



**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

Prepared by:
MATRIX SOLUTIONS INC.

January 2016
Waterloo, Ontario

31 Beacon Point Crt.
Breslau, ON, Canada N0B 1M0
Phone: 519.772.3777 Fax: 519.772.3168
www.matrix-solutions.com

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



Jeffrey Melchin, M.Sc., P. Geo.
Hydrogeologist

January 8, 2016



Patricia Meyer, M.Sc., P. Geo.
Senior Hydrogeologist

January 8, 2016

reviewed by

Steve Davies, M.Sc., P. Geo.
Senior Hydrogeologist



January 8, 2016

A handwritten signature in blue ink, reading "Gaelen Merritt".

Gaelen Merritt, B.A.Sc.
Groundwater Modelling Specialist

A handwritten signature in blue ink, reading "Zoey Zimmer".

Zoey Zimmer, B.Sc., B.Eng.
Water Resources E.I.T.

DISCLAIMER

We certify that this report is accurate and complete and accords with the information available during the site investigation. Information obtained during the site investigation or provided by third parties is believed to be accurate but is not guaranteed. We have exercised reasonable skill, care, and diligence in assessing the information obtained during the preparation of this report.

This report was prepared for Saugeen Valley Conservation Authority. The report may not be relied upon by any other person or entity without our written consent and that of the Saugeen Valley Conservation Authority. Any uses of this report by a third party, or any reliance on decisions made based on it, are the responsibility of that party. We are not responsible for damages or injuries incurred by any third party, as a result of decisions made or actions taken based on this report.

TABLE OF CONTENTS

1	INTRODUCTION	1
1.1	Overview	1
1.2	Study Area.....	2
1.3	Previous Water Resources Studies in the Hanover/ Lake Rosalind Area	3
1.4	Project Goals and Objectives	5
1.5	Report Organization.....	6
2	PHYSICAL SETTING	6
2.1	Topography	6
2.2	Physiography.....	6
2.2.1	Saugeen Clay Plain	7
2.2.2	Teeswater Drumlin Field.....	7
2.2.3	Horseshoe Moraines.....	7
2.3	Surface Water Features	7
2.3.1	Rivers and Creeks.....	7
2.3.1.1	Thermal Regimes	8
2.3.2	Significant Wetland Complexes and Lakes	8
2.4	Regional Scale Geologic Setting	9
2.4.1	Bedrock Geology.....	9
2.4.1.1	Salina Formation	9
2.4.1.2	Guelph Formation	10
2.4.2	Overburden Thickness	10
2.4.3	Quaternary Geology.....	10
2.4.3.1	Nissouri Stade	12
2.4.3.2	Erie Interstade.....	12
2.4.3.3	Port Bruce Stade	12
2.4.3.4	Mackinaw Interstade and Post-Glacial Events.....	12
2.4.4	Local-scale Cross-section Interpretations.....	13
2.4.4.1	Town of Hanover	14
2.4.4.2	Community of Lake Rosalind	14
2.5	Hydrostratigraphic Setting.....	15
2.5.1	Groundwater Flow	16
3	MUNICIPAL WATER DEMANDS	18
3.1	Municipal Water Systems and Demands	18
3.1.1	Town of Hanover Water Supply.....	18
3.1.1.1	Groundwater Supply Wells	19
3.1.1.2	Surface Water Intake	20
3.1.2	Community of Lake Rosalind Water Supply Wells.....	20
3.2	Non-Municipal Water Demands	21

	3.2.1	Data Sources	21
	3.2.1.1	Water Taking and Reporting System	21
	3.2.1.2	Permit to Take Water Database	22
	3.2.1.3	Estimated Consumptive Demands.....	23
4		WATER BUDGET ASSESSMENT TOOLS	23
	4.1	Hydrologic Water Budget Tool	24
	4.1.1	GAWSER Model Development.....	24
	4.1.2	GAWSER Model Calibration and Verification	25
	4.2	Groundwater Water Budget Tool	25
	4.2.1	FEFLOW Model Development.....	25
	4.2.2	FEFLOW Model Calibration.....	26
5		RUHL LAKE SURFACE WATER INTAKE EVALUATION	26
	5.1	Conceptual Overview.....	26
	5.1.1	Water Budget Approach	26
	5.2	Results.....	29
	5.3	Summary	31
	5.4	Assessment Limitations and Assumptions.....	31
6		GROUNDWATER ASSESSMENT	32
	6.1	Model Refinements	32
	6.1.1	FEFLOW Model Mesh	33
	6.1.2	Ground Surface and Hydrostratigraphic Layer Elevations.....	33
	6.1.3	Boundary Conditions	34
	6.1.3.1	External Regional Flow Boundary Conditions.....	34
	6.1.3.2	Surface Water Boundary Conditions	35
	6.1.3.3	Recharge	35
	6.1.3.4	Pumping Wells	35
	6.1.4	Model Properties	36
	6.1.4.1	Hydraulic Conductivity Values	36
	6.1.4.2	Storage.....	37
	6.2	Calibration Approach	37
	6.2.1	Calibration Datasets.....	38
	6.3	Calibration Results	39
	6.3.1	Quantitative Assessment	39
	6.3.1.1	Steady-State Calibration to Water Level Elevations	39
	6.3.1.2	Transient Calibration to Water Level Elevations	42
	6.3.1.3	Steady-State Calibration to Baseflow	42
	6.3.2	Qualitative Assessment	43
	6.3.2.1	Simulated Upper Aquifer Equipotential Contours.....	43
	6.3.2.2	Simulated Lower Aquifer Equipotential Contours.....	44
	6.3.2.3	Groundwater Discharge to Surface Water	44

6.3.3	Overall Groundwater Model Calibration Assessment	44
6.4	Groundwater Flow Model Limitations	45
7	SUMMARY AND CONCLUSIONS	45
8	REFERENCES	46

LIST OF CHARTS

CHART 3.1	Hanover Monthly Pumping (2013)	19
CHART 3.2	Lake Rosalind Average Monthly Pumping Rates (2013)	21
CHART 5.1	Storage-Elevation Rating Curve for Ruhl Lake	28
CHART 5.2	Storage-Outflow Rating Curve for Ruhl Lake	28
CHART 5.3	Estimated Stream Inflow, Stream Outflow, and Precipitation at Ruhl Lake	30
CHART 5.4	Estimated Monthly Stream Inflow, Stream Outflow, Groundwater Seepage and Municipal Withdrawal Rate of Ruhl Lake (Average 1950 to 2005)	30
CHART 5.5	Ruhl Lake Water Level Distribution (Average 1950 to 2005)	30
CHART 5.6	Estimated Annual Surface Water Elevation of Ruhl Lake (Average 1950 to 2005)	31
CHART 6.1	Scatterplot of Observed and Simulated Water Level Elevations	40
CHART 6.2	Transient Model Calibration: Observed and Simulated Water Levels	42

LIST OF TABLES

TABLE 1.1	Water Resources Studies Completed in the Study Area	3
TABLE 2.1	Summary of Overburden Deposits Mapped in the Study Area	11
TABLE 2.2	Hydrostratigraphic Units within the Study Area	16
TABLE 3.1	Town of Hanover Water Supply Wells/Intakes	18
TABLE 3.2	Community of Lake Rosalind Water Supply Wells	20
TABLE 3.3	Summary of Groundwater Permitted and Consumptive Demands in the Study Area	23
TABLE 3.4	Summary of Surface Water Permitted and Consumptive Demands in the Study Area	23
TABLE 5.1	Mean Annual Water Budget of Ruhl Lake	29
TABLE 6.1	Conceptual and Calibrated Hydraulic Conductivity Estimates	37
TABLE 6.2	Summary of Specific Storage/Yield Values	37
TABLE 6.3	Summary of Baseflow Calibration	43

FIGURES

FIGURE 1.1	Study Area
FIGURE 1.2	Land Cover (SOLRIS)
FIGURE 2.1	Ground Surface Topography
FIGURE 2.2	Physiographic Regions
FIGURE 2.3	Surface Water Features, Thermal Regimes and Wetland Complexes
FIGURE 2.4	Overburden Thickness
FIGURE 2.5	Surficial Geology
FIGURE 2.6	Hydrostratigraphic Cross-Section E-W
FIGURE 2.7	Hydrostratigraphic Cross-Section N-S

FIGURE 2.8	Overburden Water Level Elevations
FIGURE 2.9	Bedrock Water Level Elevations
FIGURE 3.1	Permits to Take Water and Consumptive Rates
FIGURE 6.1	Model Finite Element Mesh
FIGURE 6.2	Slice 1 Specified Head Boundary Conditions and Observation Dataset
FIGURE 6.3	Recharge Distribution
FIGURE 6.4	Plan View of Calibration Residuals
FIGURE 6.5	Simulated Hydraulic Head Contours in Upper Aquifer
FIGURE 6.6	Simulated Hydraulic Head Contours in Lower Aquifer
FIGURE 6.7	Qualitative Baseflow Calibration

APPENDICES

APPENDIX A	Municipal Production Well Logs
APPENDIX B	Permitted Water Takings in Study Area

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, MNR 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 km² 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 m³/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 m³/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 m³/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

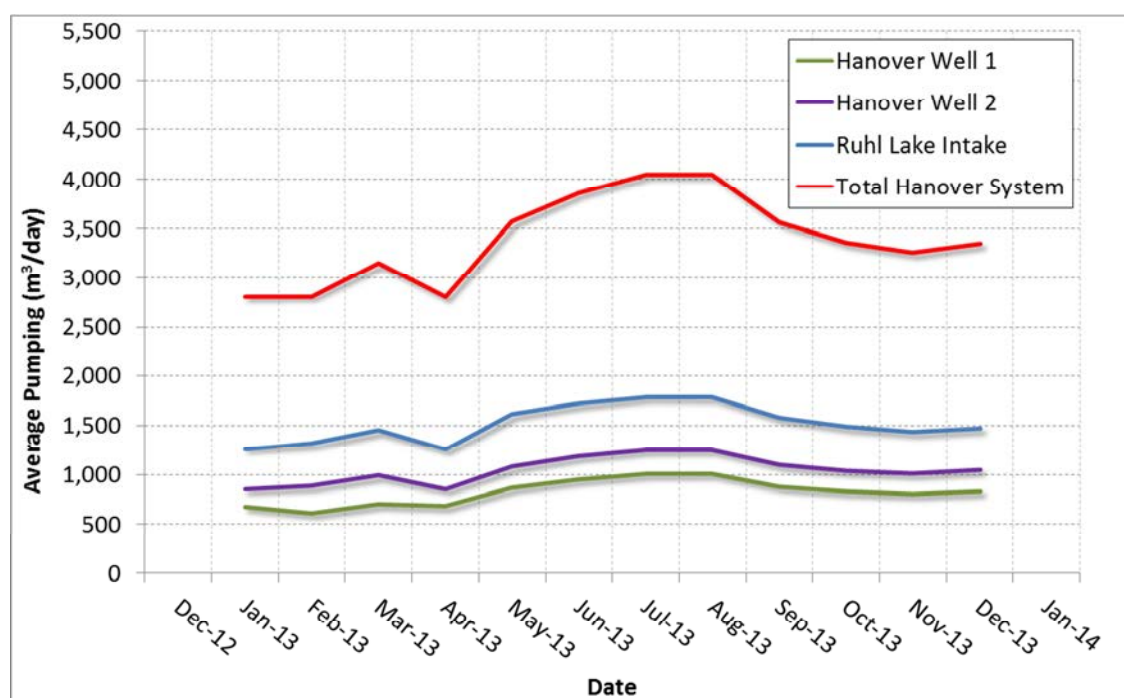
and also from the monitoring well every 15 minutes; no monitoring wells are present near Hanover Well 1. Details regarding water levels in the municipal wells and the Hanover Well 2 monitoring well will be presented in the risk assessment report.

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 m³/day), followed by elevated demands (total system maximum of 4,100 m³/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 m²/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 m³/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 m³/day; this is higher than the 2013 average annual combined taking of 27 m³/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 m³/day during the month of August.

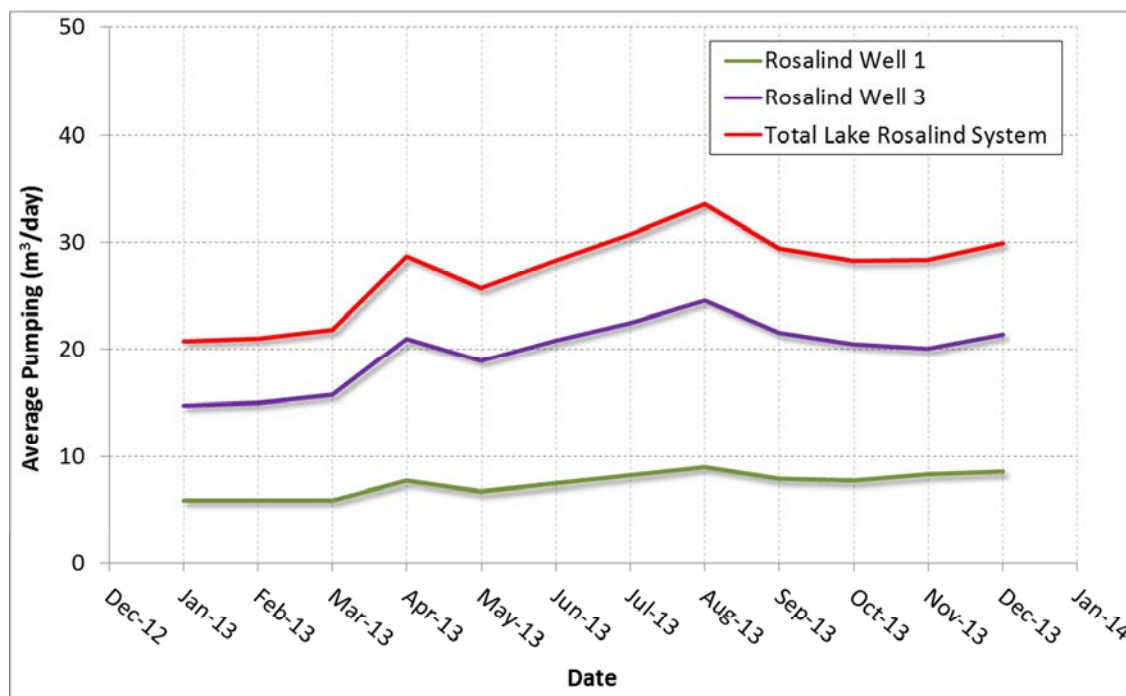
3.2 Non-Municipal Water Demands

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 Meteorology (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.

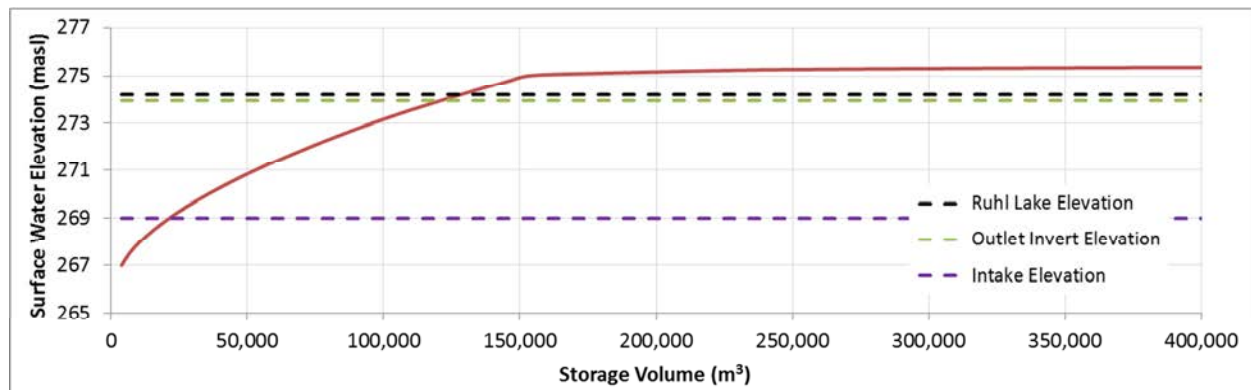
- **Surface Water Inflow:** Volume of surface water that enters Ruhl Lake from the upstream contributing area. This may include streamflow from tributaries, or direct overland flow that enters the lake. This volume was obtained from the simulated hydrograph produced by the calibrated GAWSER model for 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.

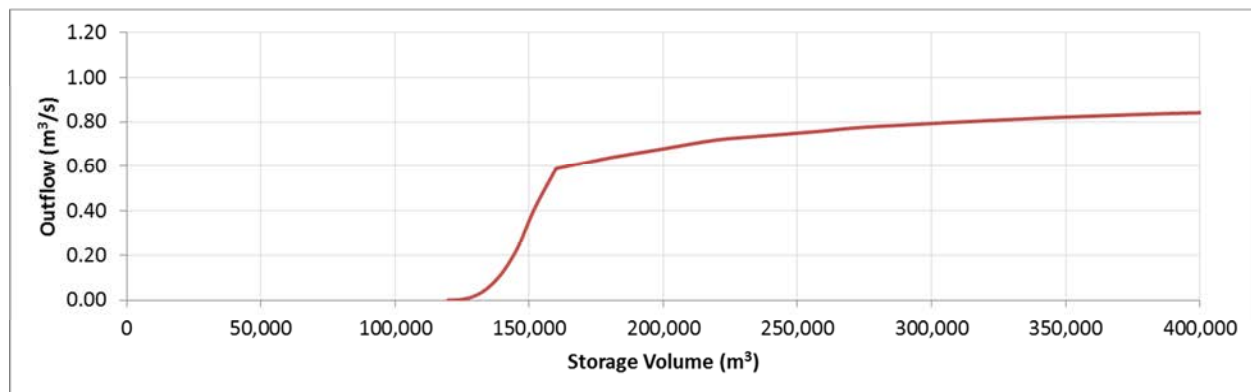
The bathymetry was digitized and combined with a 0.5 m DEM of the local drainage area. Using the estimated storage volume, a rating curve was developed for the relationship between storage volume and surface water level elevation (**Chart 5.1**).

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 m³/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

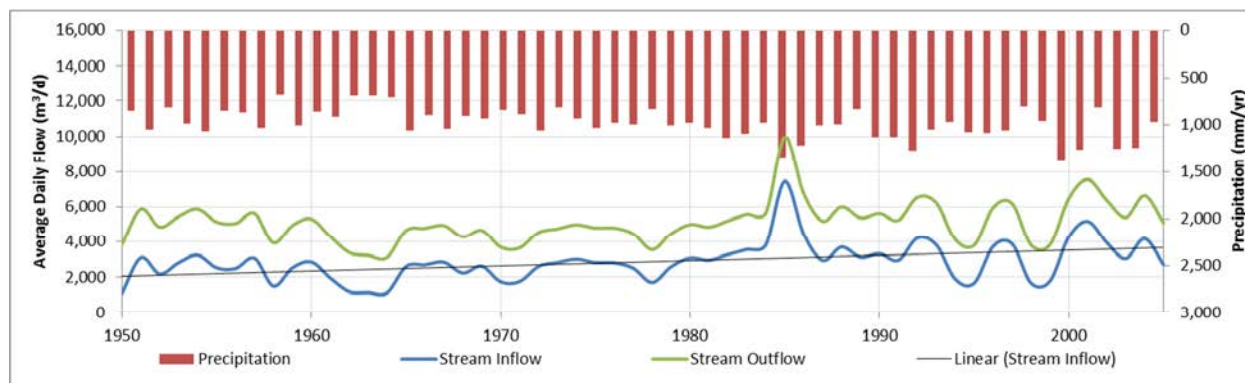


CHART 5.4 Estimated Monthly Stream Inflow, Stream Outflow, Groundwater Seepage and Municipal Withdrawal Rate of Ruhl Lake (Average 1950 to 2005)

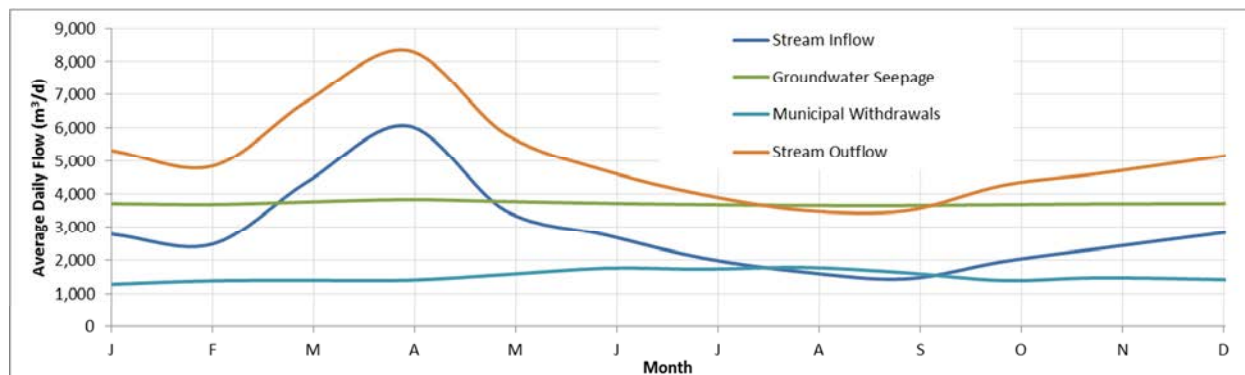


CHART 5.5 Ruhl Lake Water Level Distribution (Average 1950 to 2005)

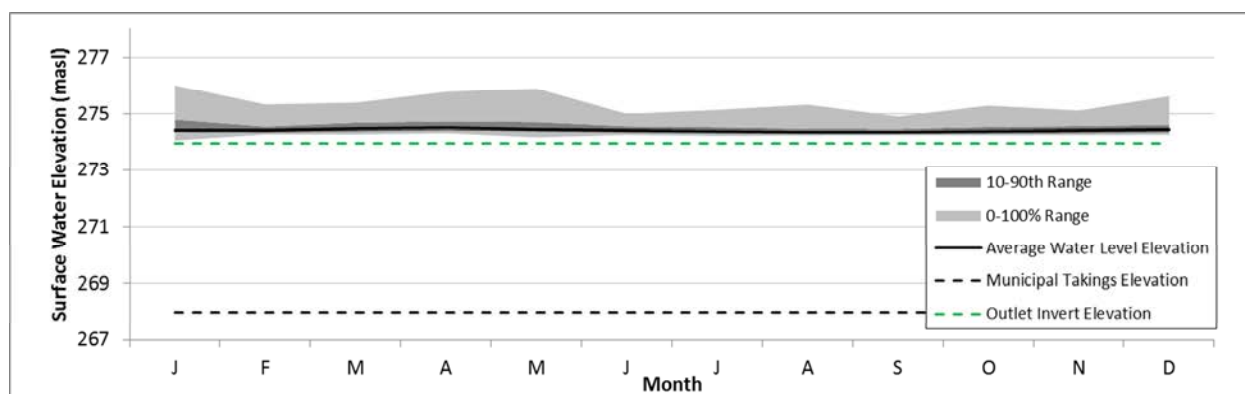
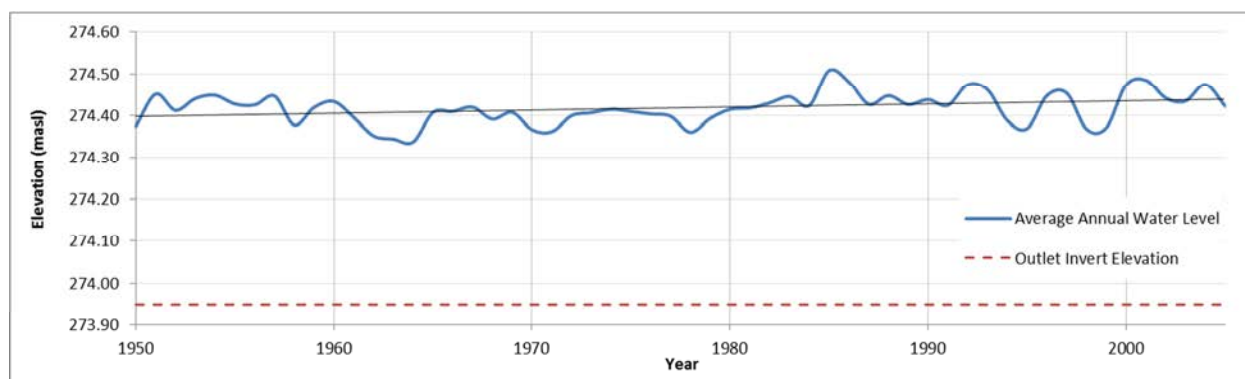


CHART 5.6 Estimated Annual Surface Water Elevation of Ruhl Lake (Average 1950 to 2005)



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 10th to 90th 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 (Sils 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 (Sils/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 (Sils and clays)	1.5×10^{-5}	0.18
Upper Aquifer (Sands/ gravels)	1.5×10^{-5}	0.20
Intermediate Aquitard (Sils/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.

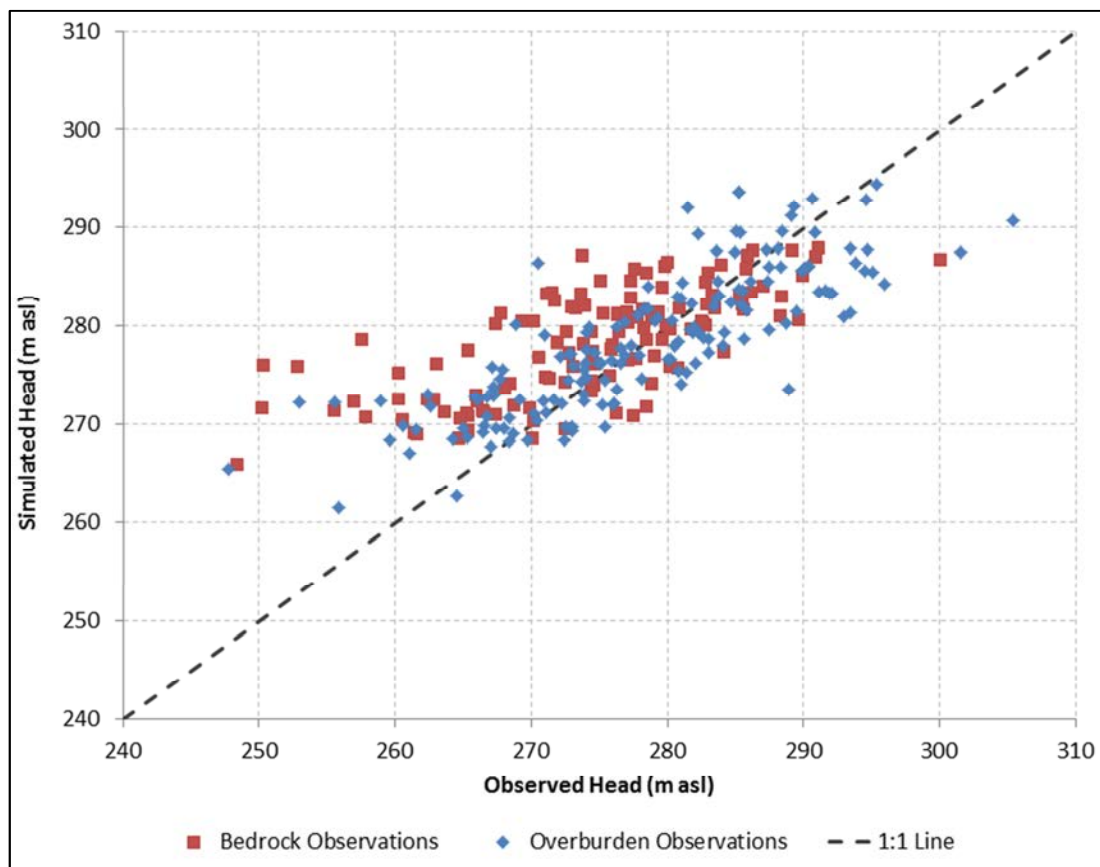
6.3.1 Quantitative Assessment

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 its 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 m²/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.

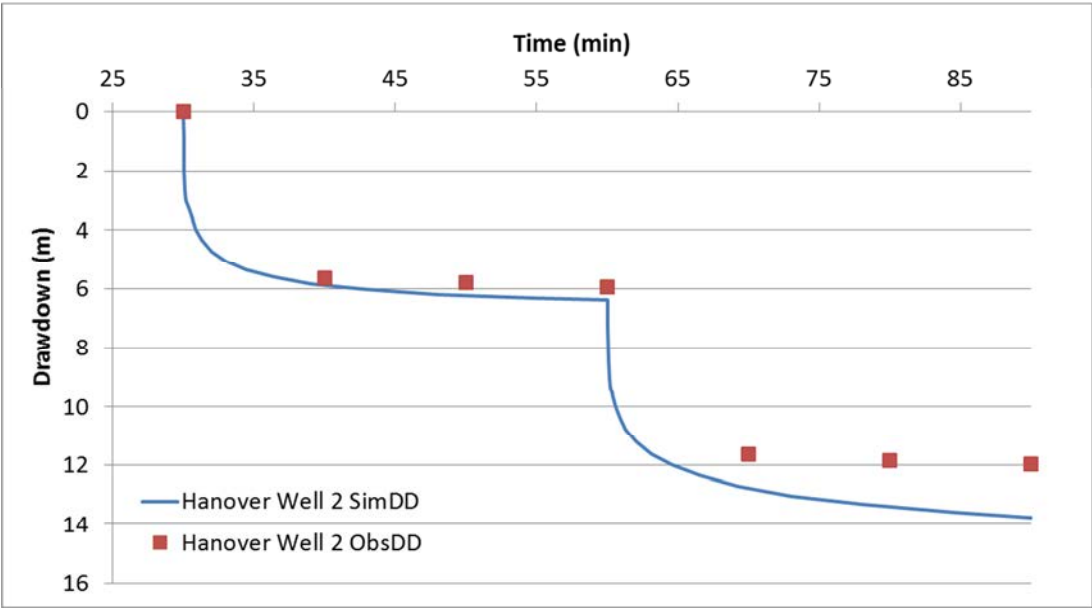
Two monitoring wells were drilled on the eastern side of Ruhl Lake as part of a hydrogeologic study of Ruhl Lake (Luinstra Earth Sciences 2008). One well was drilled into the Upper Aquifer and the other in the Lower Aquifer, with the two wells approximately 1.5 m apart. A pumping test was performed on 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.

8 REFERENCES

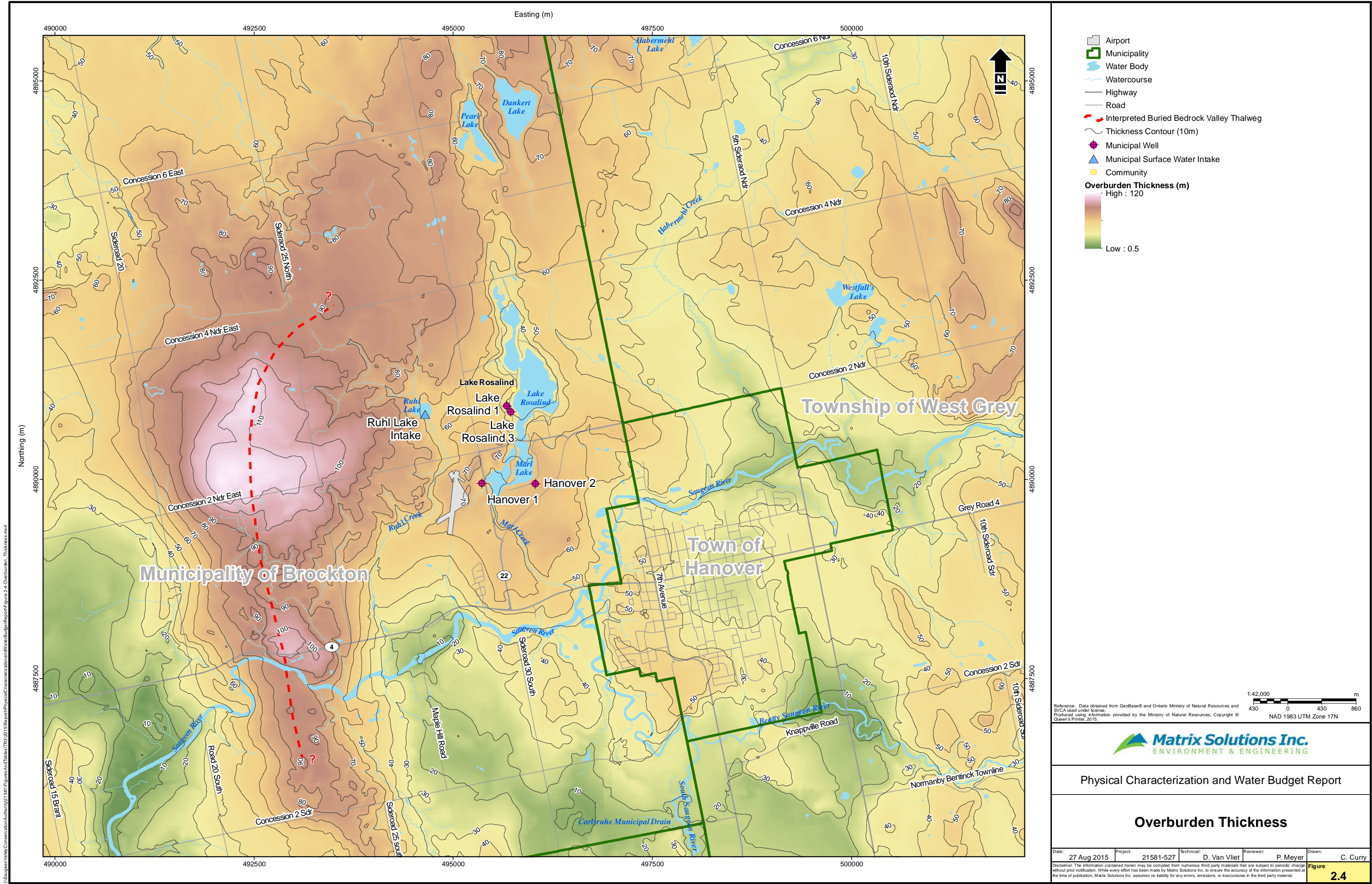
- Annable W.K. 1996. *Morphologic Relationships of Rural Watercourses in Southern Ontario and Selected Field Methods in Fluvial Geomorphology*. Prepared for Credit Valley Conservation and the Ontario Ministry of Natural Resources.
- AquaResource Inc. (AquaResource). 2010. *Saugeen Valley, Grey Sauble, Northern Bruce Peninsula Tier Two Subwatershed Stress Assessment*. Report prepared for Saugeen Valley Conservation Authority. Waterloo, Ontario. July 2010.

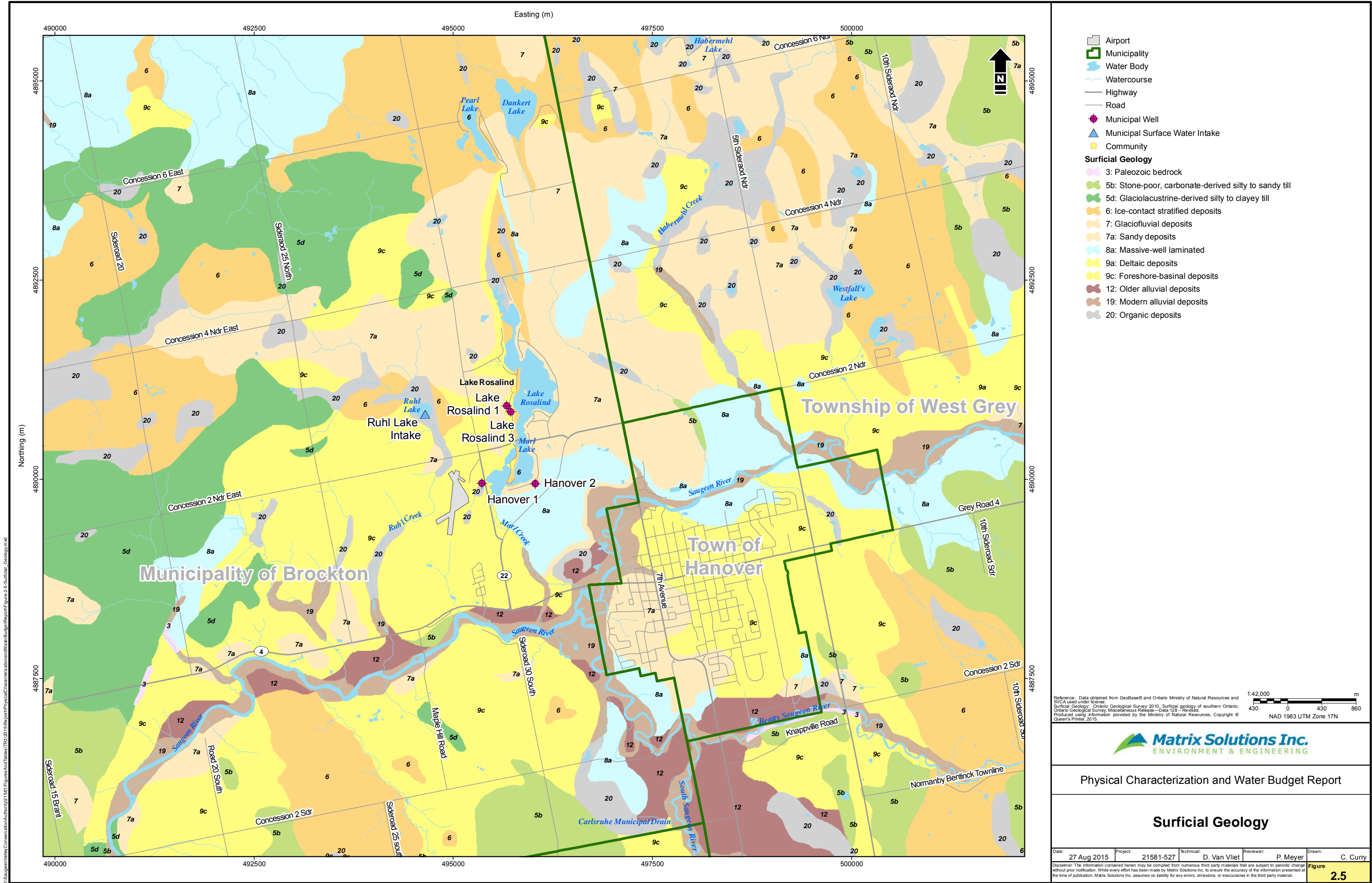
- AquaResource Inc. (AquaResource). 2009. "Hydrogeologic Modeling Groundwater and Solute Transport Modeling Assessment for Hanover/Walkerton Landfill Assessment." Volume II, Appendix 2: *Hanover/Walkerton Landfill Expansion Environmental Assessment*. Report prepared for The Corporation of the Town of Hanover. Waterloo, Ontario. July 2009.
- AquaResource Inc. (AquaResource). 2008a. *Conceptual Geologic & Water Budget Assessment*. Report prepared for Grey Sauble Conservation Authority, Saugeen Valley Conservation Authority, and Municipality of Northern Bruce Peninsula. Waterloo, Ontario. May 2008.
- AquaResource Inc. (AquaResource). 2008b. *Tier One Surface Water Budget and Subwatershed Stress Assessment*. Report prepared for the Saugeen Valley / Grey Sauble / Northern Bruce Peninsula Source Water Protection Region. Waterloo, Ontario. 2008.
- Barnett P.J. 1992. "Quaternary Geology of Ontario." In: *Geology of Ontario: Ontario Geological Survey*. Thurston P.C., Williams H.R., Sutcliffe R.H., and G.M. Stott (Eds.). Ontario Geological Survey, Toronto: 1011-1090.
- Bedient P.B. et al. 2008. *Hydrology and Floodplain Analysis, Forth Addition*. Prentice Hall Inc. Upper Saddle River NJ.
- B.M. Ross and Associates Ltd. (BMROSS). 2000. *The Municipality of Brockton Lake Rosalind Water Works Engineer's Report*. File No. 00196. Goderich, Ontario. November 30, 2000.
- Chapman L.J. and D.F. Putnam. 1984. *The Physiography of Southern Ontario*. Third Edition. Special Volume 2. Ontario Geological Survey. Ministry of Natural Resources. July 9, 1984.
- Conestogo-Rovers & Associates (CRA). 2009. *Drinking Water Source Protection Round 2 Groundwater Technical Study*. August 2009.
- Conestogo-Rovers & Associates (CRA). 2007. *2005-2006 Groundwater Technical Study*. November 2007.
- Cooper, Ron (2015), Director of Public Works, Town of Hanover. Personal communication, October 2015.
- Cooper R. 2014. *Waterworks Summary Report for 2013*. Staff Report to Council. Memorandum. Report PW-05-14. Hanover, Ontario. March 3, 2014.
- Cowan W.R. 1979. *Quaternary Geology of the Palmerston Area, Southern Ontario*. Report 187. Ministry of Natural Resources.
<http://www.geologyontario.mndmf.gov.on.ca/mndmfiles/pub/data/imaging/R187/R187.pdf>
- Domenico P.A. and M.D. Mifflin. 1965. "Water from low-permeability sediments and land subsidence." *Water Resources Research* 1 (4): 563-576.

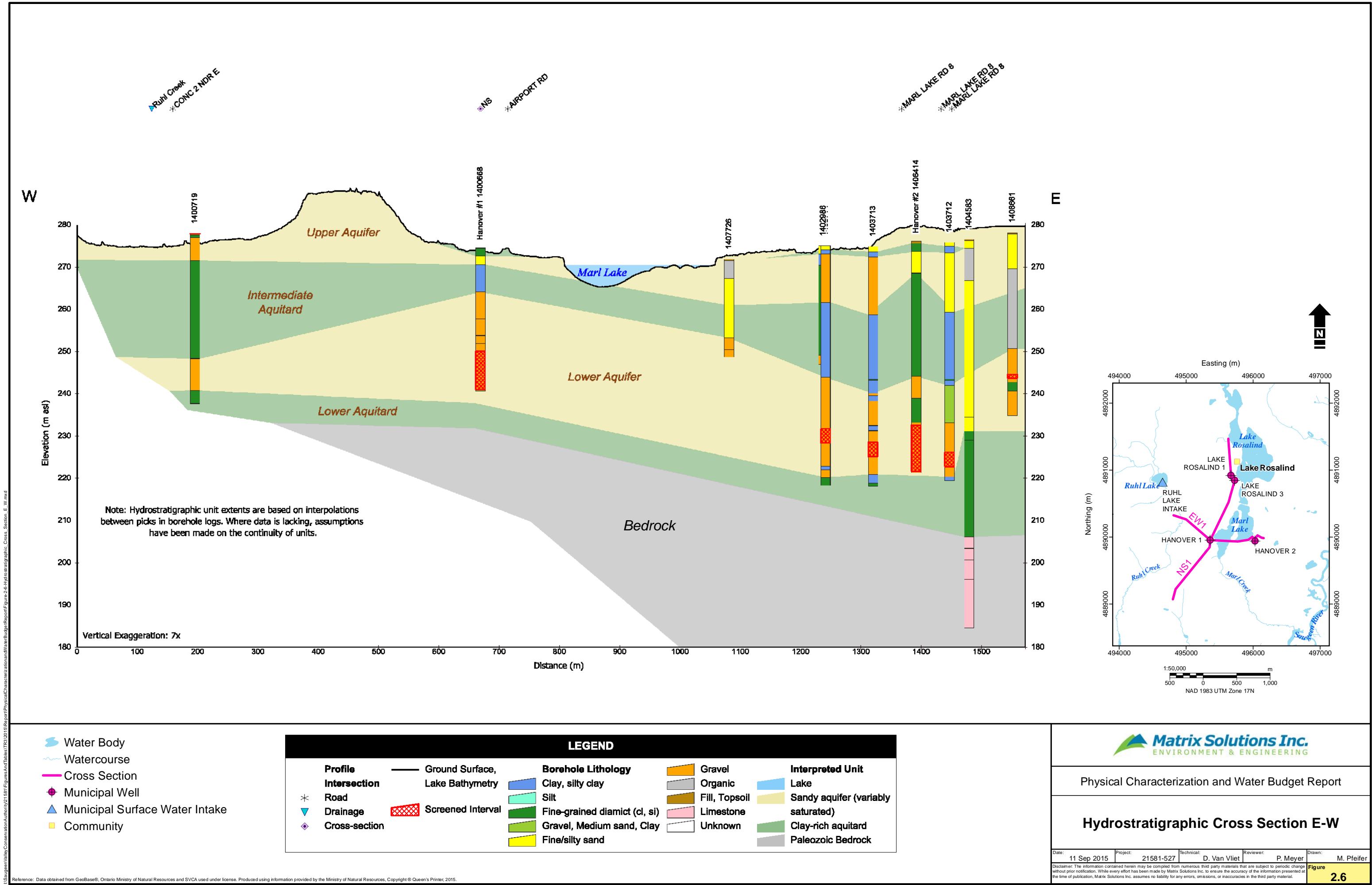
- Dremanis A. and R. P. Goldthwait. 1973. "Wisconsin glaciation in the Huron, Erie, and Ontario Lobes." *The Wisconsin Stage, Geological Society of America Memoirs* 136: 71-106.
- Freeze R.A. and J.A. Cherry. 1979. *Groundwater*. Prentice Hall. New Jersey. 604 pp.
- French Planning Services Inc. and Gartner Lee Ltd. 2004. *Lake Rosalind and Marl Lake Inland Lake Development Study*. Report prepared for the Municipality of Brockton.
- Gallardo, A.H., Reyes-Borja W., and N. Tase. 2005. "Flow and patterns of nitrate pollution in groundwater: a case study of an agricultural area in Tsukuba City, Japan." *Environmental Geology* 48: 908–919.
- Golder Associates Ltd. (Golder). 2003. *Determination of Capture Zones for Walkerton Wells 7 and 9, Municipality of Brockton County of Bruce, Ontario*. February 2003.
- Guillet, G.R. 1969. *Marl in Ontario*. Ontario Department of Mines. Industrial Mineral Report 28.
- Hanover Waterworks. 1924. *Plan Profile Ruhl Lake Intake and Plan Showing Ruhl Lake and Burrell Creek Diversion*. Scale horizontal 20 feet to 1 inch, vertical 4 feet to 1 inch. 1924.
- International Water Consultants Ltd. (IWC). 2007. *Town of Hanover Preliminary Groundwater Study*. Report prepared for the Town of Hanover. October 10, 2007.
- International Water Supply Ltd. (IWS). 1986. *The Town of Hanover Construction and Testing Well No. 2*. Project 7-0478. 1986.
- International Water Supply Ltd. (IWS). 1975. *Groundwater Investigation 1975 Town of Hanover*.
- Johnson M.D. et al. 1992. "Paleozoic and Mesozoic Geology of Ontario: in Geology of Ontario." *Ontario Geological Survey 4 (Part 2)*: 907- 1010.
- Johnson A.I. 1967. *Specific Yield - Compilation of Specific Yields for Various Materials*. U.S. Geological Survey Water Supply Paper 1662-D. 74 p.
- Karrow P.F. 1973. "Bedrock topography in southwestern Ontario: a progress report." *Geological Association of Canada, Proceedings (25)*: 67-77.
- Kinthead Consulting and AquaResource Inc. 2009. *Methodology for Identifying Large Consumptive Water Users: Great Lakes - St. Lawrence River Basin Sustainable Water Resource Agreement*. Report prepared for the Ontario Ministry of Natural Resources. Waterloo, Ontario. 2009.
- Liberty B.A. and T.E. Bolton. 1971. "Paleozoic geology of the Bruce Peninsula area, Ontario." *Geological Survey of Canada Memoir* 360: 163p.

- Luinstra Earth Sciences. 2008. *Ruhl Lake Water Supply Geological Investigation in Support of Source Water Protection Vulnerability Assessment*. Draft Report. 2008.
- Lutz A., Thomas J.M., Pohil G., and W.A. McKay. 2007. "Groundwater resource sustainability in the Nabogo Basin of Ghana." *Journal of African Earth Sciences* 49 (2): 61-70.
- Ontario Department of Lands and Forests. 1971. *Lake Survey Summary Sheet - Marl Lakes*. July 11, 1971.
- Ontario Geological Survey (OGS). 2010. *Surficial Geology of Southern Ontario*. Miscellaneous Release - Data 128 - Revised.
- Ontario Ministry of Natural Resources (MNR). 2012. *Land Information Ontario Data Description, Aquatic Resource Area Summary*.
<https://www.sse.gov.on.ca/sites/MNR-PublicDocs/EN/CMID/Aquatic%20Resource%20Area%20Summary%20-%20Data%20Description.pdf>
- Ontario Ministry of the Environment and Climate Change (MOECC). 2015. *Permit to Take Water Database*.. Accessed in June 2015. <http://www.ontario.ca/data/permit-take-water>
- Ontario Ministry of the Environment (MOE). 2014a. *Town of Hanover Drinking Water System: Inspection Report*. Report prepared for Owen Sound Area Office. Owen Sound, Ontario. December 11, 2014.
- Ontario Ministry of the Environment (MOE). 2014b. *Lake Rosalind Drinking Water System: Inspection Report*. Report prepared for Owen Sound Area Office. Owen Sound, Ontario. May 27, 2014.
- Ontario Ministry of the Environment. (MOE). 2009. *Technical Rules: Assessment Report, Clean Water Act, 2006*. November 20, 2008. Amended on December 12, 2008 (administrative amendments) and November 16, 2009 (EBR Posting Number EBRO10-7573).
<https://dr6j45jk9xcmk.cloudfront.net/documents/1385/242-technical-rules-assessment-report-en.pdf>
- Ontario Ministry of the Environment (MOE). 2006. *Clean Water Act*. S.O. 2006, Chapter 22, Ontario Regulation 287/07. Royal Assent: October 19, 2006. URL: <http://www.ontario.ca/laws/statute/06c22>
- Russell H.A.J., Brennand T.A., Logan C., and D.R. Sharpe. 1998. *Standardization and assessment of geological descriptions from water well records: Greater Toronto and Oak Ridges Moraine Areas, southern Ontario*. Current Research 1998-E: Ottawa, Geological Survey of Canada, 89-102.
http://www.sfu.ca/geog/temp/brennand2/pubs_files/_Russelletal_98_Standardization_GSC-CR.pdf
- Saugeen Valley Source Protection Region (SVCA). 2011. *Assessment Report, Saugeen Valley Source Protection Area*. November 28, 2011.
http://www.waterprotection.ca/AR/SVSPA/SVSPA_Approved_AR_Complete_Text.pdf

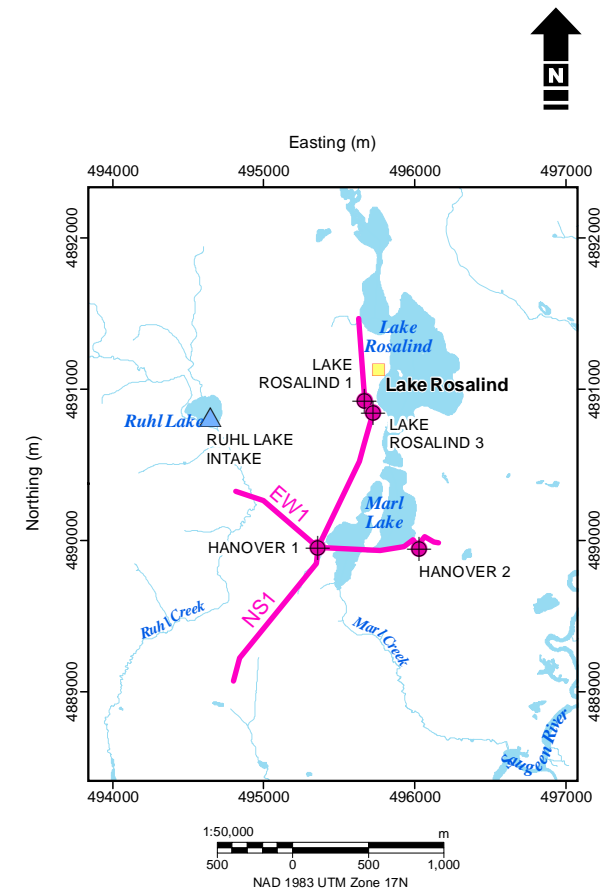
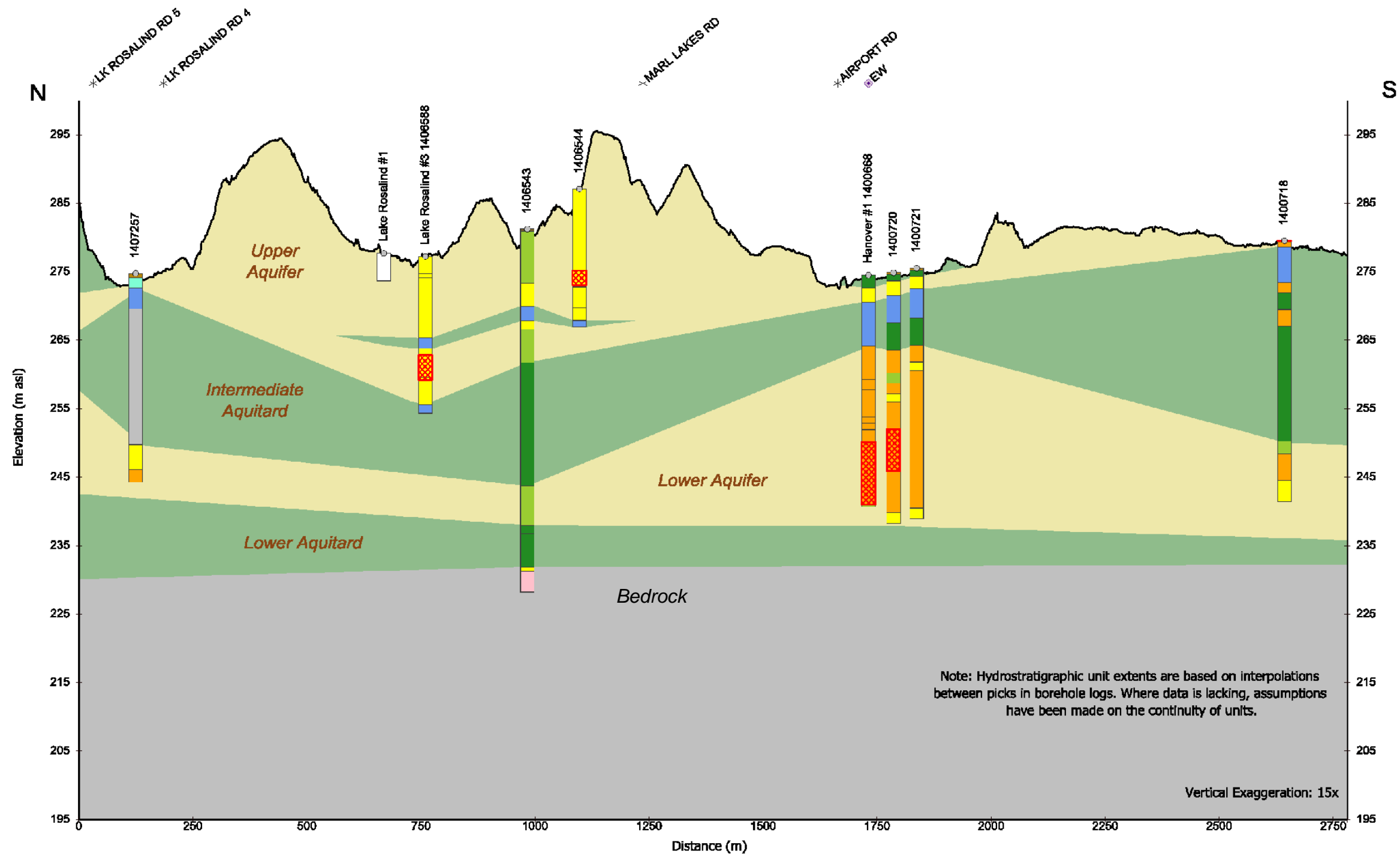
- Schroeter & Associates. 2004. *GAWSER: Guelph All-Weather Sequential-Events Runoff Model, Version 6.5, Training Guide and Reference Manual*. Report prepared for the Ontario Ministry of Natural Resources and the Grand River Conservation Authority. 2004.
- Sharpe D.R. 1975. *Quaternary Geology of Durham Area (41A/2), Grey County*. Ontario Division of Mines, Geological Branch, Miscellaneous Paper No. 28.
- Spitz K. and J. Moreno. 1996. *A Practical Guide to Groundwater and Solute Transport Modeling*. John Wiley & Sons Inc. A Wiley Inter-Science Publication.
- Statistics Canada. 2012a. *Focus on Geography Series, 2011 Census*. Statistics Canada Catalogue no. 98-310-XWE2011004. Ottawa, Ontario. Analytical products, 2011 Census. Modified on October 24, 2012. <https://www12.statcan.gc.ca/census-recensement/2011/as-sa/fogs-spg/Index-eng.cfm?LANG=Eng>
- Statistics Canada. 2012b. *Brockton, Ontario (Code 3541032) and Bruce, Ontario (Code 3541) (table). Census Profile. 2011 Census*. Statistics Canada Catalogue no. 98-316-XWE. Ottawa. Released October 24, 2012. <http://www12.statcan.gc.ca/census-recensement/2011/dp->
- Waterloo Hydrogeologic, Inc. (WHI). 2003. *Grey and Bruce Counties Groundwater Study*. Final report prepared for County of Bruce, County of Grey, and Ontario Ministry of the Environment. Waterloo, Ontario. July 2003.
- Waterloo Numerical Modelling Corp. 2011. *Walkerton Wellfield (Wells 7 & 9) Groundwater Modelling and Wellhead Protection Area Delineation*. 2011.







I:\Saugen Valley Conservation Authority\GIS\501 Figures and Tables\TR201515\Report\Physical Characterization and Water Budget\Report\Figure 2.7 Hydrostratigraphic Cross Section N-S.mxd



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

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



Physical Characterization and Water Budget Report

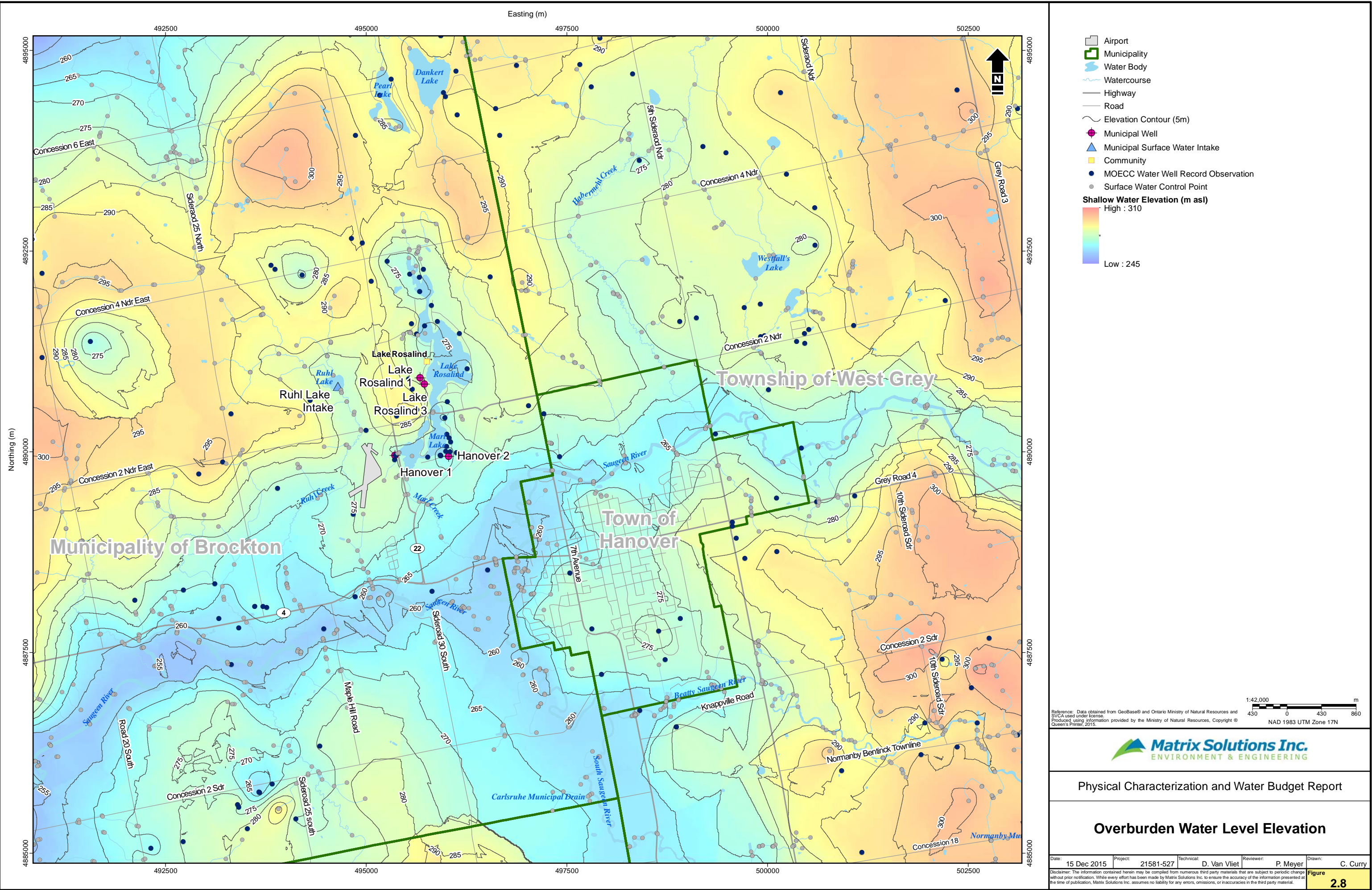
Hydrostratigraphic Cross Section N-S

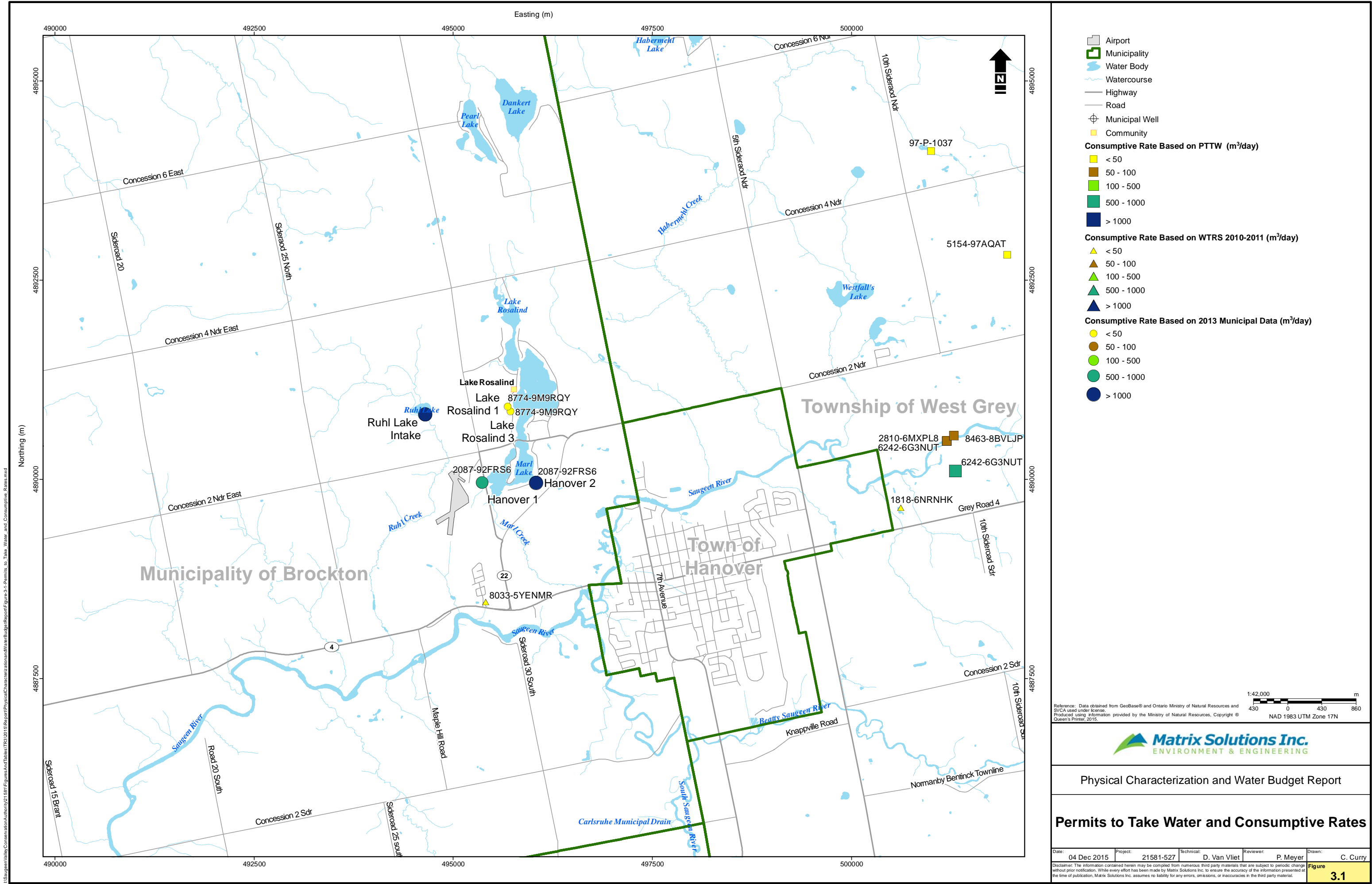
Date: 28 Aug 2015 Project: 21581-527 Technical: D. Van Vliet Reviewer: P. Meyer Drawn: M. Pfeifer

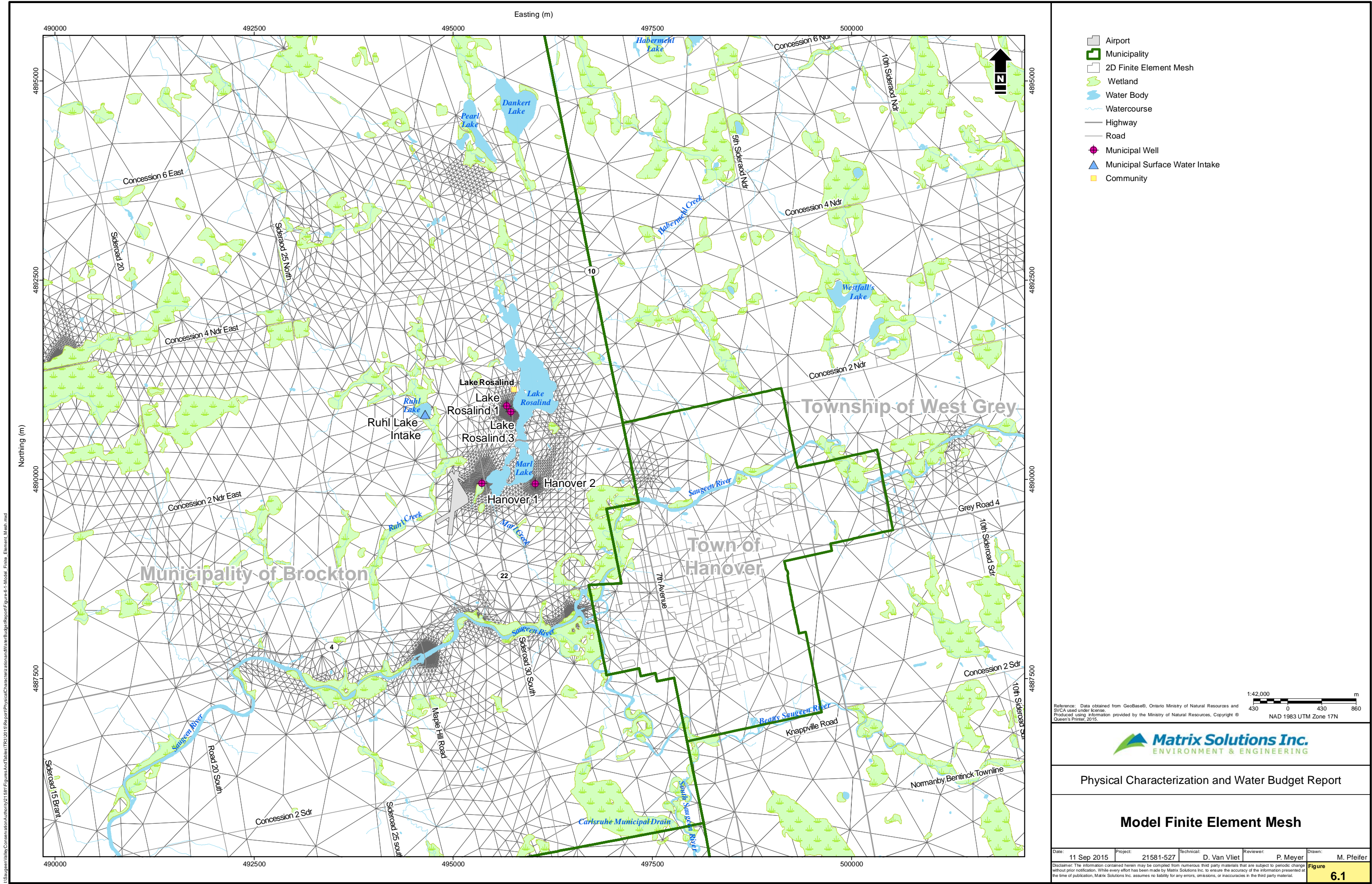
Disclaimer: The information contained herein may be compiled from numerous third party materials that are subject to periodic change without prior notification. While every effort has been made by Matrix Solutions Inc. to ensure the accuracy of the information presented at the time of publication, Matrix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

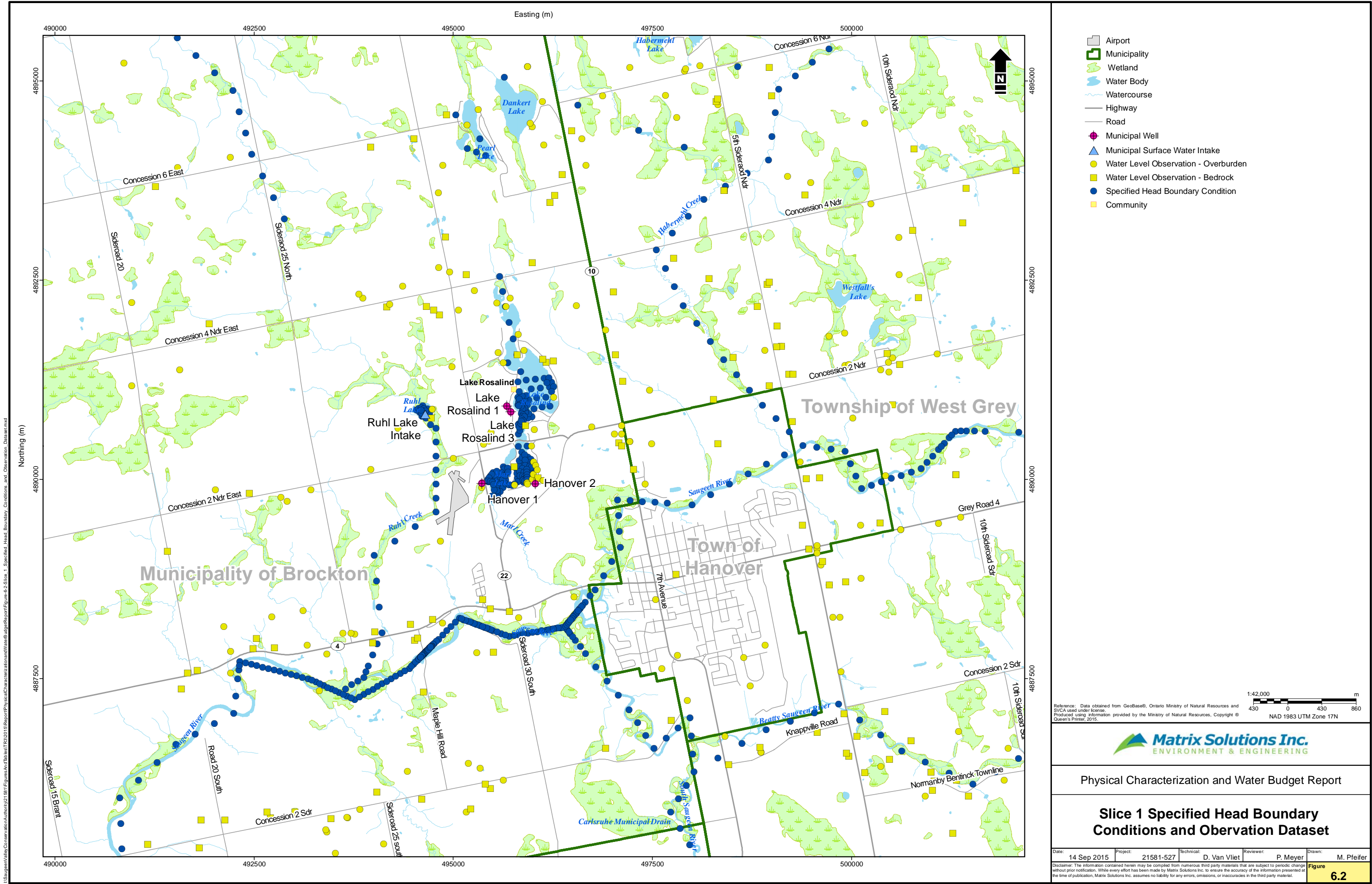
Figure 2.7

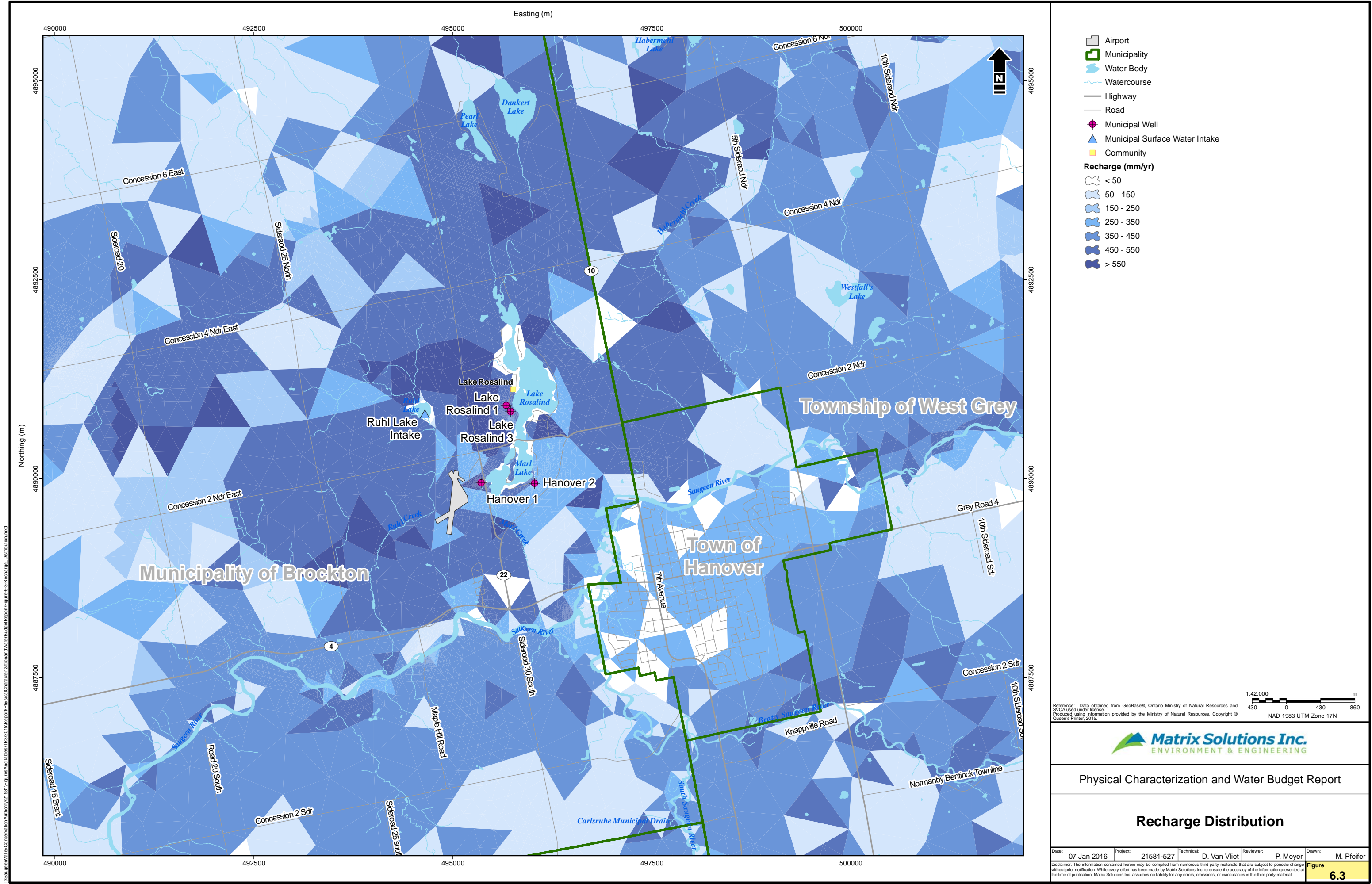
I:\Saugen\City Conservation Authority\21581-15\Report\Physical Characterization and Water Budget Report\Figure 2.8-Overburden Water Level Elevation.mxd

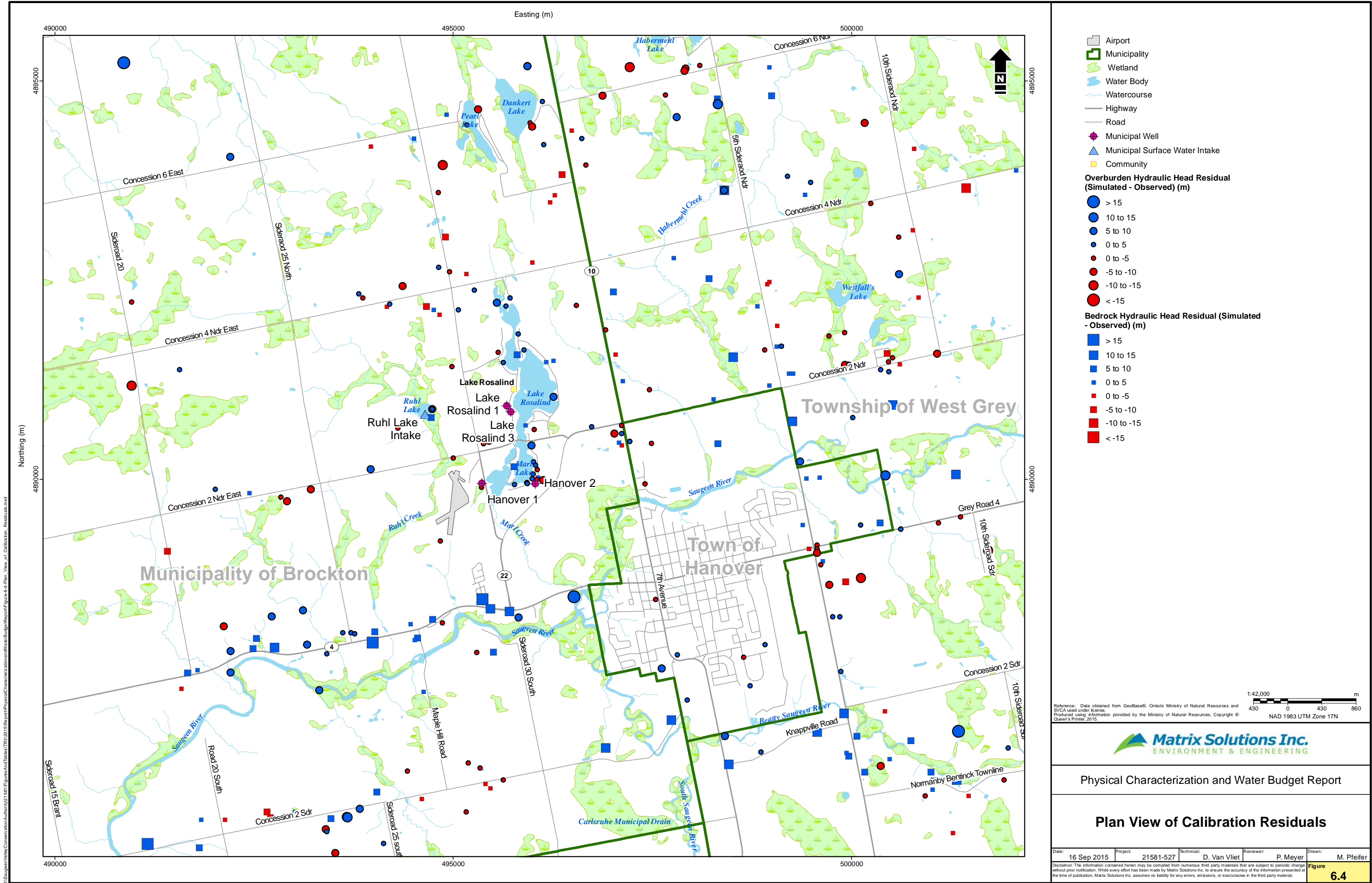


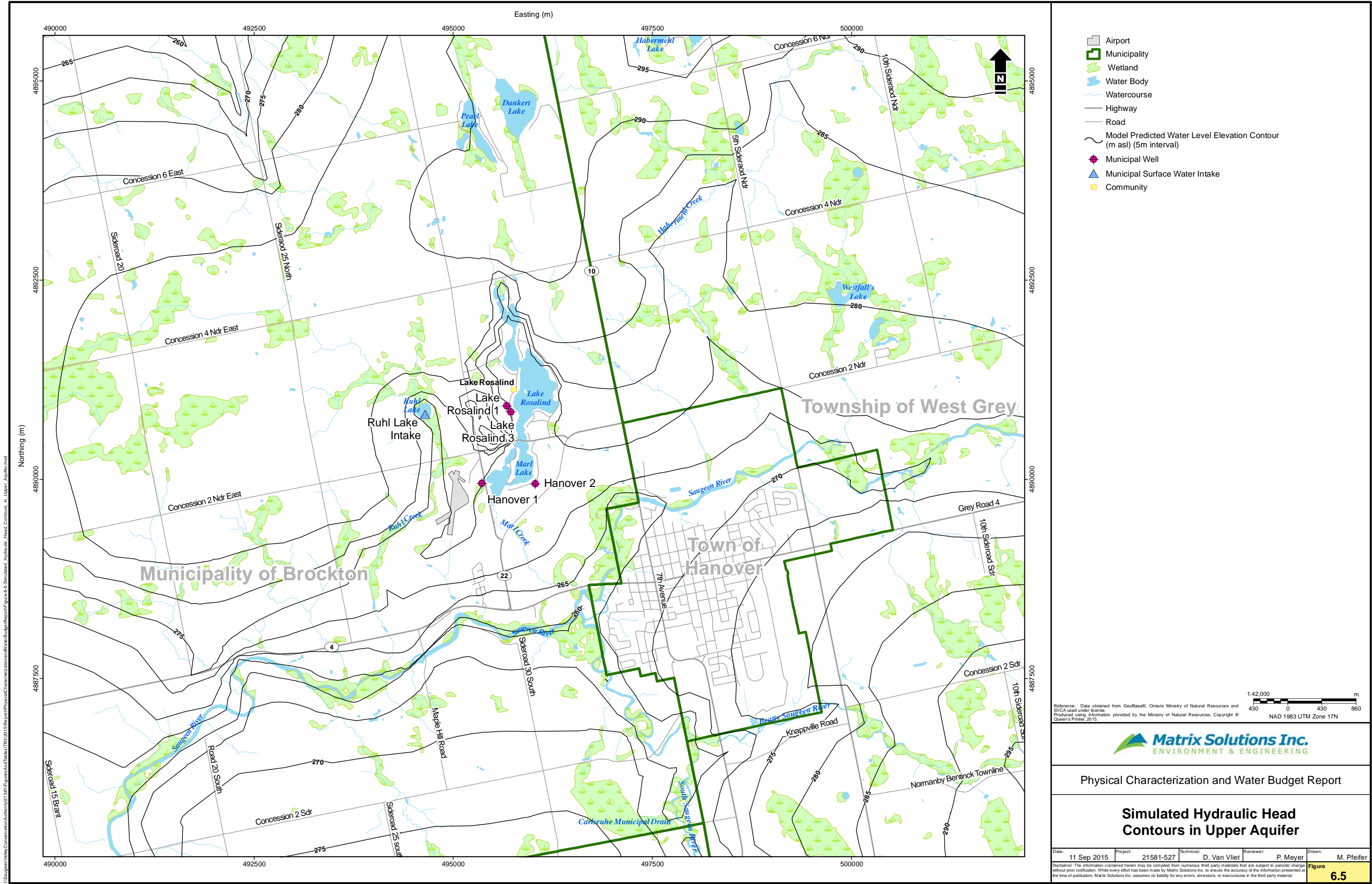


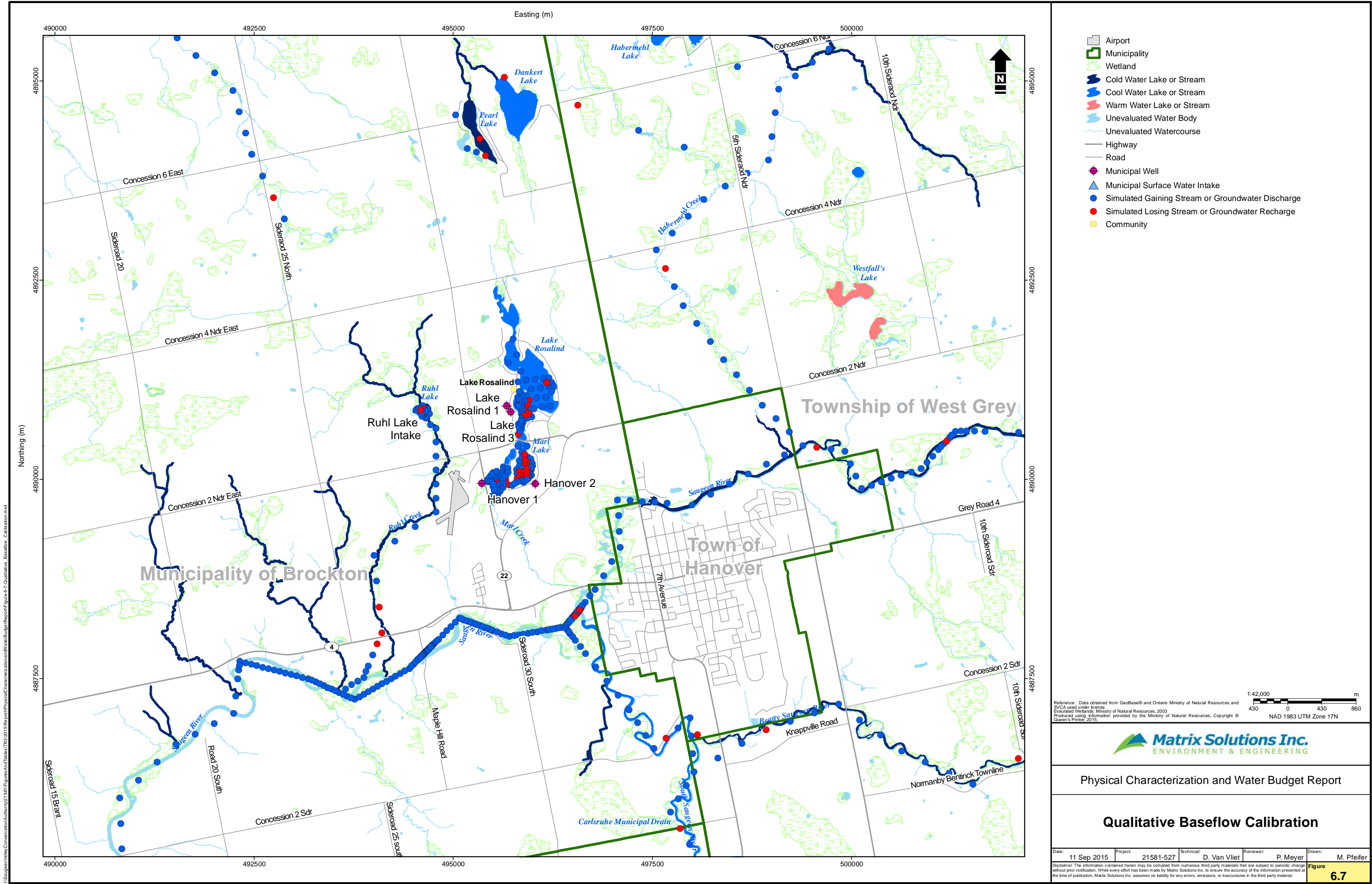












APPENDIX A

Municipal Production Well Logs

117^Z 49513510^E
 5^R 4889735^N
 5^R 488910
 22
 DE NORTH Lot 65
 PUC HANOVER
 (print in block letters)

The Ontario Water Resources Commission Act

WATER WELL RECORD

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

Township, Village, Town or City BRANT
 Date completed 29 (day) AUG (month) 1962 (year)
 Address

Casing and Screen Record		Pumping Test
diameter of casing 22" length of casing 80' of screen 30' th of screen 30' h to top of screen 80' eter of finished hole 10'		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	Water Record			
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'	
GRAVEL & SAND	50'	55'		
SAND & GRAVEL	55'	68'		
GRAVEL, SAND & Boulders	68'	71'		
GRAVEL & SAND	71'	76'		
PACKED SAND	76'	78'		
SAND, GRAVEL & Boulders	78'	110'		

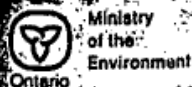
What purposes is the water to be used? Commercial Supply
 Is on upland, in valley, or on hillside?
 Drilling or Boring Firm INTERNATIONAL WATER SUPPLY LTD.
12 MAITLAND ST.
LONDON, ONT. (Box 816)
 License Number
 Name of Driller or Borer L. E. O'Brien
 Signature of Licensed Drilling or Boring Contractor
 7 5M-61-3852
 R C COPY

Location of Well #1
 In diagram below show distances of well from road and lot line. Indicate north by arrow.

Handwritten: Hanover #1

Handwritten: DW1

FIGURE A.1 Hanover Well 1



WATER WELL RECORD

Ministry of the Environment
The Ontario Water Resources Act
1406414
BRUCE GRANT
Town of Hanover Hanover Ontario
11 North Durham Rd 609
DATE COMPLETED 26 0 86

LOG OF OVERBURDEN AND BEDROCK MATERIALS (SEE INSTRUCTIONS)				
DEPTH - FEET	GENERAL DESCRIPTION	OTHER MATERIALS	COMMON MATERIAL	NATURAL COLOUR
FROM	TO			
0	2		Topsoil	
2	8	sandy	clay	Brown
8	25		Sand	
25	69	sandy, strks of sand	clay	Brown
69	105	sandy, strks of sand	clay	Grey
105	122	Boulders, some clay	Sand Gravel	
122	141	sandy & Gravel	clay	
141	180		Gravel Sand	

WATER RECORD	
WATER TABLE	KIND OF WATER
140-180	<input checked="" type="checkbox"/> FRESH <input type="checkbox"/> SULPHUR <input type="checkbox"/> SALT <input type="checkbox"/> MINERAL
180-220	<input type="checkbox"/> FRESH <input type="checkbox"/> SULPHUR <input type="checkbox"/> SALT <input type="checkbox"/> MINERAL
220-260	<input type="checkbox"/> FRESH <input type="checkbox"/> SULPHUR <input type="checkbox"/> SALT <input type="checkbox"/> MINERAL
260-300	<input type="checkbox"/> FRESH <input type="checkbox"/> SULPHUR <input type="checkbox"/> SALT <input type="checkbox"/> MINERAL

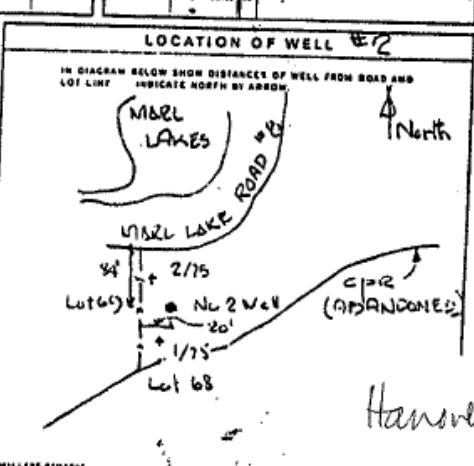
CASING & OPEN HOLE RECORD			
DEPTH - FEET	MATERIAL	THICKNESS - FEET	DEPTH - FEET
24	STEEL	.375	19.5 142
12	STEEL	.375	18.5 144

SCREEN
20 slot
12
36
Stainless steel
143

PLUGGING & SEALING RECORD
4 157 Cement Grout.

PUMPING TEST
702
72
31.53 80.91 80.7 84.15 84.75 85.66

FINAL STATUS OF WELL
WATER USE
METHOD OF DRILLING



CONTRACTOR
International Water Supply 2801
PO Box 310 Parrie Ont.
R. Wallace
14 7 86
MINISTRY OF THE ENVIRONMENT COPY

FIGURE A.2 Hanover Well 2

WATER WELL DATA SYSTEM Aug 13 1998										PAGE: 139	COUNTY: BRUCE	GROUND WATER BULLETIN REPORT									
MUNICIPALITY	CONCESSION	ETC	LOT	UTM NO	EASTING	ELEV	DATE	DRILLER	INS	CSG	KIND	WATER FOUND	STAT LVL	PUMP LVL	TEST RATE	TEST TIME	WATER USE	SCREEN DEPTH	SCREEN LENGTH	OWNER	DEPTHS IN FEET TO WHICH FORMATIONS EXTEND
CONTINUING... BRANT TOWNSHIP																					
DR N	03	066	14-	999999			1995/06		36	FR	0030	4									
				08781	9999999																
DR N	03	067	14-	495550	950		1987/04	1737													
				06589	4890690																
DR N	03	067	14-	495525	950		1987/02	1737	01	FR	0141					1 : 0		NU	0136	03	
				06542	4890520																
DR N	03	067	14-	495650	950		1987/02	1737													
				06543	4890410																
DR N	03	067	14-	495620	950		1987/03	1737	06	FR	0057	3	37	30	24 : 0		MN	0046	07		
				06544	4890300													0046	07		
DR N	03	067	14-	495560	950		1987/04	1737	08	FR	0060	3			70	48 : 0		MN	0047	12	
				06588	4890555													0047	12		
DR N	03	068	14-	495700	875		1985/10	1804	06	FR	0193	32	33	20	7 : 0		DO				
				06304	4890450																
DR N	03	069	14-	495890	900		1976/03	1804	05	FR	0170	15	30	15	3 : 30		DO				
				04092	4890450																
DR N	03	069	14-	496000	850		1985/10	1804	06	FR	0185	16	18	20	7 : 0		DO				
				06303	4890400																
DR N	03	069	14-	495966	930		1989/09	1804	05	FR	0160	44	94	6	2 : 20		DO	0156	04		
				07258	4890197																
DR N	03	069	14-	496040	926		1967/04	2801	06												
				00730	4890300																
DR N	03	071	14-	496240	940		1968/12	1804	04	FR	0152	30	65	15	2 : 0		DO				
				02191	4891260																
DR N	03	071	14-	496109	900		1974/09	1804	06	SU	0220	150	200	4	2 : 0		DO				
				03604	4891281																
DR N	03	071	14-	496240	900		1976/04	1804	05	FR	0140	FLW		25	2 : 20		DO				
				04091	4890850																
DR N	03	071	14-	496150	950		1979/10	1804	05	FR	0134	10	50	8	3 : 30		ST DO				
				05247	4891250																
WEDON, BRANT TOWNSHIP BRWN LOAM 0001 BRWN CLAY SNDR 0004 BRWN CSND 0008 BLUE CLAY SILT LYRD 0035 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 TOWNSHIP OF BRANT BRWN SILT CLAY 0012 BRWN SAND SILT FGDR 0018 GREY CLAY SILT MARL 0061 GREY SAND SILT FGDR 0076 GREY CLAY SILT FGDR 0099 GREY SAND CLAY FGDR 0136 GREY HPAN STNS GRVL 0171 GREY SHLE LMSN SOFT 0181 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 FGDR 0064 GREY CLAY SILT SAND 0123 GREY SAND CLAY FGDR 0142 GREY HPAN GRVL STNS 0146 GREY HPAN SAND MGRD 0162 GREY MSND SOFT 0164 GREY LMSN SHLE MGRD 0174 TOWNSHIP OF BRANT BRWN SAND SILT FGDR 0047 BRWN FSND CSND 0057 BRWN SAND SILT FGDR 0063 GREY CLAY SILT SOFT 0066 TOWNSHIP OF BRANT BRWN FSND SILT SOFT 0008 BRWN MSND SOFT 0019 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 SHENCK JACK GREY CLAY STNS 0022 GREY CLAY MARL 0066 GREY HPAN STNS GRVL 0173 GREY ROCK 0193 GRYGAS WINNIPED BRWN FILL 0002 BRWN CLAY STNS SAND 0020 BRWN CLAY 0090 GREY SAND 0168 BRWN CGVL 0172 KOENIG LORNE BRWN SAND CLAY 0012 BRWN CLAY CLAY 0122 BRWN STNS GRVL 0160 GREY ROCK 0185 CHARRON RON BRWN SAND 0040 BRWN SAND CLAY 0148 BRWN GRVL 0160 HANOVER PUC LOAM 0001 FSND LOAM 0014 SNDRS CLAY MSND 0025 FSND SILT 0041 CLAY SILT 0143 CLAY GRVL 0147 GRVL CLAY MSND 0190 LMSN 0191 HARTMAN BERNIE MSND 0030 GREY CLAY 0060 CLAY MSND 0100 QSND 0120 CLAY MSND 0146 GREY LMSN 0159 COSTIC D RED CLAY 0130 BLUE SHLE 0200 BRWN ROCK 0226 MULLEN LORNE BRWN FILL 0002 BRWN SAND MARL 0050 BRWN SAND GRVL CLAY 0120 BLUE SHLE SOFT 0128 BLCK ROCK 0148 OSTHOFF P GREY MARL 0081 BRWN SAND 0128 GREY STNS SOFT 0134																					

← TW 5

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