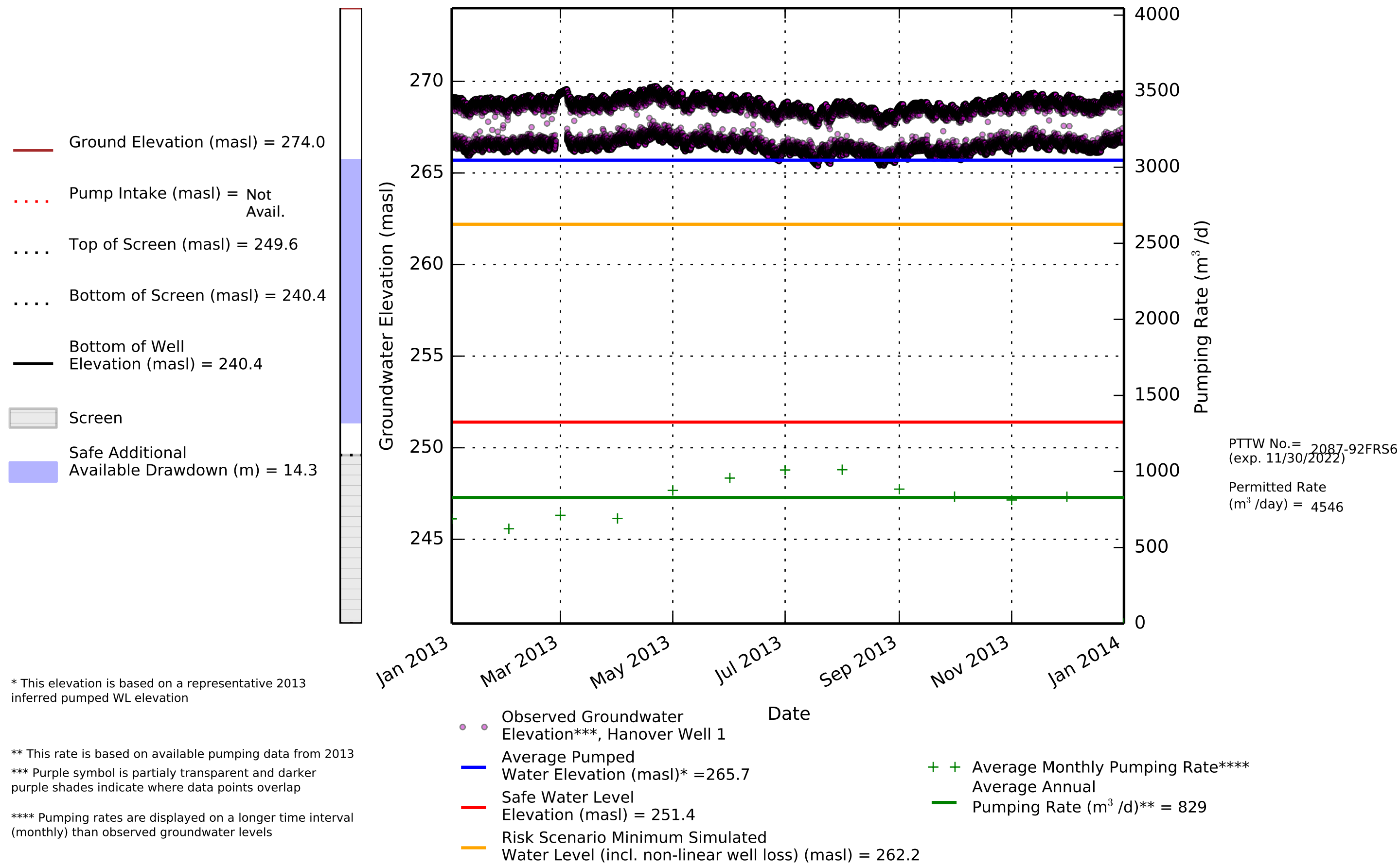


CHART B12 Water Level Fluctuations at well OW24-14



APPENDIX C
Municipal Wells and Intake – Summary Hydrographs

HYDROGRAPH
City/Town: Hanover / Well Field: Well 1 / Well Name: Hanover Well 1



* This elevation is based on a representative 2013 inferred pumped WL elevation

** This rate is based on available pumping data from 2013

*** Purple symbol is partialy transparent and darker purple shades indicate where data points overlap

**** Pumping rates are displayed on a longer time interval (monthly) than observed groundwater levels

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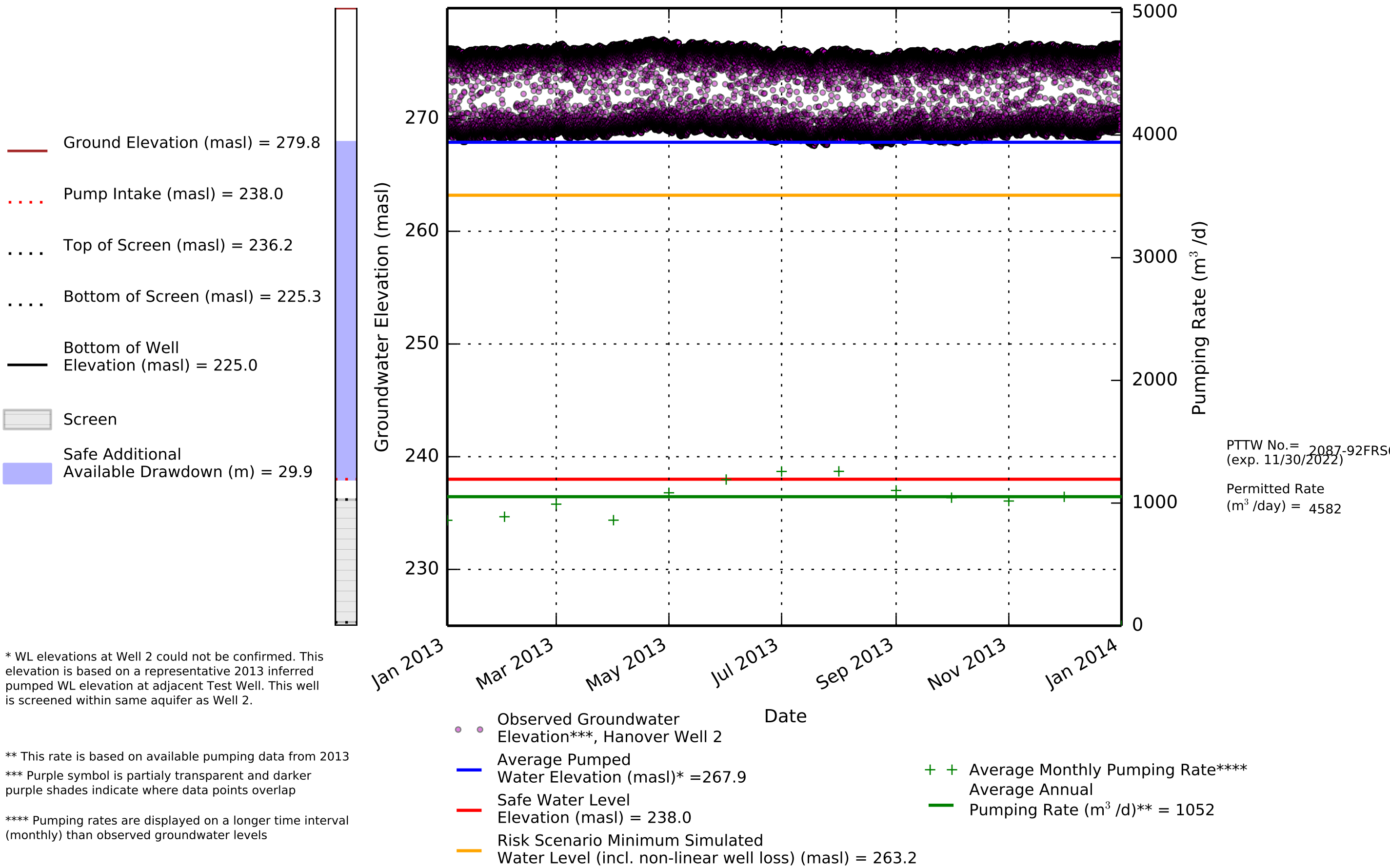
Figure C1

HYDROGRAPH
City/Town: Hanover / Well Field: Well 2 / Well Name: Hanover Well 2



* WL elevations at Well 2 could not be confirmed. This elevation is based on a representative 2013 inferred pumped WL elevation at adjacent Test Well. This well is screened within same aquifer as Well 2.

** This rate is based on available pumping data from 2013

*** Purple symbol is partialy transparent and darker purple shades indicate where data points overlap

**** Pumping rates are displayed on a longer time interval (monthly) than observed groundwater levels

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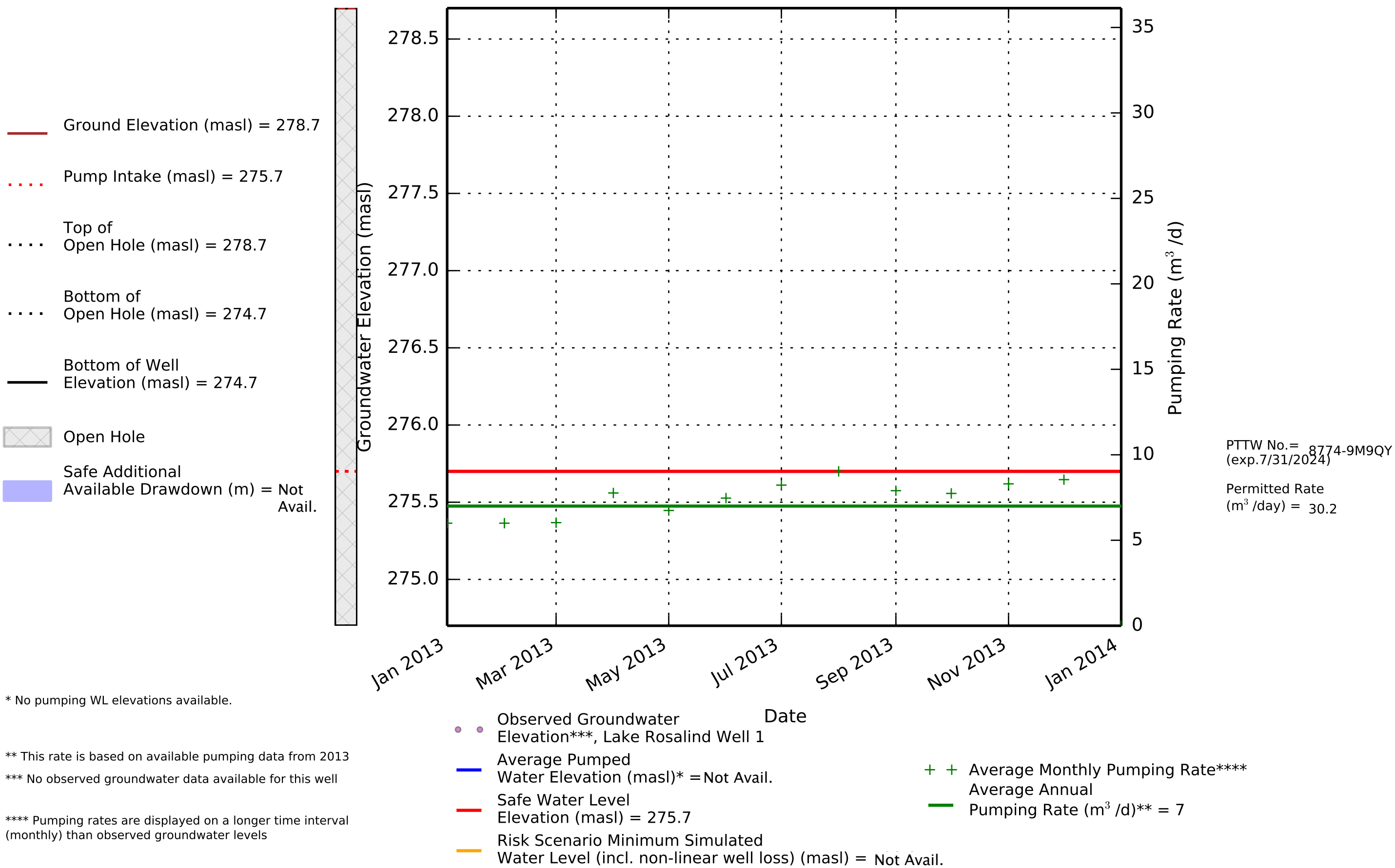
Figure C2

HYDROGRAPH
City/Town: Lake Rosalind / Well Field: Well 1 / Well Name: Lake Rosalind Well 1



* No pumping WL elevations available.

** This rate is based on available pumping data from 2013

*** No observed groundwater data available for this well

**** Pumping rates are displayed on a longer time interval (monthly) than observed groundwater levels

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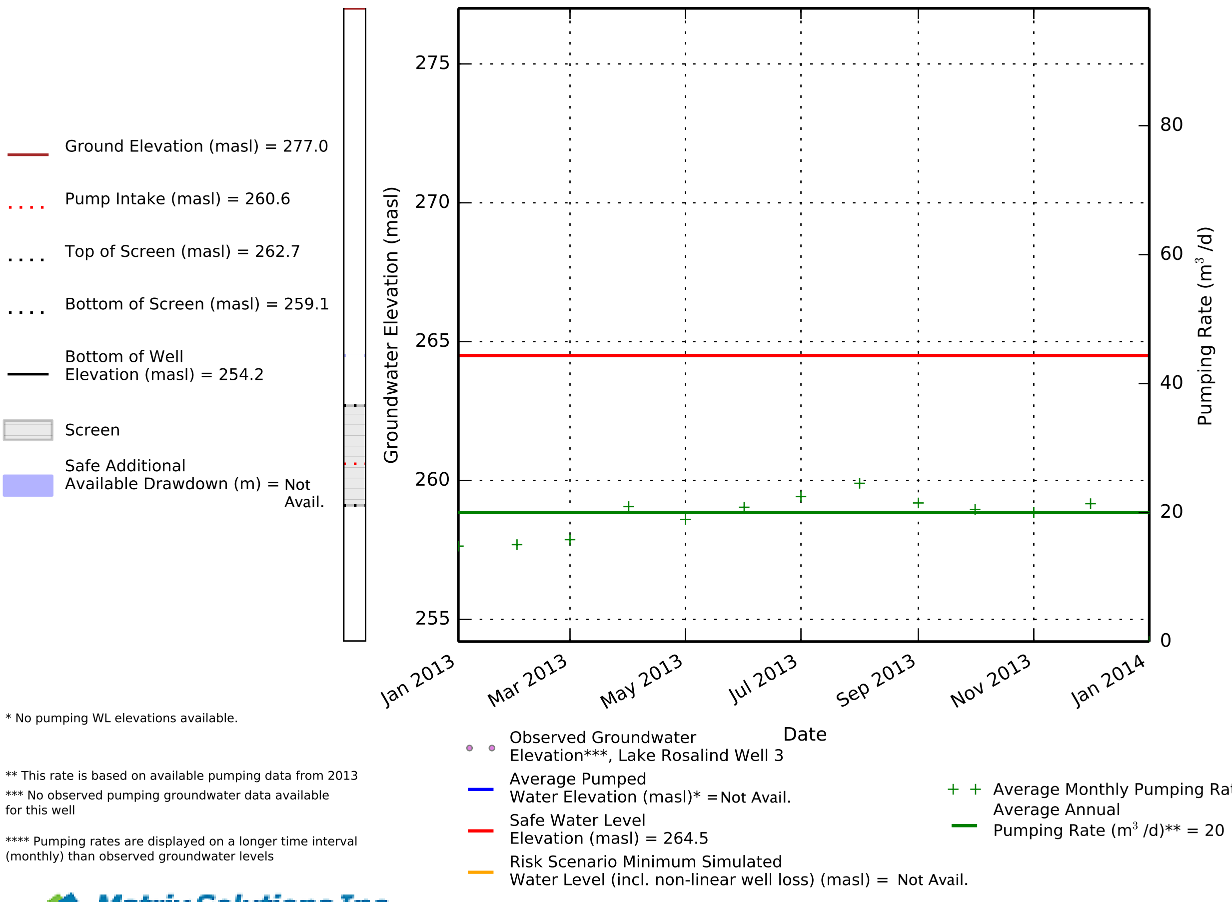
Figure C3

HYDROGRAPH

City/Town: Lake Rosalind / Well Field: Well 3 / Well Name: Lake Rosalind Well 3



PTTW No.= 8774-9M9QY (exp.7/31/2024)

Permitted Rate (m^3 /day) = 110.6

* No pumping WL elevations available.

** This rate is based on available pumping data from 2013

*** No observed pumping groundwater data available for this well

**** Pumping rates are displayed on a longer time interval (monthly) than observed groundwater levels

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Figure C4

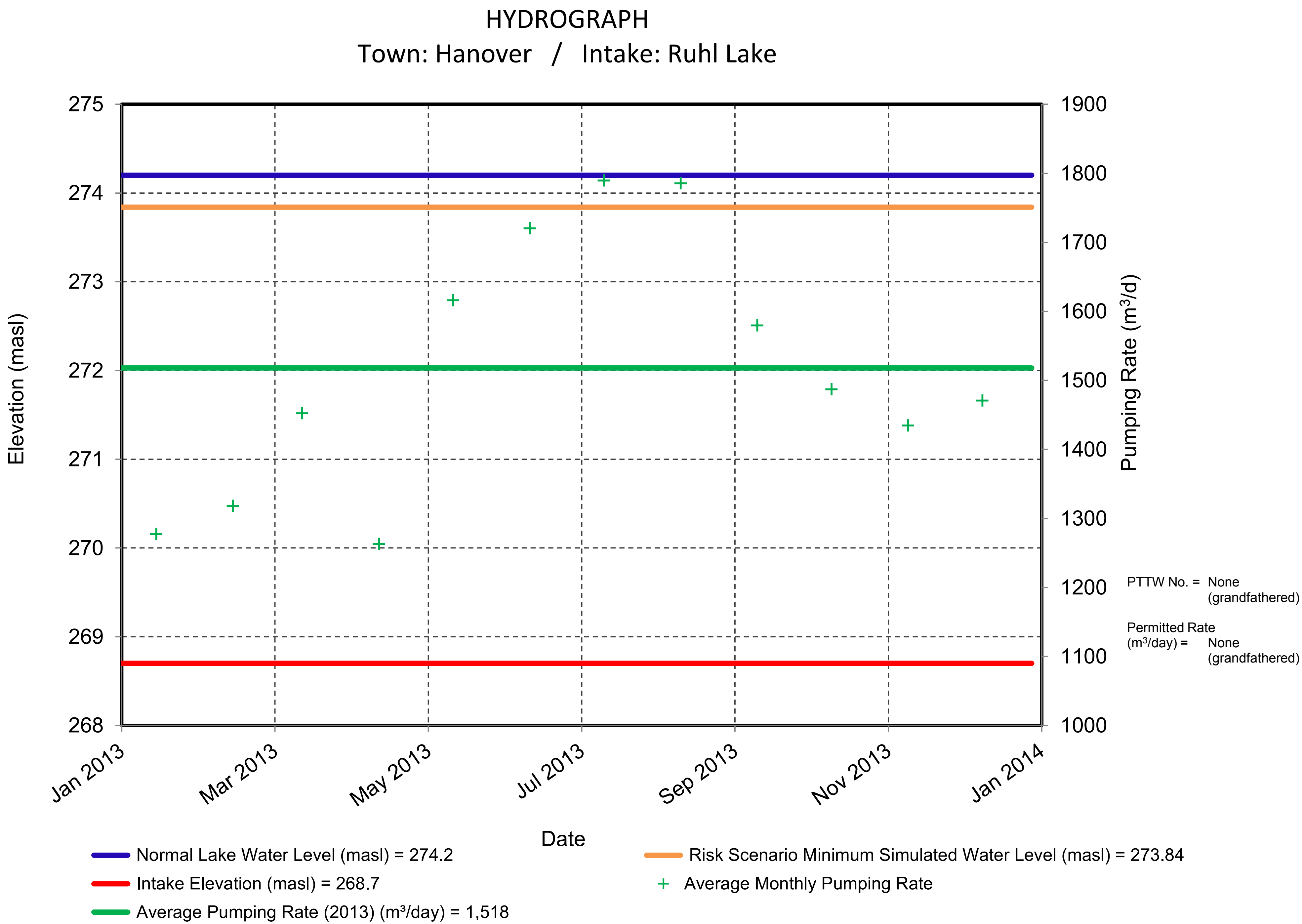

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Figure C5

APPENDIX D
Calculation of In-Well Losses

APPENDIX D

CALCULATION OF IN-WELL LOSSES

As introduced in Section 4.1.1.2, well losses refer to the difference between the theoretical drawdown in a well and the observed drawdown and are due to factors such as turbulence in the well itself as water flows into the pump. These well losses need to be considered in the Tier Three Assessment as the SAAD refers specifically to the water level in the well and not the average water level in the aquifer near the well, which is predicted by the groundwater flow model. The in-well losses are calculated as the additional drawdown that is expected within the pumping well due to the incremental increase from the Existing pumping rates to the Allocated pumping rates (Existing plus Committed Demand).

The two components of observed additional drawdown in a given pumping well are described in **Equation 1** (Bierschenk 1963; Hantush 1964; Jacob 1947):

$$s = BQ + CQ^2 \qquad \textbf{Equation 1}$$

Where *s* is drawdown, *Q* is the pumping rate, *B* is the aquifer loss coefficient (Theis 1935), and *C* is the well loss coefficient, which is constant for a given pumping rate. The first term in the equation (*BQ*) describes the linear component of the drawdown (i.e., doubling the pumping rate leads to a doubling of the drawdown). This term accounts for the drawdown in the formation near the well. The second term of the equation (CQ^2) describes the non-linear well-loss component of drawdown (Jacob 1947) in the well itself; this is the additional component that was quantified in this assessment.

Well losses can be estimated using step-test results. Step tests are hydraulic tests where a well is pumped at a series of different pumping rates and the drawdown throughout the test is recorded. Non-linear well loss coefficients were estimated using the step test results presented in well maintenance reports where available (report references are provided in **Table 4.2**).

The loss coefficient, *C*, was calculated directly from step test data following the technique developed by Kasenow (1998):

$$C = \frac{s_2 Q_1 - s_1 Q_2}{Q_1 Q_2^2 - Q_2 Q_1^2} \qquad \textbf{Equation 2}$$

Where:

s_1 is the total stabilized drawdown at the end of pumping step 1
Q_1 is the pumping rate for step 1

s_2 is the total stabilized drawdown at the end of pumping step 2
Q_2 is the pumping rate for step 2

For each step test, these coefficients were calculated for consecutive steps and then averaged to determine the loss coefficient for the well at the time of the step test. **Equation 3,** after Jacob (1947), was used to calculate drawdown due to in-well head losses for the increased pumping from Existing to the Allocated Rates:

$$\Delta S_{inwell} = C\ [(Q_{EC} +\ \Delta Q)^2\ -\ Q_{EC}^2]$$ **Equation 3**

Where: *C* is the well loss coefficient determined from step-test data
Q_{EC} is the Existing conditions (2013) pumping rate used in the base case steady-state model
ΔQ equal to the increase from Existing conditions (2013) pumping rate to the Allocated municipal pumping rate used in the Risk Assessment Scenarios

Pumping rates, the calculated well loss coefficient, and the estimated non-linear head losses related to the Allocated increase for each well are summarized in **Table 4.2** in Section 4.1.1.2. Where step test data were not available for a well, a C-value of 3.82×10^{-7} m/(m^3/day)^2 was selected based on the assumption that the well is mildly deteriorated (Walton 1962).