CITY OF GUELPH AND TOWNSHIP OF GUELPH/ERAMOSA TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

Report Prepared for:
LAKE ERIE SOURCE PROTECTION REGION

Prepared by:
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CITY OF GUELPH AND TOWNSHIP OF GUELPH/ERAMOSA

TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

Report prepared for the Lake Erie Source Protection Region, March 2017

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EXECUTIVE SUMMARY

Introduction

This report describes the Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) completed for municipal drinking water systems of the City of Guelph and the Township of Guelph/Eramosa within the Province of Ontario, Canada. As a requirement under the province's *Clean Water Act* (Bill 43; Government of Ontario 2017), the purpose of the Tier Three Assessment was to identify the Water Quantity Threats to these municipal drinking water systems.

The Province of Ontario introduced the *Clean Water Act* to ensure that all residents have access to safe drinking water. Under the *Clean Water Act*, Source Protection Authorities are required to conduct technical studies to identify existing and potential Water Quality and Quantity Threats to municipal drinking water. Through the development of community-based Source Water Protection Plans, actions will be implemented to reduce or eliminate any *Significant* Drinking Water Threats.

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

The City of Guelph's water supply system consists of 23 wells constructed within overburden aquifers and deep bedrock aquifers, and an artificial groundwater recharge system with a shallow groundwater collector referred to as the Glen Collector. The Township of Guelph/Eramosa has municipal systems located in Rockwood and Hamilton Drive, which are serviced by four and two bedrock water supply wells, respectively. The water supply wells are located within the Upper Speed Assessment Area of the Grand River Watershed. The Tier Two Water Budget and Subwatershed Stress Assessment completed for the Grand River Watershed (AquaResource 2009a, 2009b) identified this area as having a *Moderate* potential for groundwater stress. The identification of this stress indicator led to the requirement of a Tier Three Assessment for the City of Guelph and the Township of Guelph/Eramosa (Rockwood and Hamilton Drive wells), because the municipal wells are located within this area.

This report details the Tier Three Assessment carried out for the City of Guelph and the Township of Guelph/Eramosa. It summarizes the process and results of the Local Area Risk Assessment. Five peer-reviewed companion reports summarize the development of the conceptual and numerical hydrologic and hydrogeologic models used to complete the assessment:

- Appendix A: Characterization Final Report

- Appendix B: Groundwater Flow Model Report
- Appendix C: Characterization Update - Rockwood and Hamilton Drive
- Appendix D: Groundwater Flow Model Update - Rockwood and Hamilton Drive
- Appendix E: 2016 Groundwater Flow Model Updates

Scope of Work

The scope of work completed in this Tier Three Assessment and documented in this report follows the Province of Ontario's *Technical Rules: Assessment Report, Clean Water Act, 2006* (Technical Rules; MOECC 2016), *Technical Bulletin: Part IX Local Area Risk Level* (Technical Bulletin; MOE and MNR 2010), and the *Memorandum: Assignment of Water Quantity Risk based on the Evaluation of Impacts to Other Water Users* (Technical Guidance Memorandum; MOE 2013).

The following tasks were completed for this study:

- develop the conceptual understanding of the Study Area
- develop and calibrate a groundwater flow model with sufficient detail to simulate groundwater flow near municipal wells and surface water features
- develop and calibrate a streamflow-generation to simulate variable streamflow in the area and to estimate groundwater recharge rates in the Study Area
- apply the calibrated surface water and groundwater models to assess the water budget components in the Study Area and near municipal wells
- complete a Local Area Risk Assessment for the municipal wells located in the Study Area

Water Budget Tools

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

The groundwater and surface water modelling approach was designed to simulate average and drought conditions, represent the detailed hydrologic and/or hydrogeologic conceptual model, and integrate the inputs and outputs of the surface water and groundwater models (e.g., groundwater recharge and baseflow). The groundwater flow model was developed using FEFLOW (Diersch 2006) based on the best geological and hydrogeological data available for the Study Area. The continuous streamflow-generation model was developed using *Guelph All-Weather Sequential-Events Runoff* (GAWSER; Schroeter &

Associates 2004). Appendices B, D, and E of this report describe the development and calibration of the surface water and groundwater models in detail.

Consumptive Water Demand

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

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

Current and historical groundwater pumping and monitoring data were also compiled as part of this study (Appendices A and C); it was found that the City of Guelph, and the Township of Guelph/Eramosa (Rockwood and Hamilton Drive wells) have never experienced significant problems pumping water from the municipal pumping wells.

Tier Three Water Budget

The Tier Three Assessment provides an improved estimate of the water budget components included in the hydrologic cycle within the Study Area. The surface water and groundwater flow models developed for the Tier Three Assessment were used to estimate average annual values for the various components of the hydrologic cycle. The combined results of the water budget models produce an improved conceptualization of the hydrologic and hydrogeologic flow systems.

Using the improved estimates of water budget components, a Groundwater Stress Assessment was conducted for the Upper Speed Assessment Area. Using the Tier Three Water Budget models, under Existing conditions, the assessment area was found to have an estimated percent water demand of 21% under average annual demand and 26% under maximum monthly demand. These estimates result in a classification of *Moderate* potential for stress under average demand conditions and a *Moderate* potential for stress under maximum monthly demand conditions. Under Planned Conditions, the assessment area has an estimated percent water demand of 29% under average annual demand and 35% under maximum monthly demand. Based on the thresholds established by the Province (*Water Budget & Water Quantity Risk Assessment Guide*; AquaResource 2011a), these estimates result in a classification of *Significant* potential for stress under average annual demand conditions and a *Moderate* potential for stress under maximum monthly demand conditions.

Local Area Risk Assessment

Local Areas were delineated that surround the Tier Three municipal intake and supply wells and coincide with the groundwater Vulnerable Areas (WHPA-Q1/WHPA-Q2) and Surface Water Vulnerable Area (IPZ-Q). Specifically, these areas represent the following:

1) the cone of influence of each municipal well plus the cones of influence of wells that it intersects (WHPA-Q1)

2) land areas where recharge has the potential to have a measurable impact on water levels at the municipal wells (WHPA-Q2)

3) the drainage area and associated recharge area that contribute to the surface water intake (IPZ-Q)

A Local Area Risk Assessment is being completed concurrently for the Regional Municipality of Waterloo's municipal wells within the City of Cambridge. A separate three dimensional (3D) groundwater flow model has been developed to support this assessment, sharing the same conceptual geological model and part of the same geographical model area with the City of Guelph and Township of Guelph/Eramosa Tier Three Assessment; however, the Cambridge model extends west of the Grand River to include additional Cambridge wells. The WHPA-Q1 and WHPA-Q2 developed for Cambridge cover much of the same area between the cities of Guelph and Cambridge as this study; therefore, the groundwater Vulnerable Areas derived from the two studies have been truncated where they overlap into adjacent study areas. For this Tier Three Assessment, Groundwater Vulnerable Area A extends 2 km southwest of the groundwater divide between the Guelph and Cambridge Vulnerable Areas.

A set of Risk Assessment scenarios was developed to represent the municipal Allocated rates (Existing plus Committed pumping rates), and current and future land uses (as defined by the Official Plans). The calibrated groundwater flow model was used to estimate both the changes in water levels in the municipal supply aquifer and the impacts to groundwater discharge and baseflow under average and drought climate conditions.

The drawdown under each of the Risk Assessment scenarios was calculated and compared to the safe additional available drawdown at each municipal well. The drawdown at each well is calculated relative to the 2008 average pumped conditions (for the City of Guelph wells) and the interpreted low operating water levels (for the Hamilton Drive and Rockwood wells), and accounts for well losses at each municipal well. For the 10-year drought scenarios, the maximum drawdown (relative to Scenario C) over the entire drought simulation is examined. The model simulated drawdown was then compared to the safe additional available drawdown to identify municipal wells where there is a potential that the wells will be unable to pump at their Allocated rates. Queensdale Well was predicted to be unable to pump at its Allocated rate during average climate and drought conditions. As a result, Groundwater Vulnerable Area A was assigned a *Significant* Risk Level. As the Surface Water Vulnerable Area and Groundwater Vulnerable Area A are interconnected through the Glen Collector and the artificial recharge system that is supplied by the Eramosa River Intake, the Surface Water Vulnerable Area was also assigned a *Significant* Risk Level.

Simulated groundwater discharge reductions were examined for the average climate and increased demand scenario. There are six locations where baseflow is simulated to be reduced by 10% or more:

- Torrance Creek (41%)
- Chilligo/Ellis Creek at Wellington Road 32 (32%)
- Hanlon Creek South Tributary at Highway 6 (31%)
- Blue Springs Creek South Branch at 28th Side Road (27%)
- Hanlon Creek at Waterfowl Park (19%)
- Hanlon Creek at Highway 6 (11%)

As Chilligo/Ellis Creek, Blue Spring Creek, and Hanlon Creek are classified as cold-water streams and have simulated baseflow reductions of 10% or more, a Water Quantity Risk Level classification of *Moderate* would have been assigned to Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area. However, due to the Queensdale Well's inability to pump at its Allocated rate, a Risk Level of *Significant* was already assigned.

Irish Creek at Townline Road was also predicted to have groundwater discharge reduced by 10% or more (14%); however, this stream was considered to be situated too close to the model boundary for an accurate assessment of impacts in this study.

The Technical Rules state that an uncertainty assessment on the assignment of a Risk Level to the Local Areas is required. If a Vulnerable Area is assigned a Risk Level of *Moderate* based on the scenarios assessed, the Risk Level should be assigned as *Significant* if an uncertainty analysis characterizes the uncertainty as *High* and a sensitivity analysis suggests that the Risk Level of the Vulnerable Area could be *Significant*. As Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area were assigned a Risk Level of *Significant* based on predicted safe available drawdown exceedance at the Queensdale Well, an uncertainty analysis on predicted impacts to cold-water streams or Provincially Significant Wetlands (PSWs) cannot increase the Risk Level any higher but is still useful for guiding future efforts to increase the certainty of model predictions.

The uncertainty with respect to the impacts on discharge to cold-water streams and PSWs is *High*; however, this uncertainty does not impact the Risk Level that was already *Significant*. There is also a *High* level of uncertainty with respect to the predicted ability of Arkell Well 1 to pump at its Allocated rate under existing and future land uses during drought conditions. The maximum predicted drawdown at Arkell Well 1 leaves about 0.1 m of available drawdown in the well. Considering that Arkell Well 1 is a shallow overburden well and is highly influenced by recharge, and recharge is a high source of uncertainty, it is concluded that this well may not be able to pump the Allocated rate under drought conditions. If predicted drawdown at the Queensdale Well did not trigger a *Significant* Risk Level, the *High* uncertainty in the predicted results at Arkell Well 1 would have triggered a *Significant* Risk Level.

The uncertainty with respect to the predicted drawdown at other municipal wells, including the Queensdale Well, is *Low*. The refinements made to the hydrostratigraphic model of the City of Guelph and the Township of Guelph/Eramosa groundwater flow system has been developed over a number of years. The groundwater flow model is well-calibrated to water levels measured at high-quality observation wells throughout the Study Area. The model results are also consistent with well capacity estimates based on traditional hydrogeology analytical techniques.

Following the Technical Rules, all consumptive water users and potential reductions to groundwater recharge located within Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area are classified as *Significant* Water Quantity Threats. Consumptive groundwater and surface water users considered include the municipal and non-municipal permitted water demands within the Study Area. Domestic wells extract very little water as compared to permitted consumptive water users on the scale of the Tier Three Assessment. However, domestic wells are considered Drinking Water Threats in paragraph 19 of subsection 1.1(1) of O. Reg. 287/07 (General; Government of Ontario 2015) and thus were enumerated in this study. A Threats Ranking exercise will be undertaken as part of a Risk Management Measures Evaluation Process (RMMEP). This will further define the significance of each Water Quantity Threat to the Risk Level.

Conclusions

The Local Areas in this Tier Three Assessment are represented by the Groundwater and Surface Water Vulnerable Areas. Groundwater Vulnerable Area A is circular with a diameter of approximately 20 km around the City of Guelph and the Township of Guelph/Eramosa wells in Hamilton Drive. The extent of Groundwater Vulnerable Area A to the southwest toward the City of Cambridge was delineated based on the results of the groundwater flow model developed for this Tier Three Assessment and another groundwater flow model developed for the City of Cambridge wells as part of the Tier Three Assessment for the Region of Waterloo (Matrix and SSPA 2014).

The Tier Three Assessment scenarios demonstrated that the City of Guelph’s Queensdale Well will not be able to pump at the Allocated rates under average and drought conditions. All other municipal wells of the City of Guelph and the Township of Guelph/Eramosa in Rockwood and Hamilton Drive are expected to be able to pump at their current and Allocated rates under all conditions, but there is a *High* level of uncertainty with the results for the City of Guelph’s Arkell Well 1. The scenario results are supported by historical operating experience in the City of Guelph where many of the wells have pumped at rates equivalent to their Allocated rates over prolonged periods of time. The primary municipal water supply aquifer is protected in most areas by the Vinemount Member aquitard, which reduces the vulnerability of the supply to drought. While all Tier Three municipal wells except the Queensdale Well are expected to meet their Allocated rates, water levels at Arkell Well 1, Arkell Well 8, Arkell Well 14, Arkell Well 15, Burke Well, Carter Well, Emma Well, and Rockwood Well 3 may be more susceptible to drought conditions. This result demonstrates the Water Quantity Risks to the City of Guelph's water supply and, although only Queensdale Well exceeded the safe water level in the drought scenario, redistributing pumping to other wells might not mitigate the *Significant* Risk Level without other Risk Management Measures.

Even with the recent permitting of all Arkell Spring Ground wells, the City of Guelph's water supplies do not have the capacity to meet the 2031 estimated water demand due to the predicted impacts as Queensdale Well. Furthermore, the City of Guelph will require all wells to be pumped at their Allocated rates, leaving little redundancy in the system. Redundancy is required to allow for rehabilitation and maintenance of one or more wells, loss of one or more wells due to contamination, or long-term interference from other water users.

Recharge reductions, in response to future land developments defined by the Official Plans, have a minimal impact on water levels at the Tier Three municipal pumping wells. The Gasport Formation aquifer is protected in most areas by the Vinemount Member aquitard, which reduces the impact of reduced groundwater recharge occurring at locations near the production wells on water levels in the aquifer. With respect to the City of Guelph and Rockwood, future land developments generally occur around the periphery of these communities with a minimal increase in imperviousness over the Local Area.

There is a potential that pumping may decrease groundwater discharge to wetlands and cold-water streams. The steady-state model results show decreases in groundwater discharge in cold-water streams, such as the South Branch of Blue Springs Creek, Chilligo/Ellis Creek, and Hanlon Creek, that are 10% or more; there are predicted reductions of shallow groundwater levels greater than 1 m around PSWs in the northwest, northeast, and southeast areas of the City of Guelph. As a result, Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area would be assigned a *Moderate* Risk Level if the drawdown threshold had not been exceeded at the Queensdale Well resulting in a *Significant* Risk Level. There is a *High* level of uncertainty with respect to the predicted impacts to cold-water streams and wetlands.

The Risk Assessment scenarios illustrate that all but one municipal well (the Queensdale Well) can meet Allocated rates under average and drought conditions. There is also a *High* level of uncertainty that Arkell Well 1 will be able to meet Allocated rates under the same conditions. Therefore, a *Significant* Risk Level was assigned to the Groundwater Vulnerable Area A. This Risk Level was also applied to the Surface Water Vulnerable Area as it is linked to the Groundwater Vulnerable Area A through the Glen Collector and the artificial recharge system fed by the Eramosa Intake. Groundwater Vulnerable Areas B, C, and D were assigned a *Low* Risk Level.

Key Recommendations

This report suggests key recommendations to reduce the uncertainties of this Tier Three Assessment. For Blue Springs Creek, an update to the conceptual and numerical model in this area based on recent data is recommended. Particular attention should focus on groundwater/surface water interactions in the Arkell-Corwhin Wetland Complex. An integrated groundwater/surface water model (e.g., MIKE SHE) could be introduced to better represent wetland hydrology and groundwater/surface water interactions in that area. The Risk Assessment identified potential impacts to PSWs in the southeast, northeast, and northwest quadrants of the City of Guelph. Recommended work includes the refinement of the shallow conceptual model and the incorporation of new data from studies of the fractured bedrock into updated conceptual and numerical models.

Risk Management Measures Evaluation Process

As a *Significant* Risk Level was assigned to Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area, and as all consumptive water uses and areas of groundwater recharge reductions within these Vulnerable Areas are classified as *Significant* Drinking Water Threats, a RMMEP is required.

The first step in the RMMEP is a Threats Ranking exercise that evaluates the impact of individual or groups of consumptive water uses, and land use development activities on municipal water supplies. The Threats Ranking will help direct the Source Protection Committee toward possible Risk Management Measures that may be implemented to reduce or eliminate *Significant* Drinking Water Quantity Threats.

Following the Threats Ranking portion, the RMMEP involves the selection and evaluation of Risk Management Measures, using the water budget models developed in the Tier Three Assessment, to determine measures that could be used to reduce the Water Quantity Risk Level within the Local Area(s). The objective of the RMMEP is to help prepare a Threats Management Strategy that provides guidance to the Source Protection Committee to ensure the long-term sustainability of the water resource that supply the municipal drinking water systems.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

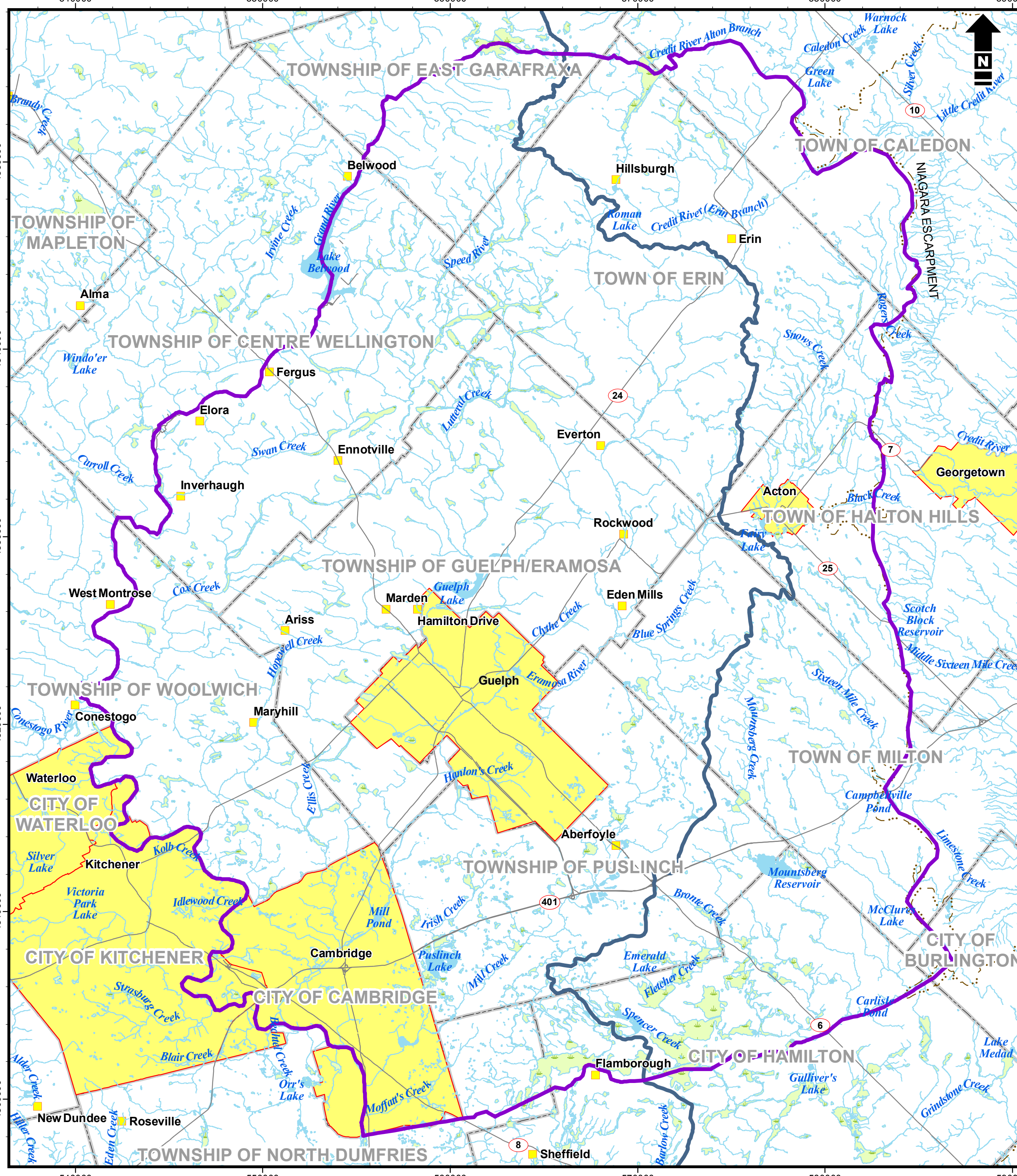
APPENDIX A	Characterization Final Report (separate companion report)
APPENDIX B	Groundwater Flow Model Report (separate companion report)
APPENDIX C	Characterization Update - Rockwood and Hamilton Drive
APPENDIX D	Groundwater Flow Model Update - Rockwood and Hamilton Drive
APPENDIX E	2016 Groundwater Flow Model Updates
APPENDIX F	Safe Additional Available Drawdown
APPENDIX G	Drought Scenario Results
APPENDIX H	Local Area Overlap Memo
APPENDIX I	Provincial Peer Review Comment Record
APPENDIX J	Municipal Peer Review Comment Record

1 INTRODUCTION

The Province of Ontario introduced the *Clean Water Act* (Bill 43; Government of Ontario 2017) to ensure that all residents have access to safe drinking water. Ontario's *Clean Water Act* requires that local communities, through local Source Protection Committees, assess existing and potential Water Quality and Quantity Threats to municipal drinking water, and that they set out and implement actions needed to reduce or eliminate these threats.

Under the requirements of the *Clean Water Act*, municipalities may be required to complete a Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) to assess the ability of the municipal water sources to meet Existing and Planned municipal water demands. Tier Three Assessments are required where municipal wells or intakes are located in subwatersheds that were classified as having a *Moderate* or *Significant* stress as part of a Tier Two Subwatershed Stress Assessment completed under the requirements of the *Clean Water Act*. The Tier Three Assessments identify municipal wells or intakes that may be unable to meet their Allocated rates or have an adverse effect on other regulated water needs such as cold-water fisheries or Provincially Significant Wetlands (PSWs). If the assessment results in conditions where municipal wells cannot meet their Allocated demands or if there is an impact on other regulated water needs, activities resulting in consumptive water use or groundwater recharge reduction may be classified as *Moderate* or *Significant* Drinking Water Threats.

Following the completion of the *Integrated Water Budget Report, Grand River Watershed* Report (AquaResource 2009a) and *Tier 2 Water Quantity Stress Assessment Report, Grand River Watershed* (AquaResource 2009b), a Tier Three Assessment was required for the municipal water supply systems of the City of Guelph and the Township of Guelph/Eramosa in Rockwood and Hamilton Drive. According to the Stress Assessment (AquaResource 2009b), some of the municipal water supplies for the City of Guelph are located within the Upper Eramosa River Subwatershed and the Upper Speed Assessment Area, which were classified as having a *Moderate* stress level from a surface water and groundwater perspective, respectively. The Township of Guelph/Eramosa municipal groundwater supplies located in Rockwood and Hamilton Drive are also found within the Upper Speed Assessment Area. While there are no documented issues with respect to the municipal sources meeting demand, the municipalities are required to complete a Tier Three Assessment. Figure 1-1 illustrates the overall Study Area and Figure 1-2 illustrates the locations of Tier Three municipal water supply wells for the City of Guelph and the Township of Guelph/Eramosa considered in this project.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Wetland
Water Body
Watercourse
Major Road
Niagara Escarpment

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Kilometres
NAD 1983 UTM Zone 17N

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Study Area

Date: 21 Dec 2016	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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Figure 1-1

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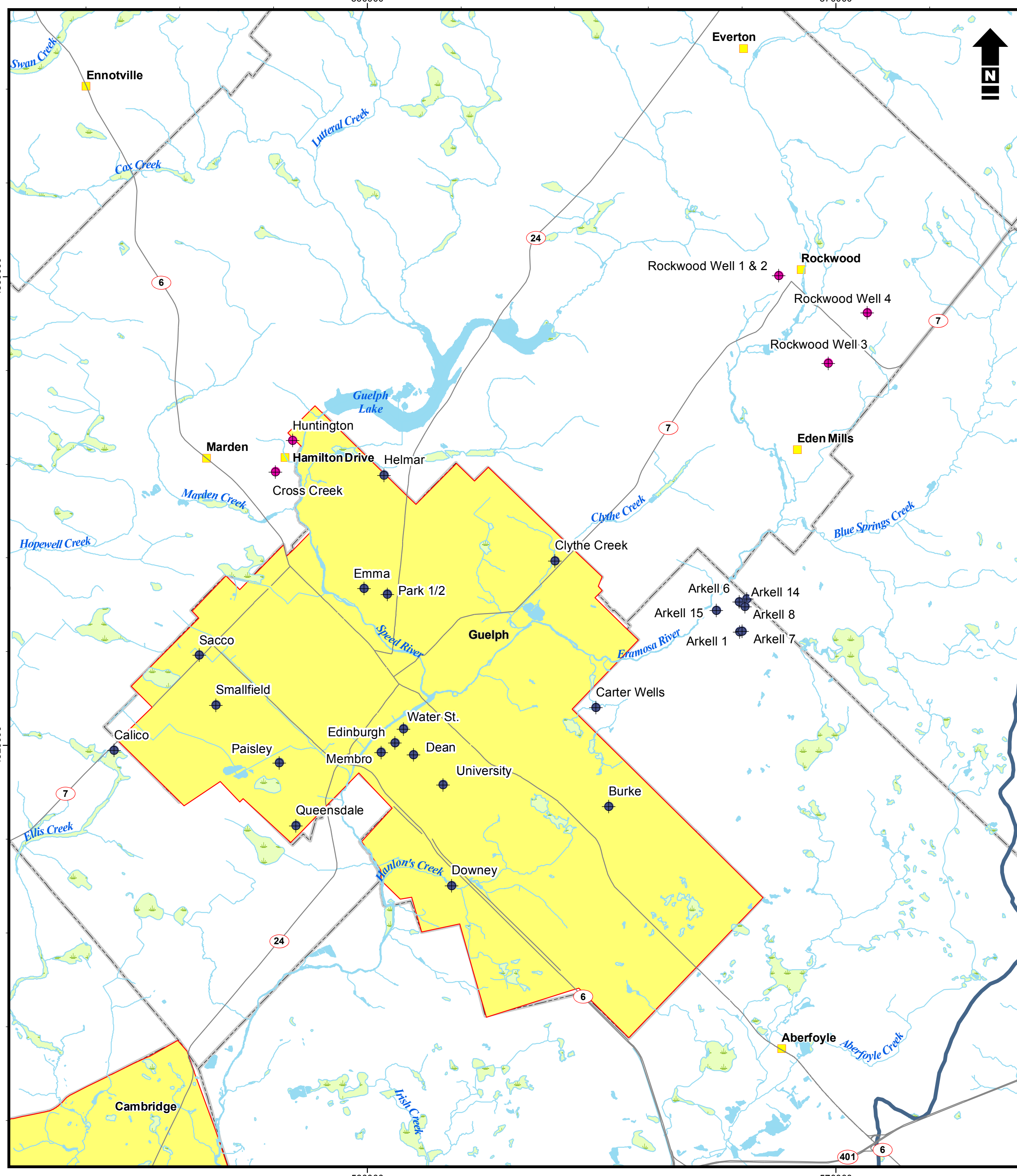

Grand River Watershed Boundary
Community
Wetland
Water Body
Watercourse
Major Road
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

1:120,000

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Kilometres

NAD 1983 UTM Zone 17N

Referenece: Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008. Produced using information provided by the Grand River Conservation Authority. Copyright © Grand River Conservation Authority, 2013. Produced using information provided by the Ministry of Natural Resources, Copyright © Queen's Printer, 2013

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Tier Three Municipal Water Supply Wells

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

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Figure 1-2

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This report details the Tier Three Assessment carried out for the City of Guelph and the Township of Guelph/Eramosa (for supplies in Rockwood and Hamilton Drive). The report summarizes background information relating to the geology and hydrogeology of the area, current and future water demands, and the process and results of the Tier Three Assessment. Two companion reports (Characterization Final Report [Appendix A] and Groundwater Flow Model Report [Appendix B]) summarize the development of the conceptual and numerical hydrologic and hydrogeologic models used to complete this Tier Three Assessment for the Study Area. The Characterization Update (Appendix C) and the Groundwater Flow Model Update (Appendix D) provide details about the refining of the conceptual and numerical models in the areas of Rockwood and Hamilton Drive. The 2016 Groundwater Flow Model Updates (Appendix E) describes updates made to the Tier Three Assessment numerical model in 2016, subsequent to those documented in Appendix D.

The Risk Assessment process and results are outlined in this report with additional details provided for the calculation of the Safe Additional Available Drawdown for the municipal wells (Appendix F), the Drought Scenario Results (Appendix G), and the delineation of Groundwater Vulnerable Area A separate from the City of Cambridge Local Area (Local Area Overlap Memo [Appendix H]).

1.1 Project Team

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

- The City of Guelph
- Lake Erie Source Protection Region
- Ontario Ministry of Natural Resources and Forestry (MNRF)
- Ontario Ministry of Environment and Climate Change (MOECC)

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

- Matrix Solutions Inc. (Matrix; Primary Consultant)
- Golder Associates Ltd. (Golder)

1.2 Peer Review

This study was peer reviewed on behalf of the Lake Erie Source Protection Region by three hydrogeology and hydrology experts to ensure the technical aspects of the study complied with the *Technical Rules: Assessment Report, Clean Water Act, 2006* (Technical Rules; MOECC 2016) and to provide guidance to the project team. Their comments and the project team's responses are provided in Appendix I. This Provincial Peer Review team consisted of the following:

- Tony Lotimer - ARL Groundwater Resources Ltd.
- Dr. David Rudolph - University of Waterloo

- Dr. Hugh Whiteley - University of Guelph

Municipalities local to the Study Area also provided technical review for consideration by the project team and the Provincial Peer Review team, and consisted of the following:

- Wellington County
- The Township of Guelph/Eramosa
- The Township of Puslinch
- The Town of Erin
- The Regional Municipality of Waterloo

Comments by the reviewers on behalf of the municipalities and responses by the project team and Provincial Peer Review team are provided in Appendix J.

1.3 Study Area

The Study Area is illustrated on Figure 1-1 and was selected to encompass the entire hydrogeological system that influences the municipal water supply wells of the City of Guelph and the Township of Guelph/Eramosa. The Study Area model domain encompasses the City of Guelph and the Townships of Puslinch and Guelph/Eramosa, as well as portions of Wellington County, Dufferin County, the Regional Municipality of Waterloo, the Regional Municipality of Halton, and the City of Hamilton. The model domain has a maximum width of approximately 45 km (west-east) and maximum length of 55 km (north-south) and an area of 1,925 km^2.

From a hydrologic perspective, the model domain encompasses the entire Speed River and Eramosa River watersheds. The model domain is bounded to the west by the Grand River, a natural groundwater flow boundary condition, and to the east by the Niagara Escarpment. The carbonate aquifers that supply a significant portion of the area's municipal water supplies pinch out at the Escarpment and, as such, represent a natural boundary condition. No natural or physical flow boundaries exist south of the model area; therefore, a boundary condition was applied that followed constant groundwater elevations based on interpreted groundwater elevation contours.

The boundaries of the model are located at a sufficient distance from the Guelph, Rockwood, and Hamilton Drive municipal water supply wells such that the boundaries do not influence the simulated groundwater flow conditions associated with the existing municipal water wells.

Additional Tier Three Assessments have been completed near the current Study Area including the Halton Hills (Acton/Georgetown) Assessment (AECOM and AquaResource 2014), located to the east, and the Regional Municipality of Waterloo (Cambridge, Waterloo, and Kitchener) Assessment (Matrix and SSPA 2014), located to the southwest. A Tier Three Assessment (AquaResource 2011b) has already been performed north of the current Study Area for the municipal drinking water systems within the towns of Orangeville and Mono and the Township of Amaranth.

1.3.1 The City of Guelph's Drinking Water Supply

The City of Guelph is one of the largest cities in Canada to rely almost exclusively on groundwater for its potable water supply. The City of Guelph maintains a groundwater supply system (Figure 1-2) that includes 23 groundwater wells that are distributed throughout the City of Guelph and a shallow groundwater collection system (Glen Collector) located at the Arkell Spring Grounds (see Arkell municipal wells located on Figure 1-2).

The groundwater supplies are predominantly drawn from deep bedrock aquifers (e.g., Gasport and Guelph formations), but are also derived from overburden deposits (e.g., outwash sands and gravels) and a mixture of overburden and weathered/shallow bedrock (i.e., Contact Zone). The shallow groundwater collection system (Glen Collector) found at the Arkell Spring Grounds collects water that has recharged the subsurface naturally and also water that is drawn from the Eramosa River Intake and recharged artificially through a recharge pit and trench located upgradient of the Glen Collector.

1.3.2 Rockwood's Drinking Water Supply

The residents of Rockwood are serviced by four municipal groundwater wells completed within the limestone bedrock. Rockwood wells 1 and 2 are adjacent to each other and located within the Station Street pump house on the northwestern side of town, west of the Eramosa River. Rockwood Well 3 is located east of the Eramosa River, within the Bernardi pump house on the southeastern side of town. Rockwood Well 4 was recently constructed northeast of Well 3 and was permitted under a consolidated permit to take water (PTTW) that covers the four wells. It is expected to be in full operation in the near future.

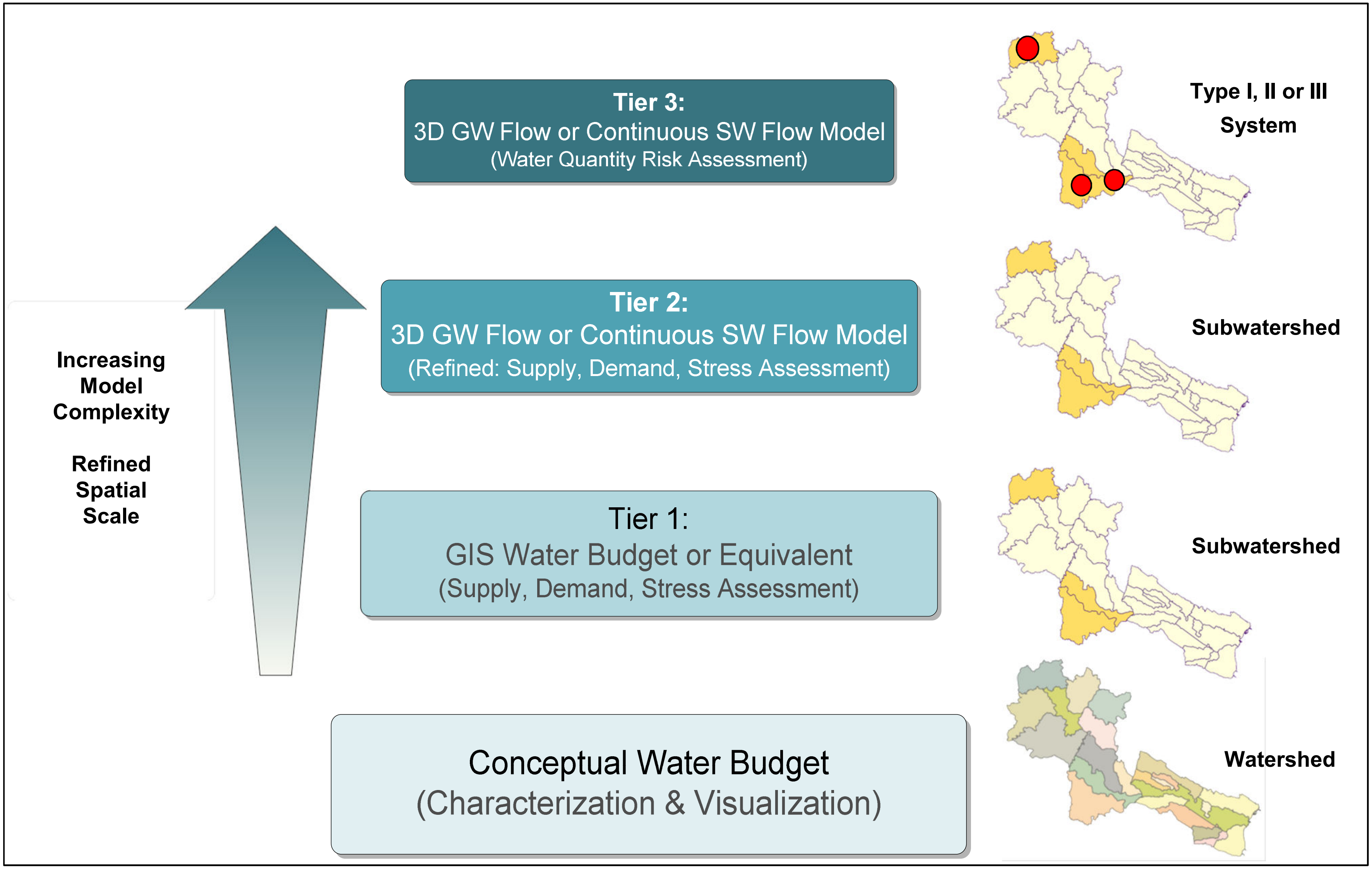
The four wells are located within the urbanized portion of Rockwood. Due to the proximity of significant surface water features and bedrock production aquifers outcropping within area watercourses, a hydraulic connection between the surface water features and the groundwater zone in the shallow bedrock is observed near Rockwood wells 1 and 2 (Burnside 2001). Therefore, these wells are designated as Groundwater Under Direct Influence (GUDI) of surface water (Burnside 2002a).

1.3.3 Hamilton Drive's Drinking Water Supply

Hamilton Drive is the smallest of the three communities being examined as part of the Tier Three Assessment. This subdivision population obtains their drinking water from two municipal groundwater wells completed within a deep, semi-confined, lower bedrock aquifer. The Huntington Estates well is located at the northeastern part of the subdivision, while the Cross Creek well is located in the central portion of the subdivision. Both wells lie within 500 m west of the Speed River, which flows to the south and separates Hamilton Drive from the northwestern part of the City of Guelph.

1.4 *Clean Water Act* Water Budget Framework

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 (Government of Ontario 2015) and the Technical Rules for the Assessment Report (MOECC 2016). A requirement of the Assessment Report is the development of water budgets that assess the threats to water quantity sources under a tiered framework. Tier One and Tier Two Assessments of this framework evaluate the subwatersheds' hydrological stresses, while the Tier Three Assessment examines threats to water quantity sources and evaluates the ability of the sources to meet a community's current and future drinking water needs. Figure 1-3 illustrates the three tiers of the water budget framework.



City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Figure 1-3: Source Protection Water Budget Framework

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Water budgets developed under the *Clean Water Act* (Government of Ontario 2017) provide a quantitative measure of the hydrologic cycle components and a conceptual understanding of the processes and pathways by which surface water and groundwater flows through a watershed or subwatershed. Key deliverables of the water budget analysis include the surface water and groundwater flow models.

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

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 plus Committed) or Planned quantities of water; and 2) to identify quantity threats placed on the drinking water sources that may influence the municipality's ability to meet their Allocated pumping rates. The Tier Three Assessment is completed for all municipalities where their drinking water sources are located within a subwatershed having a *Moderate* or *Significant* water quantity stress as determined in the Tier Two Subwatershed Stress Assessment. A Tier Three Water Budget uses numerical groundwater and/or surface water models that are refined from those used in the Tier Two Assessment models whenever possible. The Tier Three Assessment models should be developed with the accuracy and refinement needed to evaluate hydrologic or hydrogeologic conditions at a water supply well or surface water intake.

In general, Water Quantity Stress and Risk Assessments provide a consistent approach for evaluating the long-term reliability of the province's drinking water sources, and they identify Drinking Water Quantity Threats located within local Vulnerable Areas.

1.4.1 Tier Three Water Budgets and Local Area Risk Assessments

Tier Three Assessments are undertaken for municipal groundwater wells and surface water intakes that are located within subwatersheds that were; a) assigned a *Moderate* or *Significant* water quantity stress level in the Tier Two Assessment, or b) those 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 Allocated or Planned water quantity requirements considering increased municipal water demand, future land development (as defined by the Official Plans), drought conditions, and other water uses. The Tier Three Assessment uses refined surface and/or groundwater flow models and involves a much more detailed study of the available groundwater or surface water sources. Various scenarios are evaluated with the models assessing the groundwater and the surface water flows and levels, and the interactions between them.

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

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

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

Numerical groundwater and surface water models are used to delineate the “Local Area” for groundwater wells or surface water intakes, which correspond to groundwater and surface water Vulnerable Areas in this study. In the Tier Three Assessment, numerical models are used to estimate the impact of increased water demand, variable climate, and land use development on a well or surface water intake using various modelling scenarios. Where these scenarios identify the potential that a well or intake will not be able to supply their Existing or Allocated rates, the Vulnerable Area is assigned a *Significant* Water Quantity Risk Level. Once the Risk Level is assigned to the Vulnerable Area, activities within the area that remove water from an aquifer or surface water body without returning that water to the same aquifer or surface water body (i.e., consumptive water uses) are identified as Drinking Water Threats. These activities would include all consumptive uses including municipal, permitted non-municipal, and non-permitted water takings within the Vulnerable Area. Similarly, activities that reduce groundwater recharge to an aquifer within the Vulnerable Area are also identified as Drinking Water Threats. The Drinking Water Threats within the Vulnerable Area are then classified as *Moderate* or *Significant* depending on the Risk Level assigned to the area. If the Risk Level is *Significant*, all consumptive water uses and reductions in recharge are classified as *Significant* Drinking Water Threats. The Risk Assessment modelling scenarios also consider the need to meet the water demand requirements of other uses, particularly those that must be maintained by provincial or federal law such as wastewater assimilation flows or the ecological flow requirements of a cold-water fish habitat. When these other water uses are impacted beyond prescribed thresholds, a *Moderate* or *Significant* Risk Level is assigned to the Vulnerable Area, and the consumptive water uses and reductions in recharge are identified as *Moderate* or *Significant* Drinking Water Threats.

The Ontario Ministry of the Environment and Climate Change (MOECC) Technical Rules (Part IX; MOECC 2016), *Technical Bulletin: Part IX Local Area Risk Level* (Technical Bulletin; MOE and MNR 2010), and a *Memorandum: Assignment of Water Quantity Risk based on the Evaluation of Impacts to Other Water Users* (Technical Guidance Memorandum; MOE 2013) address the requirements and deliverables for Tier Three Water Budgets and Risk Level assignments to Local Areas.

1.4.2 Tier Three Methodology

The following steps were completed for the Tier Three Assessment following the Technical Rules (MOECC 2016), Technical Bulletin (MOE and MNR 2010), and the Technical Guidance Memorandum (MOE 2013).

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

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

3. Estimate the Allocated and Planned quantities of water. This task compiles and describes Existing and Committed, as well as Planned demands for municipal wells.

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

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

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

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

contributes surface water to the intake, and the area that provides recharge to an aquifer that contributes groundwater discharge to the drainage area.

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

9. Assign Risk Level. A risk ranking (*Low, Moderate, and Significant*) should be assigned to each of the Vulnerable Areas based on the results of the risk scenarios. An uncertainty level (i.e., *High, Low*) will accompany each Risk Level ranking.

10. Identify Drinking Water Quantity Threats and areas where they are *Significant* and *Moderate*. Drinking Water Quantity Threats as consumptive uses or reductions in recharge within the Vulnerable Areas should be identified.

1.5 Other Hydrogeological Studies

The City of Guelph began to conduct detailed hydrogeological investigations on a city-wide basis in the 1990s to better understand its groundwater resources. In 1991, it was recognized that the information on the City of Guelph's water supply system was incomplete and in some cases insufficient. As such, a comprehensive study was initiated to collect additional information to adequately define the water resources. This study included testing the municipal wells for extended periods of time; thus, only a portion of the system was evaluated in any given year to avoid interruption in water service. To ensure continuous service, the Study Area was divided in four quadrants with Gordon/Woolwich streets and the Speed/Eramosa rivers forming the quadrant boundaries. The study was completed on a quadrant-by-quadrant basis by Jagger Hims Limited (1995, 1998a, 1998b, 1998c). The first quadrant evaluated was the northeast quadrant in 1993, followed by the northwest in 1994, the southwest in 1995, and the southeast in 1996/1997.

The quadrant studies involved the compilation and review of available geologic and hydrogeologic information for each quadrant area and detailed testing of each municipal well located in the subject quadrant to determine its capacity to yield water. The studies also included a review of the water quality at each municipal well.

Since these initial City of Guelph quadrant studies, additional groundwater studies have been completed in and around the City of Guelph:

- *City of Guelph Water Supply System Study – Resource Evaluation* (Gartner Lee et al. 1999). This study provided a summary of the groundwater resources within the City of Guelph, developed a multi-layer MODFLOW groundwater flow model, delineated capture zones, and provided recommendations relating to the management of municipal drinking water supplies.

- *Guelph/Eramosa Township Regional Groundwater Characterization and Wellhead Protection Study* (Gartner Lee 2004). This Study developed a finite-difference groundwater flow model and used it to map wellhead protection areas. In addition, the susceptibility of the aquifer to potential surficial sources of contamination was characterized, and a potential contaminant sources inventory within the Township's wellhead protection areas was included.

- *Arkell Spring Grounds - Groundwater Supply Investigation* (Gartner Lee 2003). This investigation evaluated the potential of the Arkell Springs Grounds to provide additional groundwater supplies. The study included pumping tests, groundwater and surface water monitoring, and the use of the previously developed groundwater model (Gartner Lee 2003) to predict aquifer drawdown, assess groundwater-surface water interactions, and to delineate capture zones.

- *Guelph-Puslinch Groundwater Protection Study* (Golder 2006a). This study developed a FEFLOW (Finite Element Subsurface Flow and Transport Simulation System; Diersch 2006) groundwater flow model to delineate capture zones for the municipal water supply wells. The study also included regional groundwater characterization, groundwater susceptibility (vulnerability) mapping, a regional contaminant source inventory (threats database), and a groundwater use assessment.

- *Wellington County Groundwater Protection Study* (Golder 2006b). This study refined the 2001/2002 regional scale mapping and focused on areas susceptible to groundwater contamination from surficial sources, as well as wellhead protection areas using hydrogeological maps from across the County. This study would later form the basis of a groundwater protection strategy created for the County. Similar to the threats database developed in the Guelph-Puslinch study (Golder 2006a), a regional potential contaminant sources database was developed as part of this study.

- *Source Water Protection Project - Groundwater Study* (AquaResource 2007).This project developed preliminary wellhead protection areas based on the Guelph-Puslinch groundwater model (Golder 2006a) and groundwater vulnerability maps for the City of Guelph. A second phase of the study (AquaResource 2010) used a preliminary version of the Guelph Tier Three model to update capture zones and delineate Vulnerable Areas.

- *City of Guelph Southwest Quadrant Water Supply Class Environmental Assessment - Interim Draft Hydrogeologic Report* (Golder 2010). This in-progress study is investigating the potential to increase the capacity of existing wells and install new wells in the Study Area. The study will also develop a well testing and monitoring program to determine long-term well capacities for the municipal wells and assess potential environmental impacts.

Various local-scale studies were also reviewed to support the conceptual model development and refinement of the hydrogeologic conditions represented in the groundwater flow model in and around wells or properties located in the Tier Three Assessment Study Area. Some of these key reference materials are listed below:

- *Engineers Report for the Township of Guelph-Eramosa, Rockwood Water Supply System* (Burnside 2001)
- *Rockwood Environmental Assessment Hydrogeologic Report, Construction and Testing of TW3/02, Proposed Rockwood Well 3, Township of Guelph/Eramosa* (Burnside 2002a)
- *Town of Rockwood Hydrogeology Study to Examine Groundwater Sources Potentially Under Direct Influence of Surface Water* (Burnside 2002b)
- *Town of Rockwood - Township of Guelph/Eramosa New Rockwood Well 4 Category 3 PTTW Application* (Burnside 2015a)
- *Level I and II Hydrogeological Investigation, Hidden Quarry, Rockwood, Ontario* (Harden 2012)
- *Test Pumping Investigation, Supply Well TW3-80:* Nestlé Waters Canada (CRA 2004)
- *2010 Annual Monitoring Report:* Nestlé Waters Canada (CRA 2011)
- *Test Pumping Investigation for TW2-11:* Nestlé Waters Canada (CRA 2012)
- *Meadows of Aberfoyle - 2014 Annual Monitoring Report, Permit to Take Water No. 5626-7WLQ3W* (Banks 2015)
- *Hydrogeological Assessment and Pumping Test, Highway 401 and County Road 46, Puslinch, Ontario* (SNC-Lavalin 2005)

1.6 Report Outline

This report is organized into the following sections:

Section 1: Introduction. The *Clean Water Act* water budget framework and the scope of this project are outlined in this section, along with an introduction to the Study Area.

Section 2: Conceptual and Numerical Models. A general overview of the geology, hydrogeology, and land use within the Study Area are provided, along with an overview of the surface water and groundwater flow models refined for use in the Tier Three Assessment.

Section 3: Water Demand. This section describes the municipal water supply systems and the current (Existing) and Planned system municipal water demands within the Study Area. It also describes the non-municipal water uses within the Study Area including non-municipal permitted water takers.

Section 4: Tier Three Water Budget. This section outlines the water budget results compiled using the output of the calibrated groundwater and surface water flow models.

Section 5: Local Area Risk Assessment. This section outlines the Risk Assessment methodology, the delineation of Vulnerable Areas, the Risk Assessment thresholds (including descriptions of safe additional drawdown and other water uses), as well as the model scenarios and results. Spatial mapping and the delineation of the WHPA-Q1, WHPA-Q2, and IPZ-Q are presented and Risk Levels for these Vulnerable Areas are assigned. This section also describes the uncertainty assessment.

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

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

Section 8: Conclusions and Recommendations. This section outlines the study conclusions and provides recommendations to address data and knowledge gaps.

Section 9: Acknowledgements.

Section 10: References.

2 CONCEPTUAL AND NUMERICAL MODELS

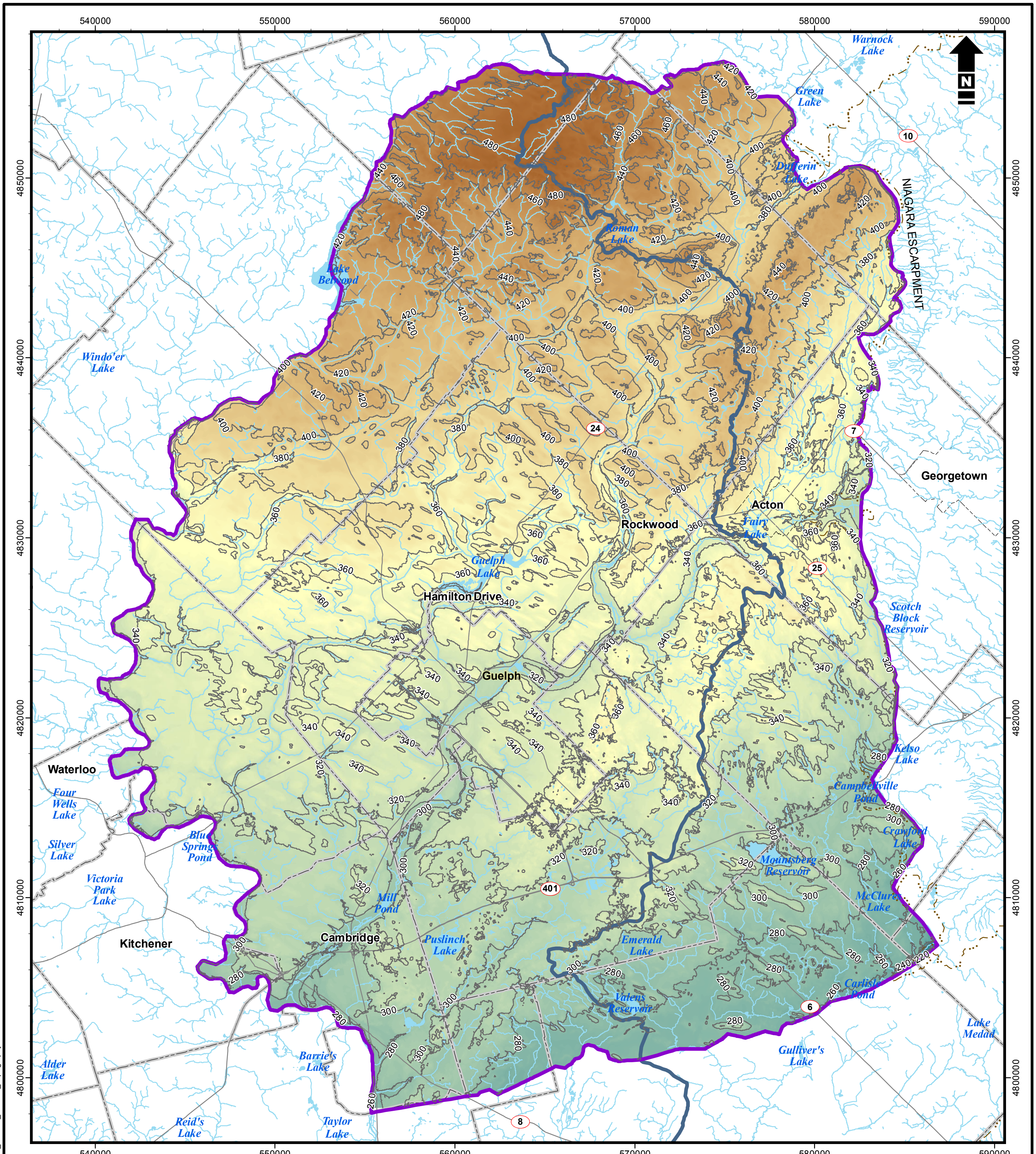
The following sections summarize the conceptual and numerical models developed to complete the water budget and the Risk Assessment. The conceptual model, described in detail in Appendices A and C, includes the following:

- topography
- surface water hydrology
- geology
- hydrogeologic characterization
- groundwater and surface water interactions
- land use and land use changes

The numerical models include a streamflow-generation model and groundwater flow model and are described in detail in Appendix B, with groundwater flow model updates documented in Appendices D and E.

2.1 Topography

Ground surface topography in the Study Area, as illustrated on Figure 2-1, varies from a high of 500 m above sea level (asl) on the crest of the Orangeville Moraine in the northern portion of the Study Area, to a low of approximately 220 m asl in the southeastern portion of the Study Area, south of the Niagara Escarpment. The topography is characterized by deep river valleys that have eroded into the landscape, and Quaternary landform features including the northeast to southwest trending Orangeville, Breslau, Paris, Galt, and Moffat Moraines; the Guelph, Ariss, and Eramosa Eskers; and northwest to southeast trending drumlins.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Water Body
Watercourse
Major Road
Niagara Escarpment
Ground Surface Contour Interval 20m

Elevation (m asl)
High : 515
Low : 200

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Kilometres
NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Ground Surface Topography

Date: 21 Dec 2016	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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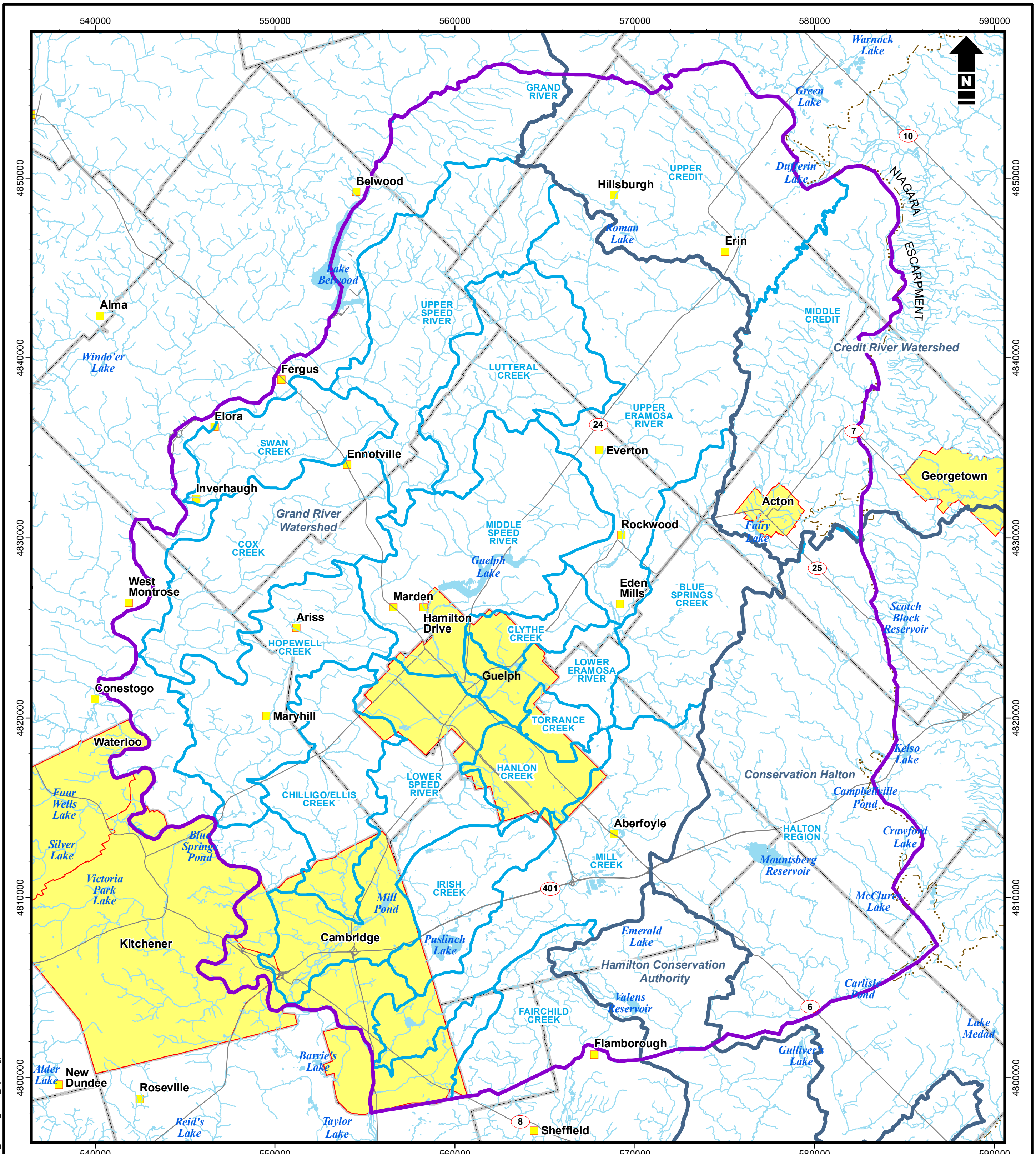
Figure 2-1

2.2 Surface Water Hydrology

Surface water features such as rivers, streams, lakes, and wetlands affect shallow groundwater flow and are an important part of a conceptual model. The bulk of the Study Area lies within the west-central portion of the Grand River Watershed as shown on Figure 2-2. Subwatersheds of the Credit River Watershed drain the land to the northeast along the eastern boundary of the Study Area, and subwatersheds of the Halton and Hamilton Conservation Authority jurisdictions lie to the southeast. Immediately surrounding the Rockwood and Hamilton Drive areas of the Township of Guelph/Eramosa and the City of Guelph are the Speed River, Eramosa River, and Mill Creek subwatersheds, which are discussed below. Additional details for the overall Study Area are provided in Appendix A. Details local to Rockwood and Hamilton Drive are provided in Appendix C.



Tier Three Model Boundary (Study Area)
Watershed Boundary
Subwatershed Boundary
Community
Municipal Boundary
Water Body
Watercourse
Major Road
Niagara Escarpment

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Surface Water Hydrology

Date: 06 Mar 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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Figure 2-2

The Speed River originates in the northern part of the Study Area near the Orangeville Moraine. It flows southward through the Township of Guelph/Eramosa adjacent to Hamilton Drive, though the City of Guelph, and feeds into the Grand River in Cambridge. The Speed River Watershed comprises several subwatersheds; these subwatersheds, and their spatial areas include the Upper Speed River (103 km^2), Middle Speed River (114 km^2), Lower Speed River (91 km^2), Lutteral Creek (70 km^2), Hanlon Creek (26 km^2), Irish Creek (43 km^2), and Chilligo/Ellis Creek (56 km^2).

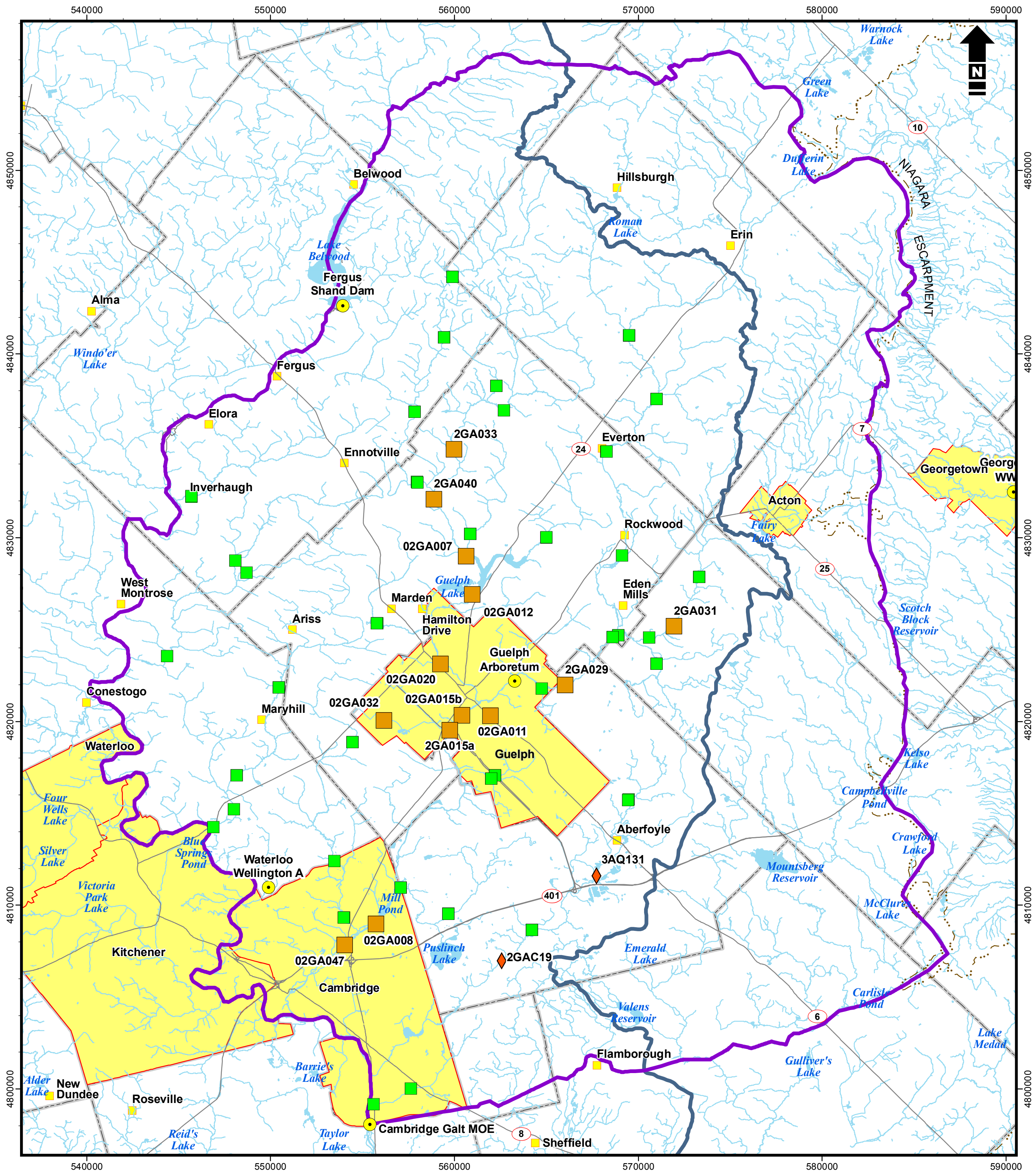
The headwaters of the Eramosa River are located in the northern part of the Study Area, on the edge of the Orangeville Moraine near Hillsburgh. The river flows south through the northern portion of the Township of Guelph/Eramosa past Everton and adjacent to Rockwood and on through the City of Guelph where it drains into the Speed River. The Eramosa River Watershed has a total area of 270 km^2 and is made up of the Upper and Lower Eramosa River and Blue Springs Creek subwatersheds (238 km^2), as well as the Torrance Creek (11 km^2), and Clythe Creek (21 km^2) subwatersheds (Appendix A).

The Mill Creek Watershed has a spatial area of 104 km^2 and is located to the southeast and south of the City of Guelph. The watershed drains an area south of the Blue Springs Creek Subwatershed to the confluence with the Grand River in Cambridge. Ground surface elevation in the watershed is highest on the Paris Moraine and lowest in the Mill Creek valley.

In addition to rivers and creeks, several large reservoirs constructed for recreation and flood control are located in the Study Area. In the Study Area, these features include Belwood Lake and Guelph Lake located in the northwest portion of the Study Area, and within the Township of Guelph/Eramosa, north of Hamilton Drive and the City of Guelph, respectively. In the Region of Halton to the southeast, the Mountsberg Reservoir lies south of Highway 401, and Valens Reservoir lies along the east side of the Grand River Watershed boundary in the southern part of the Study Area. The only natural lake found in the Study Area is Puslinch Lake, a kettle lake found south of Highway 401 in the Cambridge area.

2.2.1 Climate and Surface Water Monitoring

Climate and surface water monitoring is conducted at numerous locations within the Study Area as shown on Figure 2-3. The Meteorological Service of Canada (MSC) and the Grand River Conservation Authority (GRCA) maintain climate stations throughout the area, while the Water Survey of Canada (WSC) and the GRCA record streamflow at surface water flow monitoring stations.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Water Body
Watercourse
Major Road
Niagara Escarpment

Climate Station
Spotflow Measurement

Streamflow Gauge

GRCA
WSC

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Kilometres

NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Climate and Surface Water Monitoring

Date: 10 Mar 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M.Urtheil

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Figure 2-3

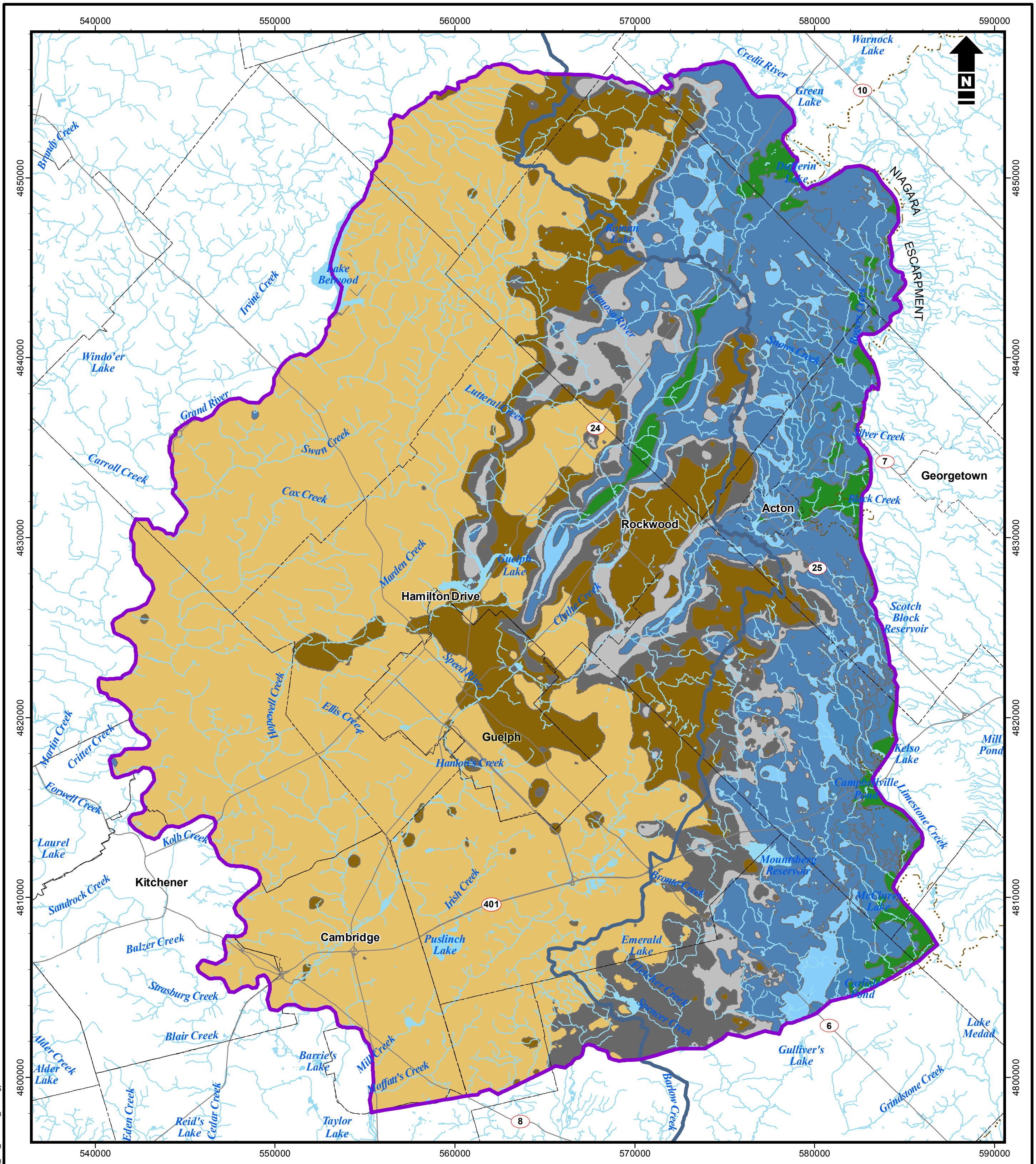
A baseflow monitoring program was completed in the Study Area (Appendix A) to supplement streamflow data collected by the WSC and GRCA. Baseflow is defined as the portion of streamflow that is derived from a combination of groundwater discharge and delayed flow from natural and artificial storage at surface. The purpose of the baseflow monitoring program was to provide estimates of groundwater discharge to enhance the understanding of the groundwater and surface water interaction within the Study Area, and also to support the calibration of the groundwater flow model.

Surface water flow measurements were collected at 32 locations along various streams/rivers in the Study Area. Flow measurements were scheduled following a minimum of four consecutive days without observed precipitation to minimize the proportion of runoff in streamflow. Baseflow was estimated using the “velocity-area” method utilizing an impeller or electromagnetic flow meter and measuring cross-sectional stream areas, and “timed volume flow method” utilizing a bucket and stopwatch. Concurrent with the baseflow measurements, surface water quality measurements such as pH, conductivity, and temperature were collected and provided a snapshot of water quality conditions. Additional details regarding the streamflow values and water quality measurements collected are located in Appendix A.

2.3 Geology

2.3.1 Bedrock Geology

The Paleozoic bedrock stratigraphy beneath the Study Area consists of sedimentary Silurian-aged dolostones, shales, limestones, and associated interbedded sedimentary bedrock formations that dip regionally to the southwest. The uppermost bedrock formations in the Study Area, as delineated in the conceptual model, are illustrated on Figure 2-4. Bedrock outcrops at surface along the river valleys in Elora, Fergus, Rockwood, Eden Mills, and Guelph and in the eastern portion of the Study Area in Flamborough and Acton. Table 2-1 lists the bedrock formations found in the Study Area from youngest (top) to oldest (bottom), as well as a brief description of the bedrock lithologies and the estimated thicknesses of the units beneath the Study Area. Table 2-1 also summarizes bedrock stratigraphy for the past (Golder 2006a) and revised (Brunton 2009) conceptualizations.



Tier Three Model Boundary (Study Area)

Grand River Watershed Boundary

Community

Water Body

Watercourse

Major Road

Niagara Escarpment

Bedrock Geology

- Guelph Fm
- Eramosa Fm - Reformatory Quarry
- Eramosa Fm - Vinemount
- Goat Island Fm
- Gasport Fm (Upper Unit)
- Gasport Fm (Middle Unit)
- Gasport Fm (Lower Unit)
- Cabot Head Fm

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NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Bedrock Geology

Date: 06 Mar 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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Figure 2-4

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TABLE 2-1 Bedrock Geology Underlying the Study Area

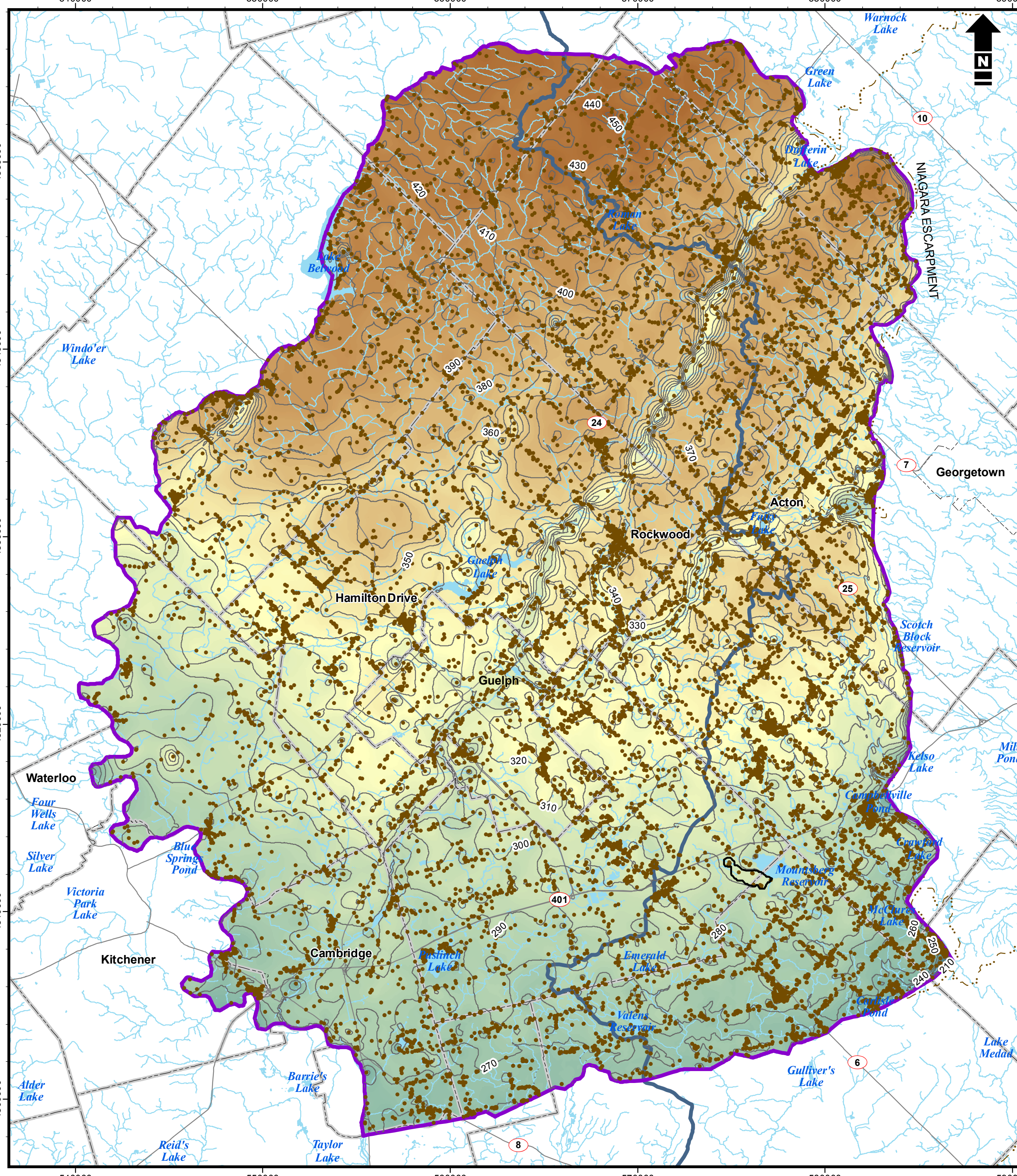
Previous Conceptualization[1]		Revised Conceptualization[2]		Lithology Description	Approximate Thickness (m)
Formation	Member	Formation	Member		
Guelph Fm.		Guelph	Hanlon	Cream-coloured, medium to thick bedded, fossiliferous grainstones, wackestones, and reefal complexes	Up to 62
			Wellington		
Amabel	Eramosa	Eramosa	Stone Road	Cream-coloured, coarsely crystalline dolostone	
			Reformatory Quarry	Light brown-cream, pseudo-nodular, thick bedded, coarsely crystalline dolostone	5 to 50
			Vinemount	Grey-black, thinly bedded, fine crystalline dolostone with shaley beds	2 to 10
	Wiarton / Colpoy / Lions Head	Goat Island	Ancaster / Niagara Falls	Ancaster-Grey, cherty, fine crystalline dolostone; Niagara Falls-Fine crystalline, cross-laminated crinoidal grainstone with small reef mounds	5 to 40
		Gasport	Gothic Hill	Cross-bedded crinoidal grainstone-packstone with reef mounds and shell beds	25 to 70
		Rochester / Irondequoit / Rockway / Merritton Fm.		Rochester- Calcareous shale with carbonate interbeds; Irondequoit- Thick-medium bedded crinoidal limestone; Rockway- Fine crystalline argillaceous dolostone with shaley partings; Merritton- Fine crystalline dolostone with shaley partings	3 to 5
Cabot Head / Reynales Fm.		Cabot Head Fm.		Non-calcareous shale interbedded with sandstone and limestone	10 to 39

Sources:
[1] Golder (2006a)
[2] After Brunton (2009)

While not listed in the above table, the Salina Formation (an interbedded dolostone unit with interbeds of shale, gypsum, and anhydrite) is present in the Study Area in the westernmost areas of Cambridge, and inferred to be present in the Breslau area (Golder 2009). This formation is younger than the Guelph Formation but is not explicitly represented in the numerical model due to its limited spatial extent within the Study Area. The Salina Formation was grouped together with the Guelph Formation in this Study, as the two units are interpreted to have similar hydrogeologic properties where the unit is present within the Study Area.

Overall, the bedrock formations described above form a thick (40 to 100 m) and extensive groundwater aquifer system. The cities of Guelph and Cambridge, Rockwood, and the communities within the Township of Centre Wellington rely on the Gasport and Guelph Formation units for the majority of their potable drinking water supplies. The Gasport Formation represents the most common aquifer used for groundwater supply within the Study Area due to the transmissive nature of the limestone unit. The Eramosa Formation overlies the Gasport Formation, and the Vinemount Member in particular consists of mud-rich dolostone beds that act as an aquitard limiting the lateral and vertical flow of water through the unit. The Vinemount Member is extensive and acts as an important aquitard throughout the Study Area although it was interpreted to have been removed by erosion in some areas, including an area near Rockwood, between Blue Springs Creek and the Eramosa River.

Figure 2-5 illustrates the bedrock topographic surface developed using MOECC water well records, high-quality borehole data, bedrock outcrops, and information listed in previous hydrogeological studies. Additional information on the creation of this bedrock surface is provided in Appendices A and C. The Speed and Eramosa rivers have carved valleys into the bedrock surface, and other bedrock channels are interpreted to have been eroded into the bedrock surface thousands of years ago and were subsequently filled with sediment. These buried bedrock valleys extend from Rockwood in the northeastern portion of Guelph toward the modern-day Eramosa River valley (Greenhouse and Karrow 1994).



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- Tier Three Model Boundary (Study Area)
- Grand River Watershed Boundary
- Community
- Municipal Boundary
- Water Body
- Watercourse
- Major Road
- Niagara Escarpment
- Bedrock Surface Contour Interval 10m
- Data Point

Elevation (m asl)
High : 460
Low : 195

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Kilometres
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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Bedrock Topography

Date: 21 Dec 2016	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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Figure 2-5

2.3.2 Quaternary Geology and Physiography

The major physiographic regions in the area are illustrated on Figure 2-6 and include the following:

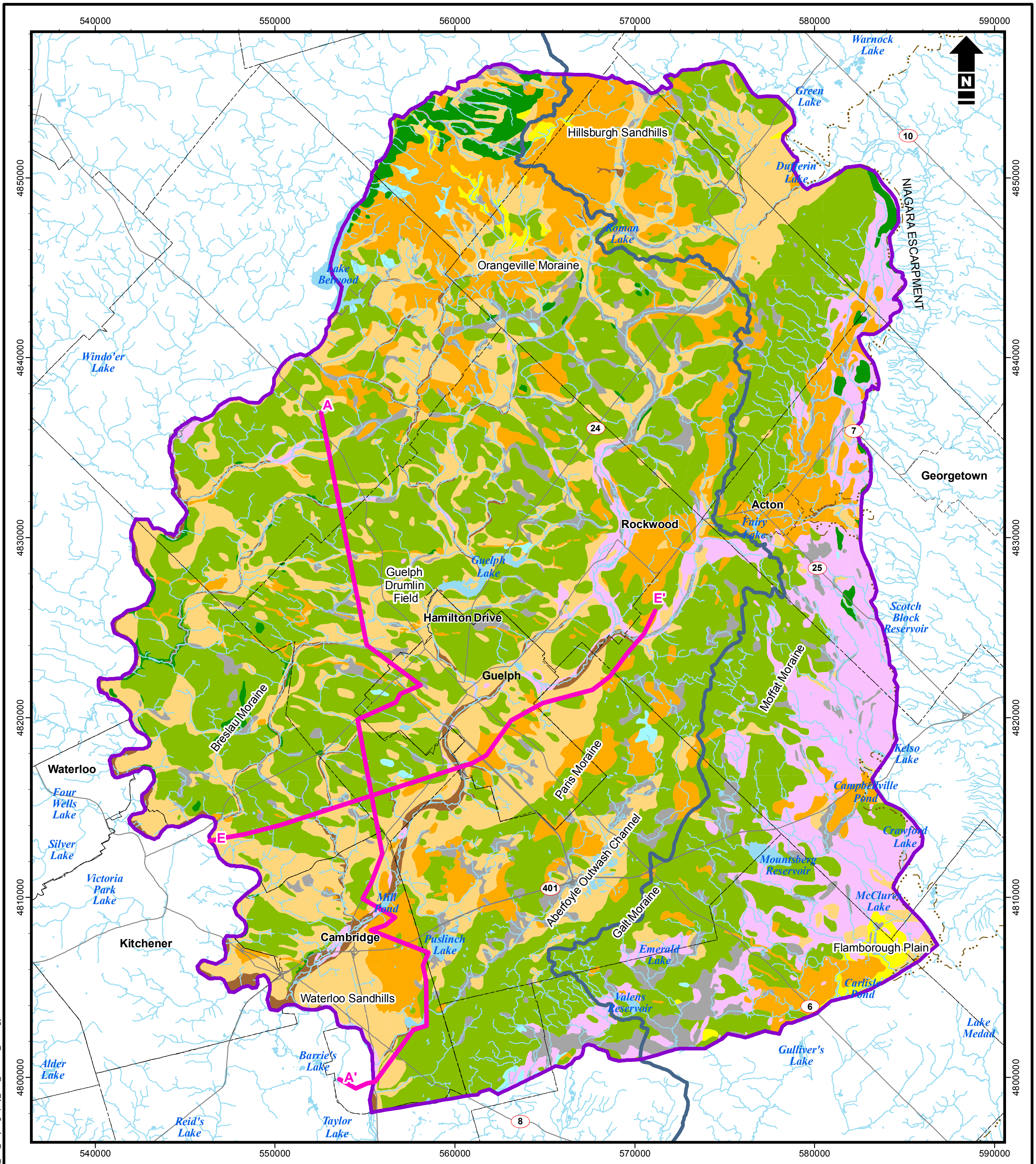
- **Guelph Drumlin Field**. The Guelph Drumlin Field is located in the western and central portion of the Study Area and is characterized by till drumlins fringed by gravel terraces and separated by swampy valleys (Chapman and Putnam 1984; Appendix A).

- **Horseshoes Moraines**. This region covers the central eastern portion of the Study Area, east of the Guelph Drumlin Field and is characterized by moraines (e.g., Galt and Paris moraines) and old spillways with broad gravel and sand terraces and swampy floors (Chapman and Putnam 1984).

- **Flamborough Plain**. The Flamborough Plain encompasses a small portion of the southeastern part of the Study Area. It consists of limestone bedrock with little or no overburden cover and a few drumlins (Chapman and Putnam 1984). The area is poorly drained and large swampy areas are common.

- **Waterloo Sandhills (Waterloo Moraine)**. The Waterloo Sandhills encompass a small portion of the southwestern part of the Study Area. The surface is composed of well-drained sandy hills, some of them being ridges of sandy till while others are kames or kame moraines, with outwash sands occupying the intervening hollows (Chapman and Putnam 1984).

- **Hillsburgh Sandhills / Orangeville Moraine**. The most elevated region in the Study Area is the Orangeville Moraine, (Hillsburgh Sandhills; Chapman and Putnam 1984). This region encompass the northern portion of the Study Area and is characterized it as having rough topography primarily with sandy materials.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Water Body
Watercourse
Major Road
Niagara Escarpment
Cross Section Location

Surficial Geology
- 3,4,4a: Paleozoic bedrock-drift complex
- 5a: Shield-derived silty to sandy till
- 5b: Stone-poor, carbonate-derived silty to sandy till
- 5d: Glaciolacustrine-derived silty to clayey till
- 6: Ice-contact stratified deposit
- 7,7a,7b: Glaciofluvial deposits-Sandy/Gravelly deposit
- 8,8a,8b: Fine-textured glaciolacustrine deposit
- 9: Coarse-textured glaciolacustrine deposit
- 9c: Foreshore-basinal deposit
- 19: Modern alluvial deposit
- 20: Organic deposit

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2 0 2
Kilometres
NAD 1983 UTM Zone 17N

Reference: Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008. Ontario Geological Survey 2010. Surficial geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 128 – Revised. Produced using information provided by the Ministry of Northern Development, Mines, and Forestry, Copyright © Queen's Printer, 2013

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Physiography and Surficial Geology

Date: 21 Dec 2016	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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Figure
2-6

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Surficial geology for the Study Area is illustrated on Figure 2-6 and was mapped by various individuals including Karrow (1987, 1968) and compiled by the Ontario Geological Survey (2003). Surficial deposits are predominantly a combination of sand and gravel glaciofluvial and ice-contact stratified deposits, and silty to sandy tills that were laid down during glacial advance from the Lake Ontario basin. Overburden thickness ranges from 0 m, where bedrock outcrops in incised river valleys and along the eastern Study Area boundary, to 80 m in buried bedrock valleys and on the Orangeville Moraine. The main till units found in the Study Area include the Catfish Creek, Port Stanley, and Wentworth Tills. The Catfish Creek Till is discontinuous, dense, sandy silt till located at depth within the majority of the Study Area, and outcrops in the banks of eroded river valleys. The younger Port Stanley Till is less stony and is mapped at the surface west of the Paris Moraine. East of and on the Paris Moraine, the Wentworth Till dominates as the surficial till unit (Karrow 1987; McKenzie 1990). The Wentworth Till is younger and coarser in texture than the Port Stanley Till and within the Study Area, contains interbeds of sand and gravel.

In addition to till units, moraines, eskers, drumlins, and kames are landforms present within the Study Area. The Paris, Galt, Moffat, and Orangeville Moraines are mapped within the Study Area and are composed primarily of till, but also contain associated ice-contact stratified drift, outwash deposits, or a mixture of the three on the flanks of the moraine. Eskers and kames mapped within the area are composed of sand and gravel, and drumlins of the Guelph Drumlin Field are generally composed of tills or a mixture of till and stratified sediment (Barnett 1992). Glaciofluvial deposits such as the Aberfoyle outwash channel along Mill Creek are composed of sand and gravel and are generally found in low-lying areas on the surfaces of the till plain or bedrock. A more detailed discussion on the Quaternary or overburden geology of the Study Area is provided in Appendices A and C.

2.4 Hydrogeologic Characterization

2.4.1 Monitoring

A comprehensive field-based monitoring program was developed and carried out in the Study Area (Appendix A) in support of the Tier Three Assessment and is summarized below. This program included subsurface hydrogeologic monitoring and stream baseflow monitoring.

2.4.1.1 Hydrogeologic Drilling and Monitoring

In addition to the City of Guelph’s ongoing monitoring program, an advanced hydrogeologic drilling and monitoring program was carried out as part of the Tier Three Assessment.

This purpose of the subsurface monitoring program was to obtain high-quality geologic and hydrogeologic information outside of the City of Guelph and to establish a network of deep monitoring wells outside the City of Guelph. In all, 11 deep boreholes were drilled, logged, and investigated using geophysical methods to provide a complete stratigraphic profile from ground surface to the Cabot Head Formation. Hydraulic testing of the boreholes was completed utilizing packer tests, short-term pumping tests, and a new technique known as FLUTe hydraulic conductivity profiling. Once borehole testing was completed, multi-level monitoring wells were installed utilizing traditional equipment and custom multi-level technology supplied by Westbay® Instruments, Solinst®, and FLUTe.

Water levels were monitored in all wells using a combination of automated data-logging pressure transducers and manual measurements. Finally, water quality samples were obtained from four of the multi-level wells followed by laboratory analysis for dissolved metals, nutrients, anions, and dissolved organic carbon.

In addition to ongoing monitoring and the Tier Three Assessment monitoring program, aquifer response tests were carried out as part of hydrogeological investigations to support the ongoing management of municipal groundwater resources. Additional details of these tests and the results are found in Appendix A.

2.4.2 Hydrostratigraphy

Hydrostratigraphy refers to the structure of geologic units in relation to the flow of groundwater through those units. Hydrostratigraphic units are derived from stratigraphic units based on their general hydrogeologic properties and are the fundamental "building blocks" of conceptual and numerical groundwater flow models. The delineation of hydrostratigraphic units based on geologic descriptions from cored borehole logs can be a relatively rough approximation; however, the available information is used in conjunction with regional and local scale interpretations of the spatial distribution of geologic units. Units composed primarily of coarse-grained overburden materials (e.g., sands and gravels) or highly transmissive bedrock units are referred to as aquifers and units composed of lower permeability overburden (e.g., clay or fine tills) or poorly transmissive bedrock units are referred to as aquitards.

The Study Area contains overburden water supply aquifers predominately associated with coarse-grained outwash sand and gravel deposits, and bedrock water supply aquifers predominantly the Upper to Middle Gasport and Guelph formations, as well as Contact Zone aquifers where coarse-grained overburden overlies weathered bedrock. Aquitard units in the Study Area are characterized in the overburden by glacial tills and in the bedrock by weakly or poorly transmissive units such as the Vinemount Member of the Eramosa Formation and the Cabot Head Formation.

Table 2-2 lists and describes the 11 hydrostratigraphic units identified within the Study Area: 2 overburden units, 8 bedrock units, and 1 overburden/bedrock unit.

TABLE 2-2 Hydrostratigraphic Units in the Study Area

Hydrostratigraphic Unit	Geological Description	Specific Geologic Units
Upper Sand and Gravel Aquifer (Overburden A)	Outwash sand and gravel deposits and glacial tills	Coarse sand and gravel, Wentworth Till, Port Stanley Till, Fine-grained Sediments
Lower Till Aquitard (Overburden B)	Glacial tills (dense, sandy, silty) occasionally interbedded with discontinuous lenses of coarse sands/gravels	Wentworth Till, Port Stanley Till, Catfish Creek Till
Contact Zone Aquifer	Fractured bedrock and overlying basal unconsolidated deposits	Coarse, granular deposits overlying weathered bedrock
Bedrock Aquifer	Medium to thick bedded fossiliferous dolostone	Guelph Formation (incl. Eramosa Formation - Stone Road Member)
Bedrock Aquifer/Aquitard	Thickly bedded, coarsely crystalline dolostone	Eramosa Formation - Reformatory Quarry Member
Bedrock Aquitard	Thinly, shaley bedded, fine crystalline dolostone	Eramosa Formation - Vinemount Member
Bedrock Aquifer/Aquitard	Chert-rich, fine crystalline dolostone and cross-laminated crinoidal grainstone	Goat Island Formation
Bedrock Aquifer	Cross-bedded grainstone-packstone with sequences of reef mound and coquina lithofacies	Upper Gasport Formation
Bedrock Aquifer (High Permeability)	Cross-bedded grainstone-packstone with sequences of reef mound and coquina lithofacies; Highly transmissive with secondary porosity (cavities, vugs, fractures)	Middle Gasport Formation
Bedrock Aquifer	Cross-bedded grainstone-packstone with sequences of reef mound and coquina lithofacies	Lower Gasport Formation (incl. Roch./Iron./Rock./Merri. Fms.)
Bedrock Aquitard	Shale interbedded with sandstone and limestone	Cabot Head Formation

The Tier Three Assessment Groundwater Flow Model was developed to reflect the hydrostratigraphic units described in Table 2-2. The following key updates were made to the previous three dimensional (3D) conceptual model (Golder 2006a) as part of this Tier Three Assessment:

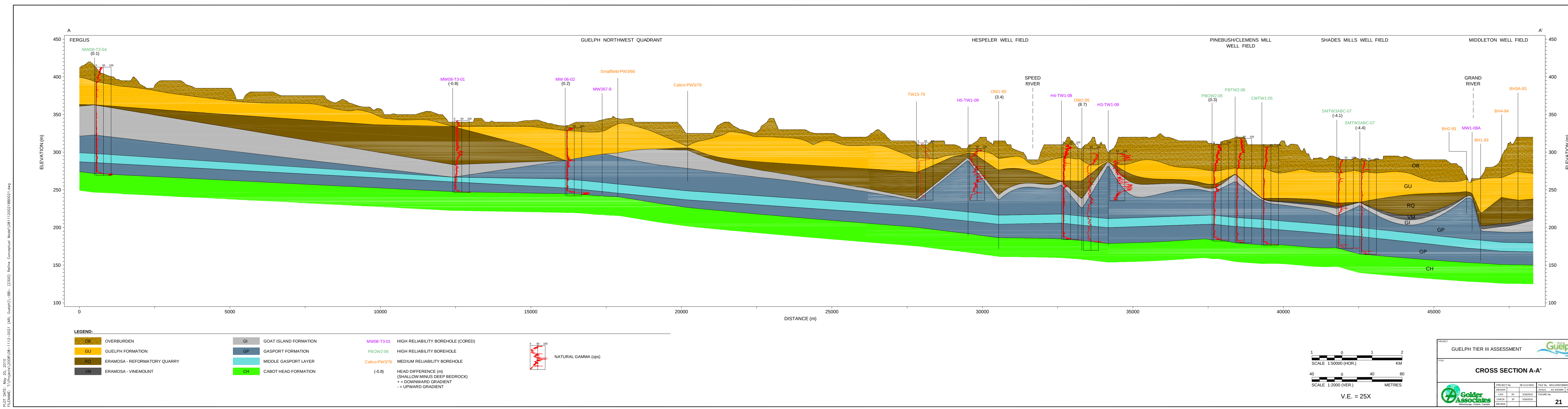
- The 3D bedrock formation surface elevations were updated based on current data and following a revised stratigraphic framework presented by the Ontario Geological Survey (Brunton 2009).
- Delineation and explicit representation of various bedrock units was improved including the following:
  - Separating the Eramosa Member into the Vinemount and Reformatory Quarry Members as these two members have distinctly different hydraulic properties.
  - Separating the unsubdivided Amabel Formation into the Gasport and Goat Island Formations.
- Bedrock geology characterization derived from the concurrent Region of Waterloo Tier Three Water Budget and Local Area Risk Assessment in the Cambridge Area (Matrix and SSPA 2014) was integrated.

The conceptual model revisions that were completed as part of this project focused on improving the delineation and characterization of the bedrock units as they have a significant influence on the groundwater flow in the municipal aquifer system. The overburden conceptual model layer structure developed as part of the Guelph-Puslinch Study was largely retained for this project (Golder 2006a). Key exceptions are in the southwest quadrant area of Guelph where a local-scale review and refinement of the Guelph-Puslinch model's overburden stratigraphy was completed in conjunction with the Southwest Quadrant Class Environmental Assessment (Golder 2010), as well as in the Arkell Spring Grounds.

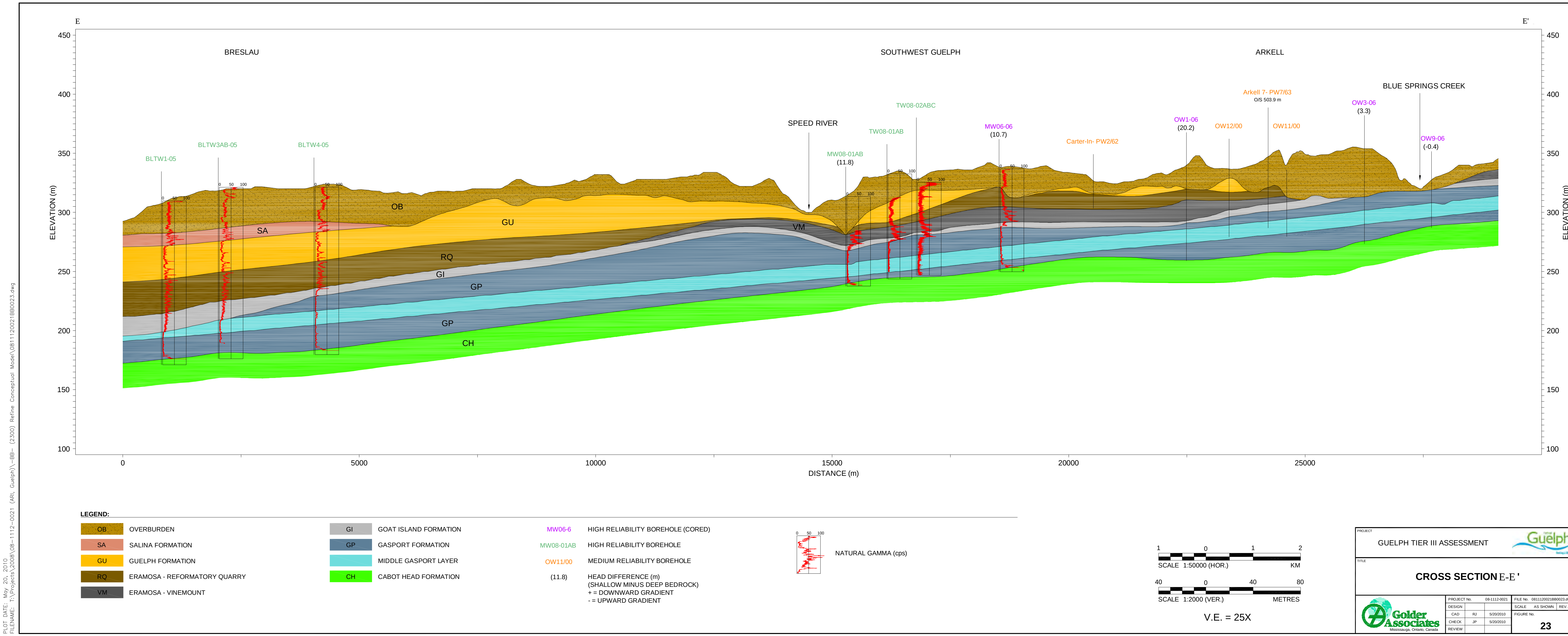
The representation of hydrostratigraphic units in the conceptual model was modified locally in the Rockwood and Dolime Quarry areas where the results of local-scale hydrogeologic studies suggested additional revisions were required. The Vinemount Member was conceptualized to have been removed by erosion in the area between the Eramosa River and Blue Springs Creek, near Rockwood.

Near the Dolime Quarry, updates were made to the geologic and hydrogeologic conceptualization in the Gasport Formation; these updates are described in detail in Appendix E.

Figures 2-7 and 2-8 illustrate conceptual hydrostratigraphic units in north-south and east-west cross-sections, respectively.



North-South Cross-Section
Figure 2-7



East-West Cross-Section
Figure 2-8

2.5 Groundwater and Surface Water Interactions

Interactions between surface water and groundwater occur in natural conditions in all types of landscapes and within the Study Area. These interactions are summarized as follows:

- Precipitation migrates to groundwater through the process of infiltrating into shallow unsaturated soils followed by recharge into the underlying groundwater aquifers.
- Surface water bodies and wetlands gain water from the discharge of shallow and deep groundwater.
- Surface water bodies and wetlands recharge water to the underlying groundwater flow system by outflow.

The following sections describe the hydrological and ecological system characterization completed to support the assessment of groundwater and surface water interactions in the Study Area.

2.5.1 Groundwater Recharge

Groundwater recharge is a hydrologic process where water moves downward from the ground surface to the underlying groundwater flow system. This process usually occurs in the unsaturated zone below plant roots and is often expressed as a flux to the water table surface. Recharge is the residual portion of precipitation left after the subtraction of water returned to the atmosphere by evapotranspiration or transferred to stream channels by overland flow and interflow above the groundwater system. The amount of groundwater recharge is influenced by the infiltrability of the ground surface; land use or vegetation; the depth, hydraulic conductivity and soil water storage characteristics of surficial overburden layers; and slope of the topography (if extremely steep).

Calibrated surface water or streamflow-generation models are used to generate recharge estimates for the groundwater flow model. Recharge estimates for the Study Area were estimated using three surface water models for the three watershed areas present within the Study Area (i.e., Grand River Watershed, Credit River Watershed, and the watersheds under the jurisdiction of the Halton and Hamilton Region Conservation Authorities, respectively). Estimated recharge rates ranged from a low of 0 mm/year where groundwater discharges to some wetlands, to a high of 533 mm/year on hummocky regions associated with the Paris and Galt moraines that are underlain by sand and gravel.

Within the Grand River Watershed, the surface water and groundwater flow models were calibrated to low-flow conditions and the estimated overall average recharge rate across the model is considered reliable. Appendix B outlines the development and calibration of the GAWSER (Guelph All-Weather Sequential Events Runoff; Schroeter & Associates 2004) hydrologic model of the Grand River Watershed used to estimate the majority of the recharge distribution within the Study Area.

Recharge rates within the Credit River Watershed in the eastern portion of the Study Area were estimated using a HSPF (Hydrology Simulation Program - Fortran) model (AquaResource 2009c). Similar to Grand River Watershed, the recharge rates derived for the Credit River Watershed are reliable and estimated through an integrated calibration of surface water and groundwater flow models for the watershed.

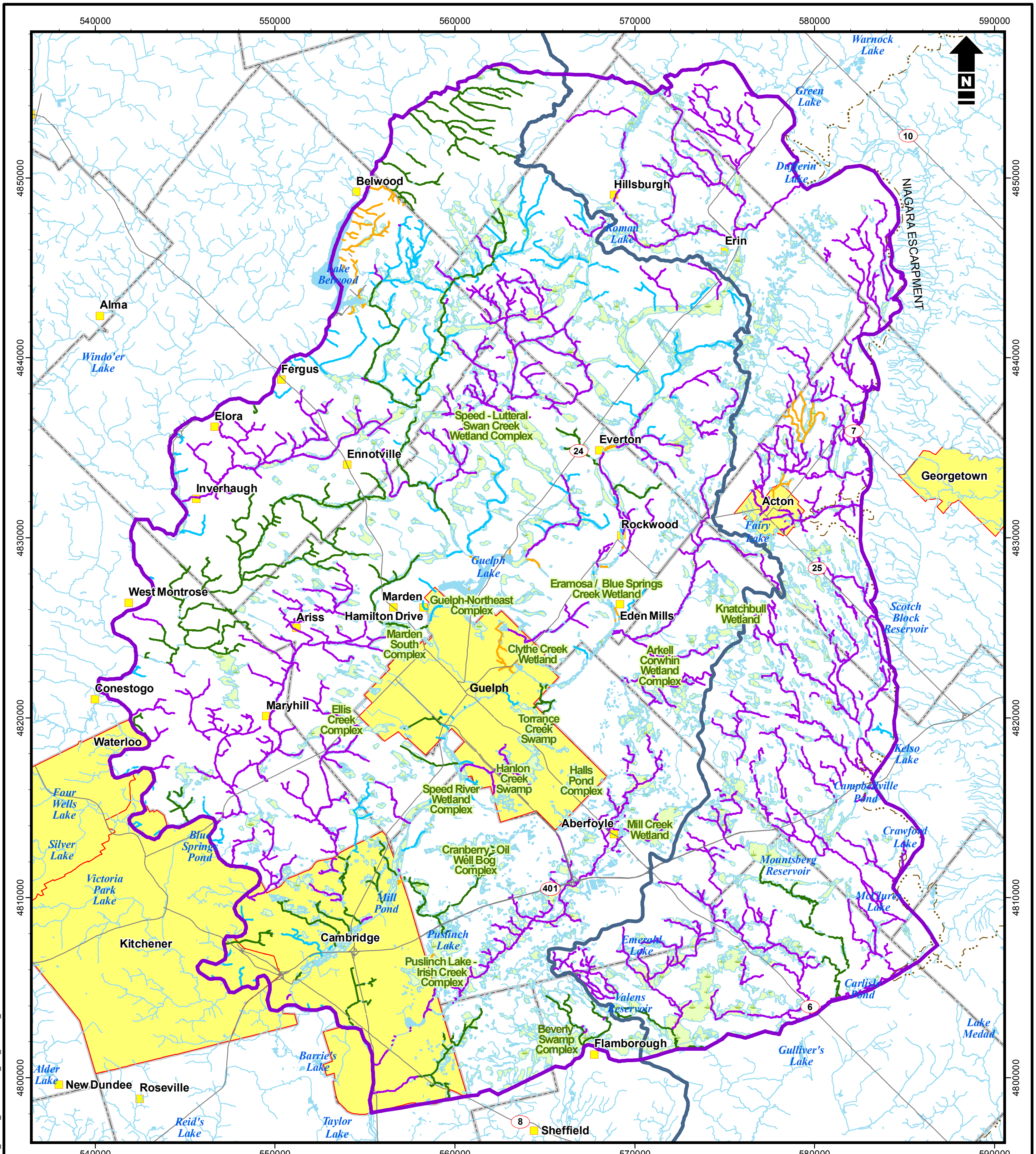
Recharge rates estimated in the southeast portion of the Study Area were estimated using the PRMS (Precipitation-Runoff Modeling System) model (EarthFx 2009). Estimation of these rates did not involve calibration to low-flow streamflow conditions, and as a result there is a degree of uncertainty in their values as compared to those applied in the Grand River and Credit River watersheds.

Appendix B describes how the recharge rates estimated across the Study Area were applied to the model including adjustments made to those rates as part of the model calibration.

2.5.2 Groundwater Discharge and Ecological Resources

Appendix A describes many of the important ecological resources in the Study Area including Environmentally Sensitive Areas (ESAs) and Areas of Natural and Scientific Interest (ANSIs). Those resources that rely on groundwater and surface water interactions are described in the following sections.

Groundwater discharge is important to sustaining cold water and cool water fisheries as the upwelling areas are critical for fisheries spawning and also for maintaining a moderate temperature and flow in creeks and streams. Cold water fisheries are mapped by the province (MNR 2013) and GRCA (2013) in various stream reaches within the Study Area, particularly in the headwaters of the Grand River, as shown on Figures 2-9 and 2-10. Cold-water fish communities are mapped in all of or parts of the Eramosa River, Blue Springs Creek, Clythe Creek, Hanlon Creek, Speed River, Ellis Creek, Mill Creek, and Hopewell Creek. Due to the presence of online ponds, some of the stream designations have changed from cold-water streams to cool or warm-water designations, as shown on Figures 2-9 and 2-10.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Municipal Boundary
Wetland
Water Body
Watercourse
Major Road
Niagara Escarpment

Stream Temperature Classification

Cool Water
Cold Water
Warm Water
Unknown

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NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa

Tier 3 Water Budget and Local Area Risk Assessment

Stream Classification and Wetlands (Model Scale)

Date: 21 Dec 2016	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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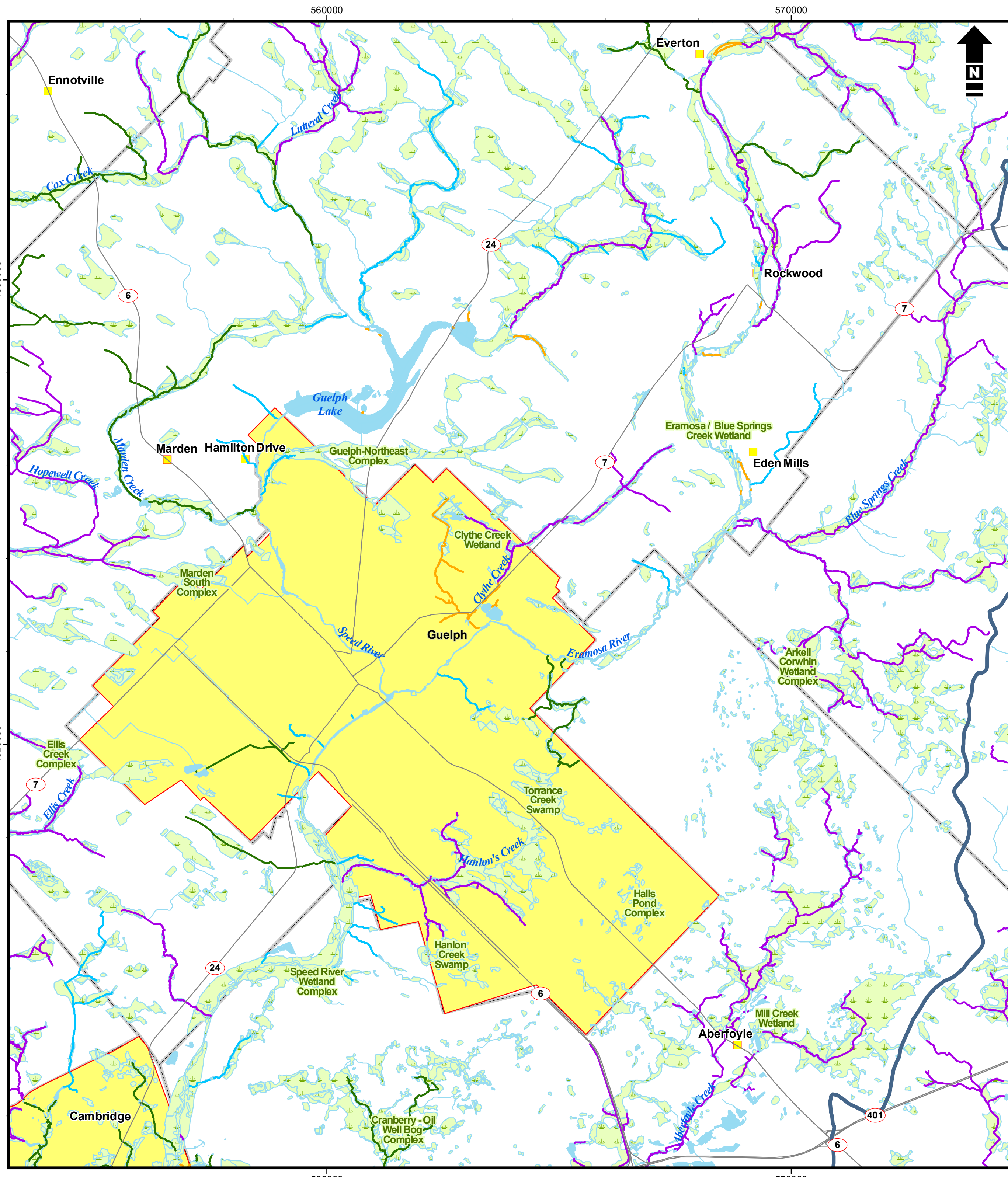
Figure 2-9



Grand River Watershed Boundary
Community
Wetland
Water Body
Watercourse
Major Road

Stream Temperature Classification

Cool Water
Cold Water
Warm Water
Unknown

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Stream Classification and Wetlands (Area of Interest)

Date: 06 Mar 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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Figure 2-10

PSWs are those areas identified by the province as being the most valuable. They are determined by a science-based ranking system known as the Ontario Wetland Evaluation System (OWES). Figure 2-9 illustrates the locations of these wetlands within the Grand River Watershed. PSWs within the City of Guelph (Figure 2-10) include Hanlon Creek Swamp, Torrance Creek Swamp, Clythe Creek Wetland, and Guelph-Northeast Complex. The latter is east of Hamilton Drive and extends in to the Township of Guelph/Eramosa.

PSWs within the Eramosa River subwatershed include the Eramosa/Blue Springs Creek Wetland (lying mostly in the Township of Guelph/Eramosa near and south of Rockwood), Knatchbull Wetland, Arkell-Corwhin Wetland, Torrance Creek/Hamilton Corners Wetland and Clythe Creek Wetland. PSWs within the Speed River subwatershed include Hanlon Creek Swamp and Halls Pond Wetland.

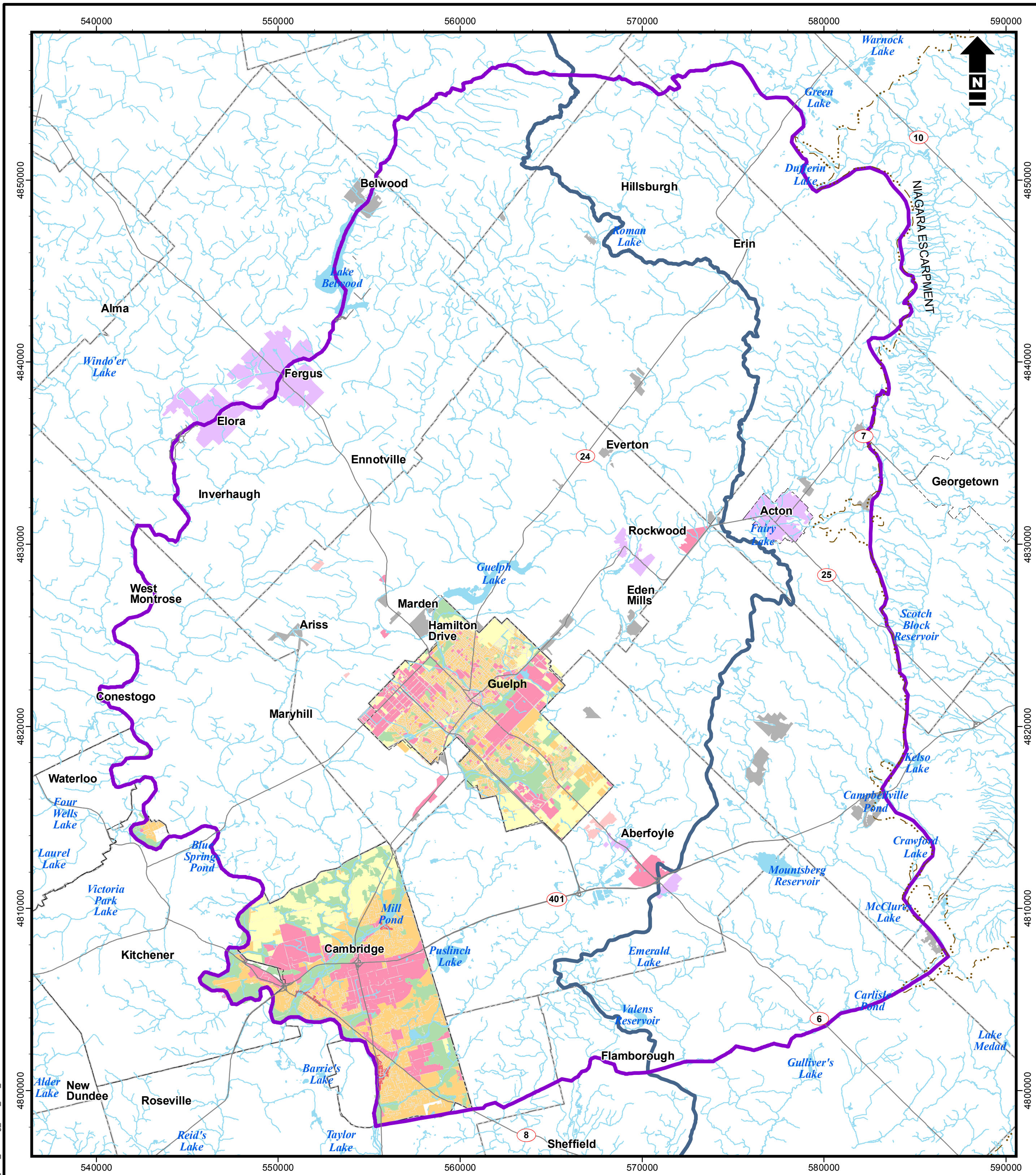
PSWs within the Mill Creek subwatershed include Mill Creek Wetland and Arkell-Corwhin Bog.

2.6 Land Use and Land Use Change

The Technical Rules (MOECC 2016) identify reductions in groundwater recharge as potential Water Quantity Threats. The Tier Three Assessment modelling scenarios must consider the impact of existing and future land development as defined in the Official Plans, on groundwater recharge and municipal water sources. The assessment of the impact arising from land use development needs to reflect changes in imperviousness and does not include an assessment of low impact development or other measures that may act to enhance groundwater recharge.

2.6.1 Existing Conditions Land Use

Existing land use within the Study Area is illustrated on Figure 2-11 and was created using land use mapping provided by the Township of Guelph/Eramosa, the City of Guelph within the city, the Region of Waterloo for the Cambridge area, and by various municipalities for the surrounding rural areas. The existing conditions land use is representative of the 2008 year. Satellite imagery from 2007 to 2008 was examined to confirm that planned development lands were not already developed in 2008 and were not included in the 2008 existing conditions scenario.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Water Body
Watercourse
Major Road
Niagara Escarpment

Current Land Use
Agricultural
Rural Agricultural
Commercial/Industrial/Institutional
Core
Urban Centre
Country Residential
Hamlet Area
Residential
Park / Open Space
Transportation

Note: Areas outside of the Cities of Guelph and Cambridge only include developed land uses

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Existing Land Use (2008)

Date: 21 Dec 2016	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: C. Curry

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Figure 2-11

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2.6.2 Official Plan Land Use

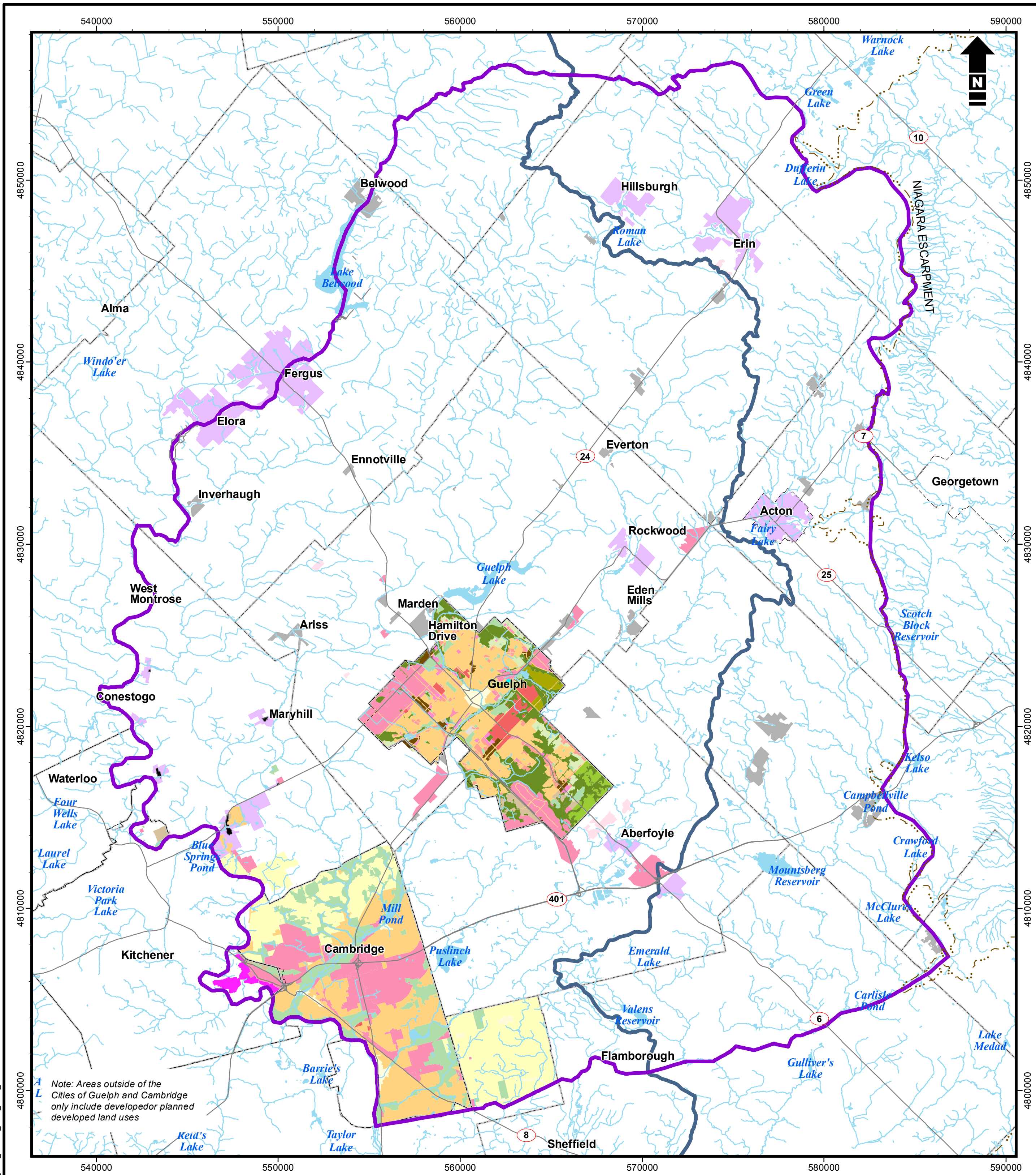
Future land use according to municipal Official Plans is illustrated on Figure 2-12. This map reflects the current Official Plans for County of Wellington, the City of Guelph, and the adjacent municipalities.

The City of Guelph approved its Official Plan Amendment 48 (OPA 48) in 2012 (currently being reviewed by Ministry of Municipal Affairs and Housing). OPA 48 was developed to address growth to the year 2031, bringing the City of Guelph's plan into conformity with the Provincial Growth Plan and also to preserve and enhance the City of Guelph's river systems and natural spaces.

Planning for the Township of Guelph/Eramosa falls under the Official Plan of the County of Wellington. The County of Wellington approved its Official Plan Amendment 81 (OPA 81) in 2013. OPA 81 anticipates a population growth up to 122,000 for the year 2031. The result of a 5-year review, OPA 81 ensures compliance with current provincial policies and expands the Official Plan's vision on the preservation of natural heritage features.

2.6.3 Land Use Change and Estimated Recharge Reductions

Future recharge reductions were identified by highlighting land areas where land use is forecasted to change from those designated in the current land use and those designated on the Official Plans. The change in imperviousness from the current to the future land use type was also determined. Figure 2-13 illustrates the potential future percent imperviousness increases due to land use change in the Study Area.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Water Body
Watercourse
Major Road
Niagara Escarpment

Official Plan Land Use

Special Study Area
Natural Area
Reserve Land
Business Park/ Mixed Business
Community Mixed-Use Centre
Commercial/Industrial
Institutional
Urban Centre/ Urban Area
Hamlet Area
Country Residential
Core Area
Low Density Greenfield Residential
Agricultural
Rural Agricultural
Residential
Settlement Residential
Low Rise Residential
Medium Density Residential
High Density Residential
Park / Open Space
Transportation/Utility Area
Downtown

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Kilometres
NAD 1983 UTM Zone 17N

Reference: Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008. Produced using information provided by the Grand River Conservation Authority. Copyright © Grand River Conservation Authority, 2013. Official Plan - City of Guelph, 2013, Official Plan - Region of Waterloo, 2013, Official Plan - Wellington County, 2013

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Official Plan Land Use

Date: 21 Dec 2016	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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Figure 2-12

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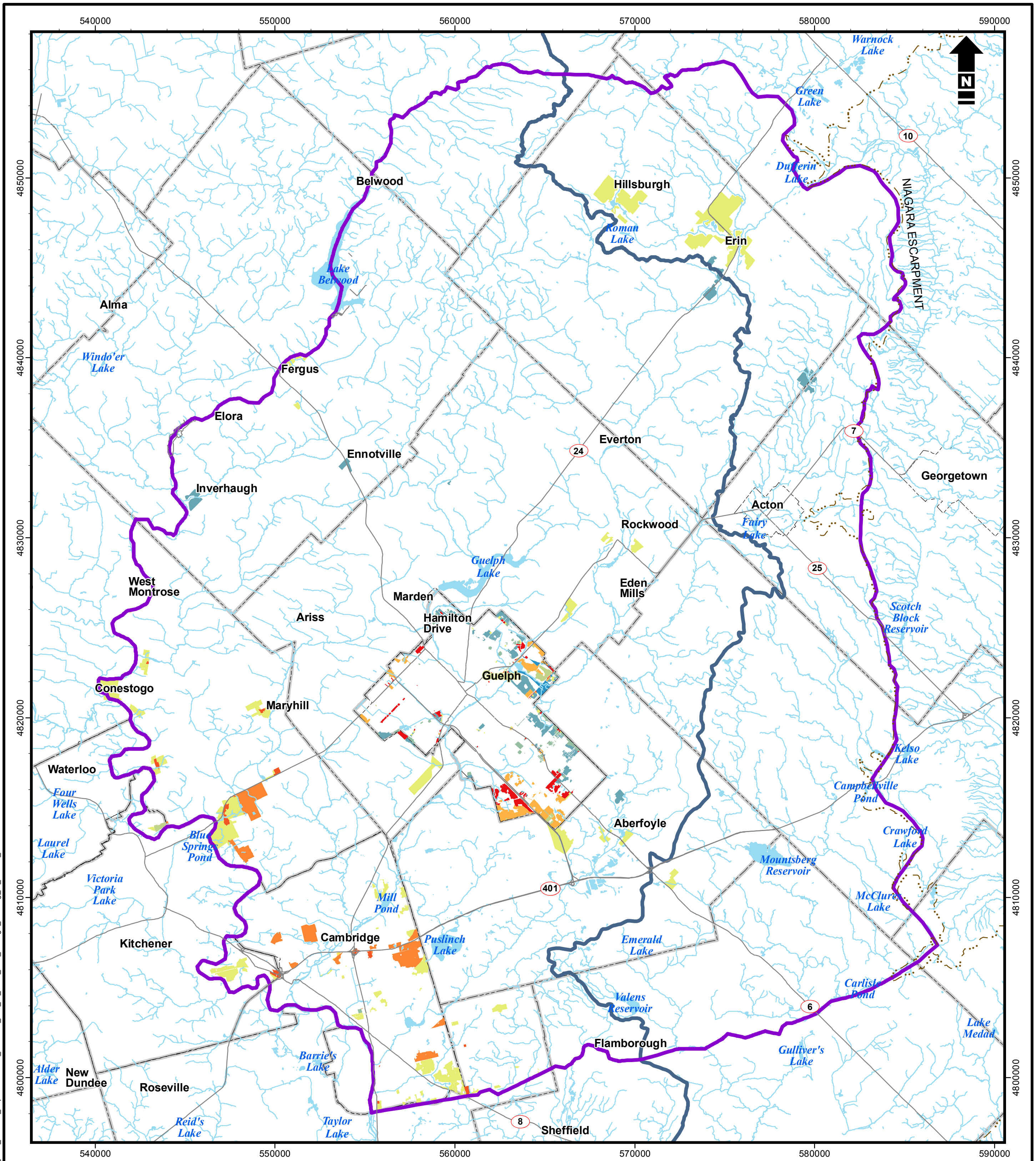

Tier Three Model Boundary (Study Area)

Grand River Watershed Boundary

Community

Major Road

Niagara Escarpment

Percent Imperviousness Increase

- < 10%
- 10% - 20%
- 20% - 30%
- 30% - 40%
- 40% - 50%
- 50% - 60%
- 60% - 70%
- 70% - 80%
- 80% - 90%
- > 90%

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Kilometres

NAD 1983 UTM Zone 17N

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I:\CityofGuelph\15072\FiguresandTables\QHG\2013\Report\RiskAssessment\Figure_2-13_Percent_Imperviousness_Increase_due_to_Land_Use_Change_Existing_to_Official_Plan.mxd

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City of Guelph and Township of Guelph/Eramosa

Tier 3 Water Budget and Local Area Risk Assessment

Percent Imperviousness Increase due to Land Use Change (Existing to Official Plans)

Date: 21 Dec 2016	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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Figure 2-13

Future imperviousness estimates were assigned to those areas planned to be developed according to Table 2-3 adapted from the Guelph Storm Water Management Plan (AMEC 2012) to include land use designations from the County of Wellington, the Region of Waterloo, and rural communities.

TABLE 2-3 Future Land Use - Imperviousness (after AMEC 2012)

Land Use Designation	% Imperviousness
Agriculture / Rural Agriculture	0
Commercial / Industrial	65
Community Mixed-Use Centre	95
Core Area	90
Corporate Business Park	95
Downtown	95
Hamlet Area	20
Institutional / Research Park	30
Low Rise Residential	50
Major Institutional	30
Mixed Business	95
Mixed Office Commercial	95
Mixed-Use Corridor	95
Natural Area	5
Neighbourhood Commercial Centre	95
Park / Open Space	5
Regeneration Areas	no change
Reserve Lands	no change
Residential	30
Residential (High Density)	50
Residential (Low Density / Greenfield / Country)	20
Residential (Medium Density)	30
Residential (Settlement)	50
Service Commercial	95
Significant Natural Area	5
Special Study Area	no change
Transport / Utility Area	65
Urban Centre / Urban Area (Rural Class)	50

2.7 Water Budget Models

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

In this Tier Three Assessment, the groundwater and surface water modelling approach was designed to simulate average and drought conditions, represent the detailed hydrologic and/or hydrogeologic conceptual model, and integrate the input and outputs of the surface water and groundwater models (e.g., groundwater recharge, baseflow). A groundwater flow model was developed and calibrated using the FEFLOW code (version 5.4; Diersch 2006) and a streamflow generation model was developed using the GAWSER model (Schroeter & Associates 2004) for the Grand River Watershed. The following sections summarize the development and application of these models. Appendix B describes the refinement and application of the streamflow generation and groundwater models for the Study Area in detail. Refinements made to the groundwater flow model near Rockwood and Hamilton Drive are described in Appendix D. Further refinements to the groundwater flow model in the area of Rockwood, the Dolime Quarry, and Aberfoyle are documented in Appendix E.

2.7.1 GAWSER Streamflow Generation Model

The GAWSER streamflow generation model is a physically based, deterministic hydrologic model used to predict the total streamflow resulting from inputs of rainfall and/or snowmelt. It can operate in both continuous and event-based modes. It can be used to model recharge ponds and can predict pollutant accumulation, wash off, and transport. Climate input data required for continuous modelling includes daily maximum and minimum temperatures, daily total precipitation, and hourly rainfall.

The GRCA developed and calibrated a continuous GAWSER model to simulate the hydrology of the Grand River Watershed. The hydrologic model was originally constructed for flood forecasting purposes in the late 1980s, and the model has continually improved and evolved since that time as new information and updates in conceptualization have evolved. The event-based model was converted to a continuous model in the late 1990s when a substantial calibration and verification exercise was carried out.

More recently, the GAWSER model was applied to estimate groundwater recharge rates across the Grand River Watershed. The GRCA revisited the model as part of the Grand River Tier Two Water Budget (AquaResource 2009a) and Subwatershed Stress Assessment (AquaResource 2009b). Subsequently the GAWSER model was refined within the Tier Three Assessment Study Area (Appendix B) to better represent current land use and groundwater recharge rates and to improve the simulated streamflow in the Eramosa River supplying the City of Guelph's surface water intake. Within the Study Area, the GAWSER model refinements focused on improving the calibration of the Mill Creek Subwatershed, Upper Speed River Watershed, Eramosa River Watershed, and Blue Springs Creek Subwatershed. The land areas associated with these drainage areas represent a large proportion of the Study Area and the key groundwater recharge areas associated with the municipal drinking water supplies. The results suggested the average and transient groundwater recharge rates estimated by the GAWSER model are reasonable over the long-term and suitable for use in the Tier Three Assessment.

2.7.2 FEFLOW Groundwater Flow Model

To assess the potential impacts of increased municipal groundwater demands on other water uses, a detailed conceptual model of the geologic, hydrogeologic, and hydrologic systems was developed for the Study Area (Figure 1-1) with particular focus on the areas surrounding municipal well fields. A FEFLOW groundwater model was constructed to represent the interaction between the groundwater system and the surface water system.

The approach used to develop the groundwater flow model for this study builds upon the approach followed in the Guelph-Puslinch Groundwater Flow Model (Golder 2006a). The key advancements made in developing this updated and refined groundwater flow model are as follows:

- The geographic coverage of the groundwater flow model was extended to include the Grand River to the west and the Niagara Escarpment to the east. Carrying the model westward to the Grand River provides a natural boundary condition for groundwater flow. The Niagara Escarpment represents the physical location where the Gasport Formation bedrock aquifer, the main aquifer supplying the municipal water supplies, pinches out.

- The conceptual model developed for this study was based on detailed interpretation of geologic units at numerous high-quality boreholes located throughout the Study Area, whereas the bedrock conceptual model used in the Guelph-Puslinch Groundwater Flow Model was simplified and represented by layers of constant thickness.

- The City of Guelph has installed several groundwater monitoring wells screened in discrete hydrogeologic units within the city since the development of the Guelph-Puslinch Model. These wells measure groundwater elevations and vertical gradients throughout the city on a continuous basis and provided an improved and enhanced understanding of the bedrock flow system in the area.

- The Township of Guelph/Eramosa has conducted additional studies for the municipal systems in Rockwood that have improved understanding of the bedrock system in the area.

- The groundwater flow model was refined to include additional surface water features that were not previously represented in the Guelph-Puslinch Groundwater Flow Model.

The approach adopted to calibrate the groundwater flow model included a combination of iterative manual and software-assisted (Parameter ESTimation [PEST]; version 12; Doherty 2013) calibration. The model was calibrated to long-term steady-state conditions and to transient conditions that included the simulation of a long-term pumping test (City of Guelph) and shorter-term tests (Rockwood and Aberfoyle). Transient model verification was also undertaken to confirm the performance of the model under transient conditions in the City of Guelph and in the Rockwood and Hamilton Drive areas. The steady-state groundwater flow model was calibrated to hydraulic head measurements from MOECC domestic water wells records, City of Guelph and Township of Guelph/Eramosa high-quality monitoring wells, and other high -quality wells that are part of other studies. The model was also calibrated to low streamflow targets estimated from spot baseflow observations and streamflow gauge data collected by the GRCA, WSC, and others at locations spread throughout the Study Area.

Calibration of the groundwater flow model relies on estimates of groundwater recharge across the landscape represented by the model. Groundwater recharge estimates used in the calibration of the model include the following:

- The Grand River Watershed GAWSER streamflow generation model (version 6.5, Schroeter & Associates 2004; AquaResource 2009a)
- The Credit River Watershed HSP-F model (AquaResource 2009c)
- Halton and Hamilton Region Conservation Authorities PRMS model (EarthFx 2009)

Additional information on the streamflow-generation and hydrologic models is provided in Appendix B and the references therein (e.g., AquaResource 2009a, 2009b; EarthFx 2009).

3 WATER DEMAND

This chapter outlines the consumptive water uses within the Study Area and estimates consumptive water demand for those uses. Consumptive water demand refers to the amount of water removed from a surface water or groundwater source and not returned to that source within a reasonable amount of time. Estimates of consumptive water demand are necessary in water budget assessments to identify areas that may be under hydrologic stress.

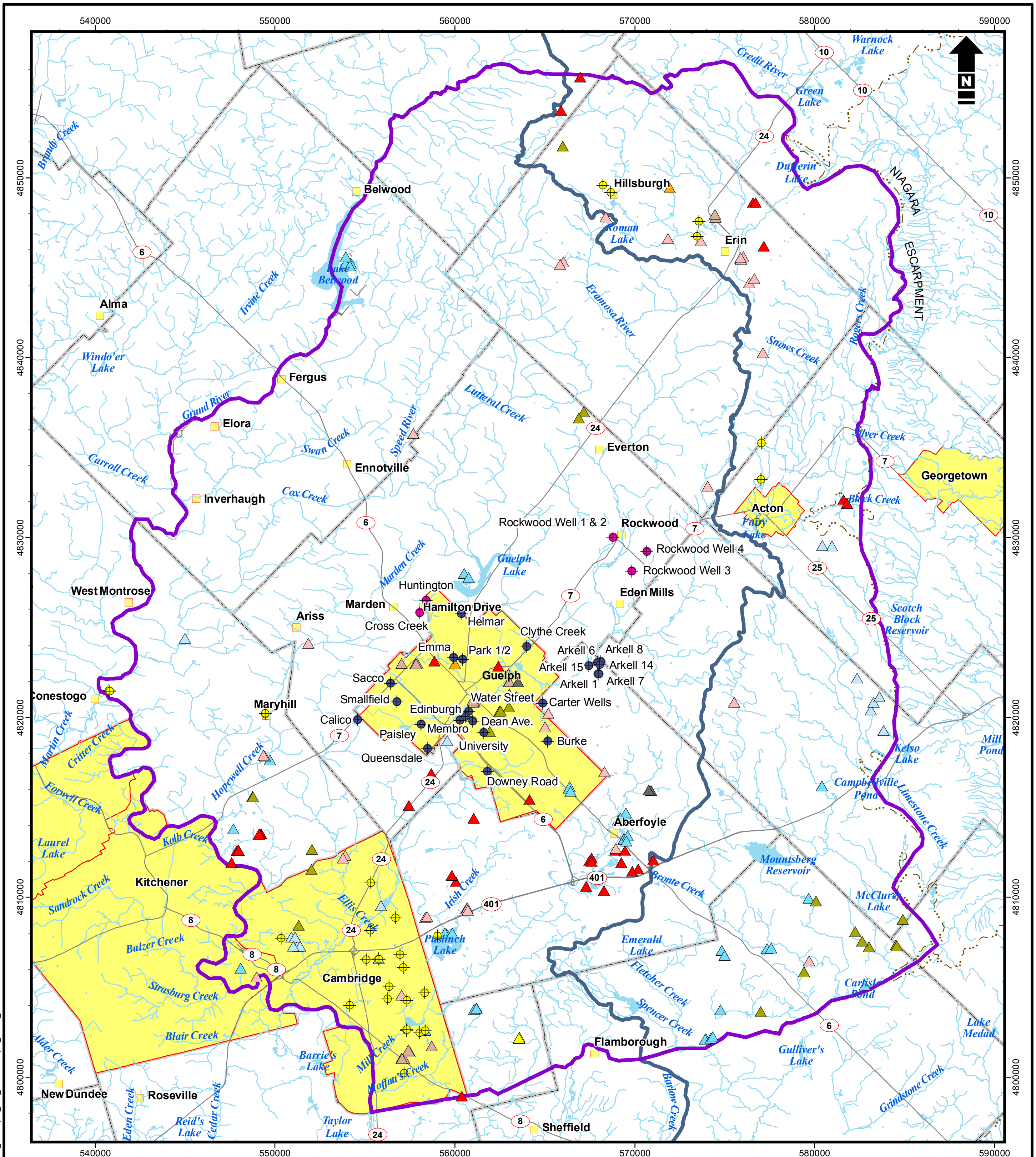
All municipal groundwater takings within the Study Area were considered consumptive in this study because water is pumped from groundwater aquifers and discharged to surface water; the pumped water is not returned to the groundwater production aquifers and as such is considered consumptive.

Section 3.1 describes the municipal water systems located within the Study Area. Current consumptive water use within the Study Area is described in Section 3.2 for municipal users and in Section 3.3 for non-municipal permitted water takings. Permitted consumptive water takings were simulated as groundwater takings within the groundwater flow model as they have the potential to influence simulated water levels and impact the model calibration. Permitted surface water takings were included in the GAWSER streamflow-generation model (Appendix B2) and are not represented in the groundwater flow model.

3.1 Municipal Water Systems

3.1.1 Existing City of Guelph Municipal Supply Wells

The City of Guelph relies mainly on groundwater for its municipal supply demands, and it obtains its water from 23 municipal wells and an artificial recharge system with a shallow groundwater collector referred to as the Glen Collector. Not all of the wells are currently in use; some wells are not being used primarily due to water quality concerns (Appendix A). The City's municipal water supply wells are illustrated on Figure 3-1 (full Study Area) and Figure 3-2 (Area of Interest) and are listed below in Table 3-1.



- Tier Three Model Boundary (Study Area)
- Grand River Watershed Boundary
- Community
- Water Body
- Watercourse
- Major Road
- Niagara Escarpment
- Municipal Well (City of Guelph)
- Municipal Well (Guelph/Eramosa Township)
- Other Municipal Water Supply Well
- Agricultural
- Commercial
- Dewatering
- Industrial
- Institutional
- Miscellaneous
- Recreational
- Remediation
- Water Supply

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City of Guelph and Township of Guelph/Eramosa

Tier 3 Water Budget and Local Area Risk Assessment

Municipal and Non-Municipal Groundwater Demands

Date:	Project:	Technical:	Reviewer:	Drawn:
06 Mar 2017	15072-527	P. Chin	D. VanVliet	M.Urtheil

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Figure 3-1

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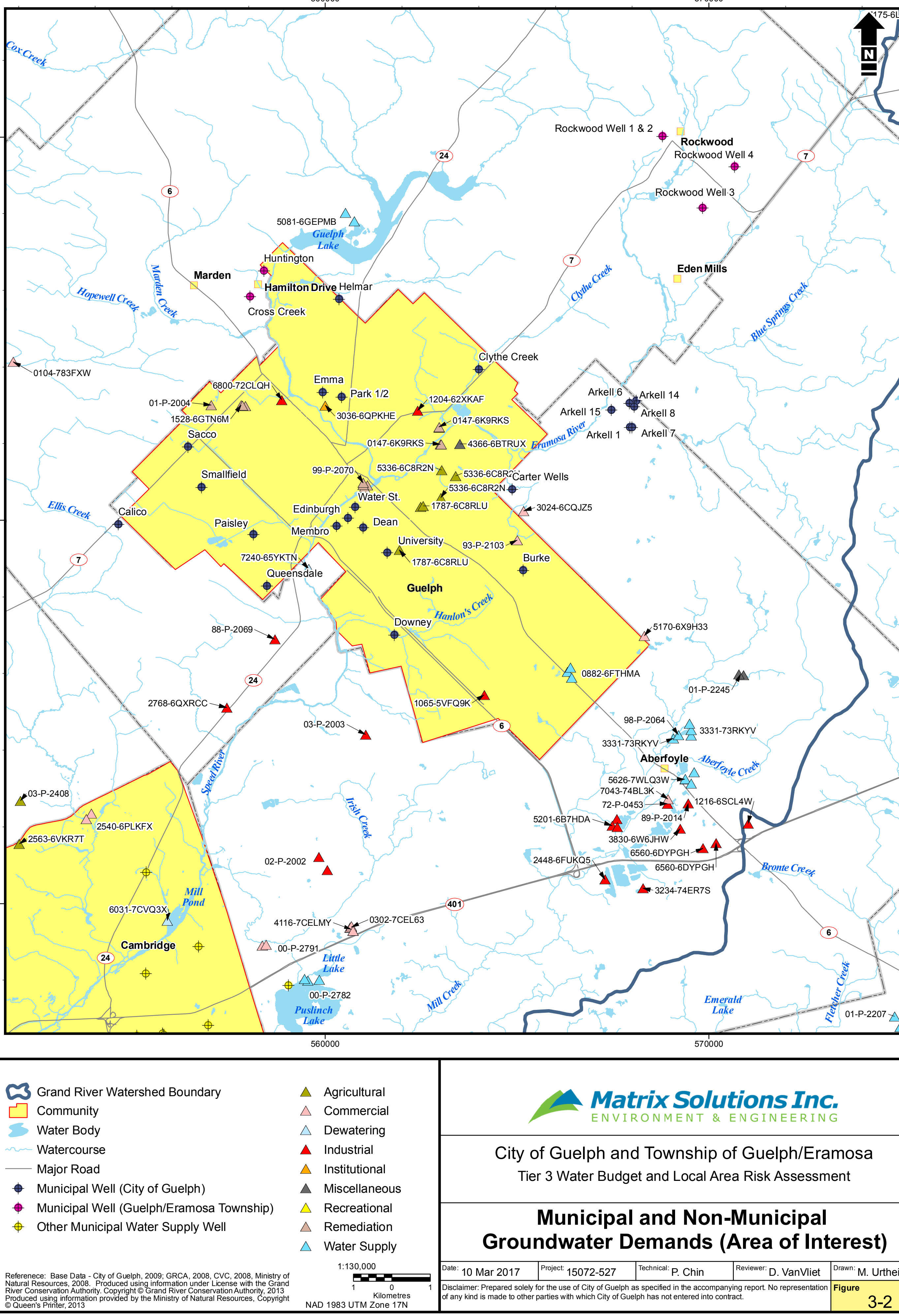

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I:\CityofGuelph\15072\FiguresandTables\QHG\2013\Report\RiskAssessment\Figure_3-2_Municipal_and_Non-Municipal_Water_Demands_CityofGuelph.mxd

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Municipal and Non-Municipal Groundwater Demands (Area of Interest)

Date: 10 Mar 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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Figure 3-2

TABLE 3-1 City of Guelph Water Supply Wells

Quadrant	Well Name	Easting (NAD83)	Northing (NAD83)	Depth (m)	Formation Screened	Permitted Rate[1] (m^3/day)
Southeast	Glen Collector	Not applicable	Not applicable	Not applicable	Overburden	25,000
	Arkell 1	567944	4822434	20.1	Overburden/ Contact Zone	3,273
	Arkell 14	568096	4823126	40.5	Upper to Middle Gasport	9,504[3]
	Arkell 15	567440	4822878	30.5	Upper to Lower Gasport	9,504[3]
	Arkell 6	567934	4823061	41.2	Upper to Middle Gasport	9,504[3]
	Arkell 7	567993	4822436	43.3	Upper to Middle Gasport	9,504[3]
	Arkell 8	568055	4822971	42.1	Upper to Middle Gasport	9,504[3]
	Burke	565157	4818701	79.6	Guelph to Middle Gasport	6,546
	Carter Wells	564870	4820808	20.7	Guelph	6,547
Southwest	Dean Ave.	560997	4819805	57.2	Upper to Middle Gasport	2,300
	Downey Rd.	561798	4817015	73.8	Upper to Middle Gasport	5,237
	Edinburgh[2]	560594	4820066	69.5	Upper to Middle Gasport	3,000
	Membro	560293	4819861	73.2	Upper to Middle Gasport	6,050
	University	561613	4819168	64.3	Upper Gasport	3,300
	Water Street	560773	4820356	60.0	Upper to Middle Gasport	3,400
Northeast	Clythe Creek[2]	564031	4823927	58.9	Reformatory Quarry to Lower Gasport	5,237
	Emma	559931	4823351	46.0	Upper to Middle Gasport	3,100
	Helmar	560357	4825777	79.6	Upper to Middle Gasport	3,273
	Park 1 and 2	560430	4823231	57.0	Upper to Middle Gasport	10,300
Northwest	Paisley	558126	4819636	80.2	Upper to Middle Gasport	3,200
	Calico	554602	4819900	64.0	Upper Gasport	5,237
	Queensdale	558482	4818297	74.4	Guelph to Upper Gasport	5,237
	Sacco[2]	556416	4821929	95.7	Guelph to Middle Gasport	1,640
	Smallfield[2]	556748	4820866	102.1	Guelph to Lower Gasport	1,964

Notes:
[1]Effective as of 2013
[2]Not currently operating
[3]Each well is individually permitted up to 9,504 m^3/day; however, the combined permitted rate is 28,800 m^3/day

The City of Guelph supplies are typically grouped into four quadrants as shown in Table 3-1. In the southeast quadrant, the Arkell Spring Grounds provide a large portion of the City of Guelph water supply. The Arkell Spring Grounds consists of five bedrock wells (Arkell wells 6, 7, 8, 14, and 15), one overburden/bedrock contact well (Arkell Well 1), and a groundwater collection system known as the Glen Collector.

The Glen Collector system collects shallow groundwater from the overburden through a series of perforated pipes. A similar system, the Lower Road Collection System, was taken offline in 2001 due to water quality concerns. The yield from the Glen Collector system varies seasonally according to fluctuations in the water table elevation. The Carter Well and the Burke Well also lie in the southeast quadrant of Guelph. The City of Guelph operates a surface water intake on the Eramosa River to enhance the supply of water into the collection system (Section 3.1.2).

The municipal wells in the southwest quadrant of Guelph also provide a large portion of the municipal supply. Five active wells exist in the southwest quadrant including the Water Street Well, Membro Well, Dean Avenue Well, University Well, Edinburgh Well (not in service), and Downey Road Well.

In the northeast quadrant, the municipal wells include Park Wells 1 and 2, Emma Street Well, Helmar Well, and the Clythe Creek Well (not in service). The Calico Well, Smallfield Well, Sacco Well, Paisley Road Well, and Queensdale Well are in the northwest quadrant of the City of Guelph; the Smallfield and Sacco wells are currently offline due to water quality concerns.

3.1.2 Township of Guelph/Eramosa Municipal Supply Wells

3.1.2.1 Rockwood

The residents of Rockwood rely entirely on groundwater for their potable water supplies. This water is currently derived from three wells completed within the Gasport Formation. A fourth bedrock well, Rockwood Well 4, was recently constructed by the Township of Guelph/Eramosa and permitted. It is expected to be added to the Rockwood water supply system in the near future. The locations of these wells are illustrated on Figure 3-2 and are listed in Table 3-2. Rockwood wells 1 and 2 share a pump house and are located west of the Eramosa River in northwest Rockwood. Due to observed hydraulic connection between the production aquifer and the surface water flow system, these wells have been designated as GUDI wells. Rockwood Well 3 and Rockwood Well 4 are located in the southeast of Rockwood, east of the Eramosa River and are considered non-GUDI.

TABLE 3-2 Rockwood and Hamilton Drive Water Supply Wells

Location	Well Name	Easting (NAD83)	Northing (NAD83)	Formation Screened	Permitted Rate (m^3/day)
Rockwood	Rockwood Wells 1 & 2	568785	4830026	Middle Gasport	1,965
	Rockwood Well 3	569833	4828156	Middle Gasport	1,310
	Rockwood Well 4	570671	4829240	Upper to Middle Gasport	1,310
Hamilton Drive	Cross Creek	558038	4825840	Upper to Middle Gasport	812
	Huntington	558405	4826512	Upper to Middle Gasport	916

3.1.2.2 Hamilton Drive

The Township of Guelph/Eramosa obtains its potable municipal water for Hamilton Drive from two wells completed in the Gasport Formation aquifer. The Huntington well is found in the northeastern part of the subdivision, along Wellington Road 38 and approximately 240 m west of the Speed River. The Cross Creek well is found in the central part of the residential subdivision, approximately 430 m west of the Speed River. Well locations are found on Figure 3-2 and well details are found on Table 3-2.

3.1.3 Additional Municipal Wells

Table 3-3 lists additional municipal water supply wells located within the Study Area. Adjacent municipalities that use groundwater for supply include Maryhill, Fergus/Elora, Acton, and Cambridge. In addition, there are a number of communal water supplies in the area including Mini-Lakes, Irish Creek Estates, McClintock's Trailer Park, and Mill Creek Camping and Country Club.

The Region of Halton operates municipal wells within in the Credit River Watershed, and these wells were studied within the Halton Hills Tier Three Assessment (AECOM and AquaResource 2014). The Region of Waterloo operates municipal drinking water wells within the City of Cambridge, and these wells were studied as part of the Region of Waterloo Tier Three Assessment (Matrix and SSPA 2014).

TABLE 3-3 Additional Municipal Water Supply Wells

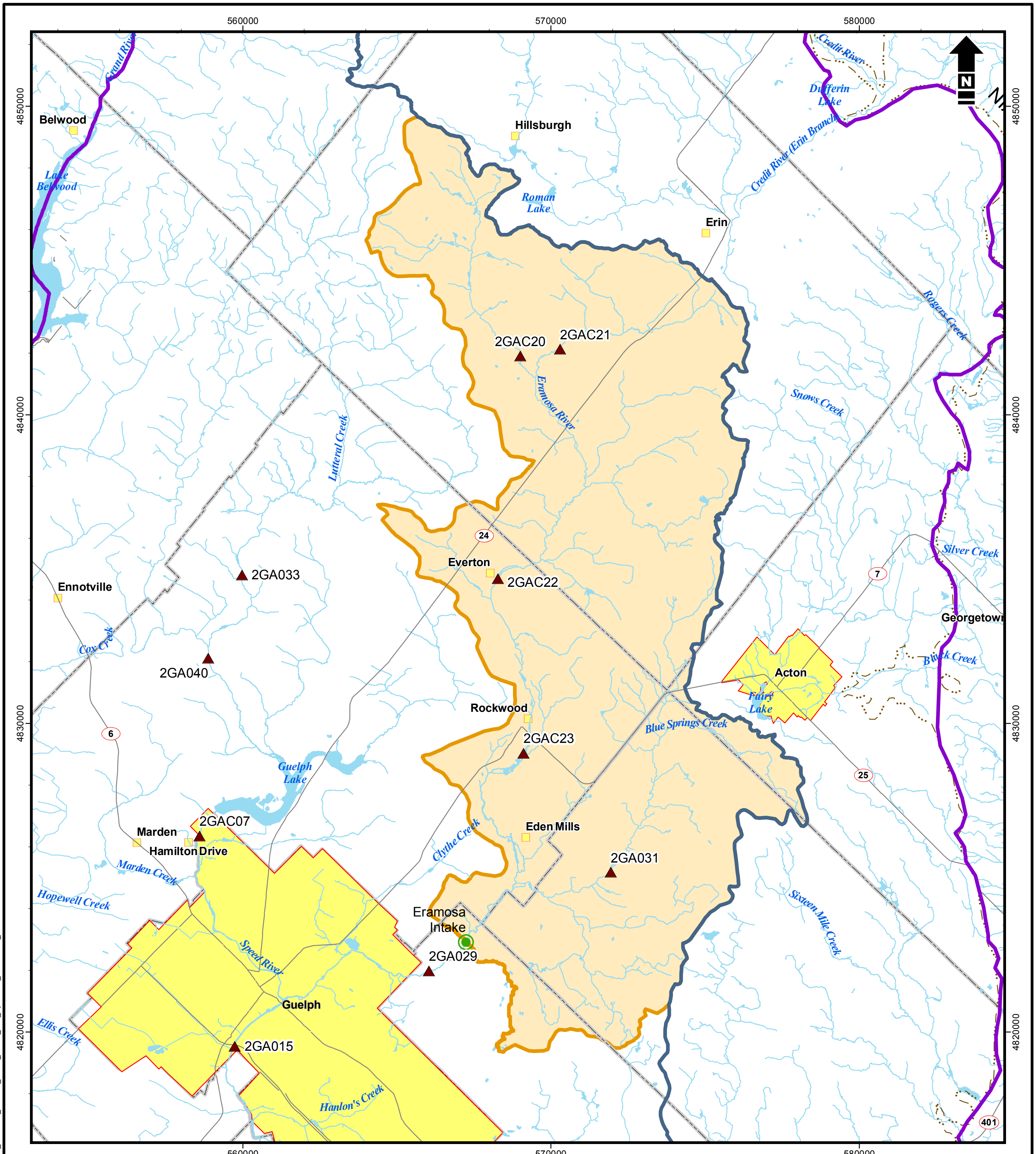
Town/ Township	Well Name	Easting (NAD83)	Northing (NAD83)	Formation Screened	Permitted Rate (m^3/day)
Puslinch	Irish Creek	559037	4807868	Guelph to Upper Gasport	327
Erin	Erin #7	573556	4847599	Gasport	2,160
	Erin #8	573466	4846759	Gasport	1,968
	Hillsburgh #2	568676	4849209	Gasport	982
	Hillsburgh #3	568233	4849607	Gasport	655
Region of Halton	4th Line Well A	577038	4835290	Gasport	1,309
	Davidson #1	577011	4833241	Gasport	1,250
	Davidson #2	577011	4833241	Gasport	1,250
	Prospect Park Wells	576804	4830877	Gasport	4,546
Region of Waterloo	C2	540782	4821527	Overburden	1,718
	C5	540828	4821478	Overburden	
	G16	558336	4804721	Guelph to Upper Gasport	3,283
	G17	556271	4804365	Contact Zone to Middle Gasport	4,320
	G18	557327	4804287	Guelph to Upper Gasport	3,269
	G38	557302	4802637	Contact Zone to Guelph	9,850
	G39	557324	4802665	Contact Zone to Guelph	9,850
	G5	555084	4806561	Contact Zone to Guelph	4,320
	G6	556355	4805062	Contact Zone to Upper Gasport	2,160
	G7	558050	4802493	Overburden to Guelph	Grandfathered[1]
	G8	558339	4802613	Contact Zone	2,292

Town/ Township	Well Name	Easting (NAD83)	Northing (NAD83)	Formation Screened	Permitted Rate (m^3/day)
	G9	557175	4800261	Guelph	Grandfathered[1]
	H3	555314	4808183	Contact Zone to Upper Gasport	Grandfathered[1]
	H4	556693	4808882	Contact Zone to Guelph	2,074
	H5	555327	4810826	Guelph	Grandfathered[1]
	MH1	549457	4820230	Guelph	TBD
	MH2	549454	4820234	Overburden	TBD
	P10	556951	4806839	Overburden to Guelph	Grandfathered[1]
	P11	557140	4806113	Contact Zone to Upper Gasport	5,184
	P15	555754	4806616	Contact Zone to Upper Gasport	1,638
	P16	550338	4807753	Contact Zone	1,961
	P17	557128	4806110	Contact Zone to Lower Gasport	5,184
	P6	554159	4804014	Guelph to Middle Gasport	Grandfathered[1]
	P9	555792	4806582	Contact Zone to Upper Gasport	Grandfathered[1]

Note:
[1] Grandfathered wells predate Ontario's PTTW system and do not require permits

3.1.4 Eramosa Surface Water Intake

The City of Guelph's Artificial Recharge System is supplied by the City of Guelph's Eramosa River Intake. The location of the intake is illustrated on Figure 3-3. Between April 15 and November 15 of each year, when needed, water is pumped out of the Eramosa River and discharged into an infiltration pit and trench where the water recharges the shallow overburden aquifer supplying the Glen Collector (Figure 3-4). Although it is shown on the figure, the Lower Road Collector is no longer in service.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Contributing Area
Community
Water Body
Watercourse
Major Road
Niagara Escarpment
River Intake
Streamflow Gauge

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Eramosa Surface Water Intake and Upstream Catchment Area

Date: 06 Mar 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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Figure 3-3

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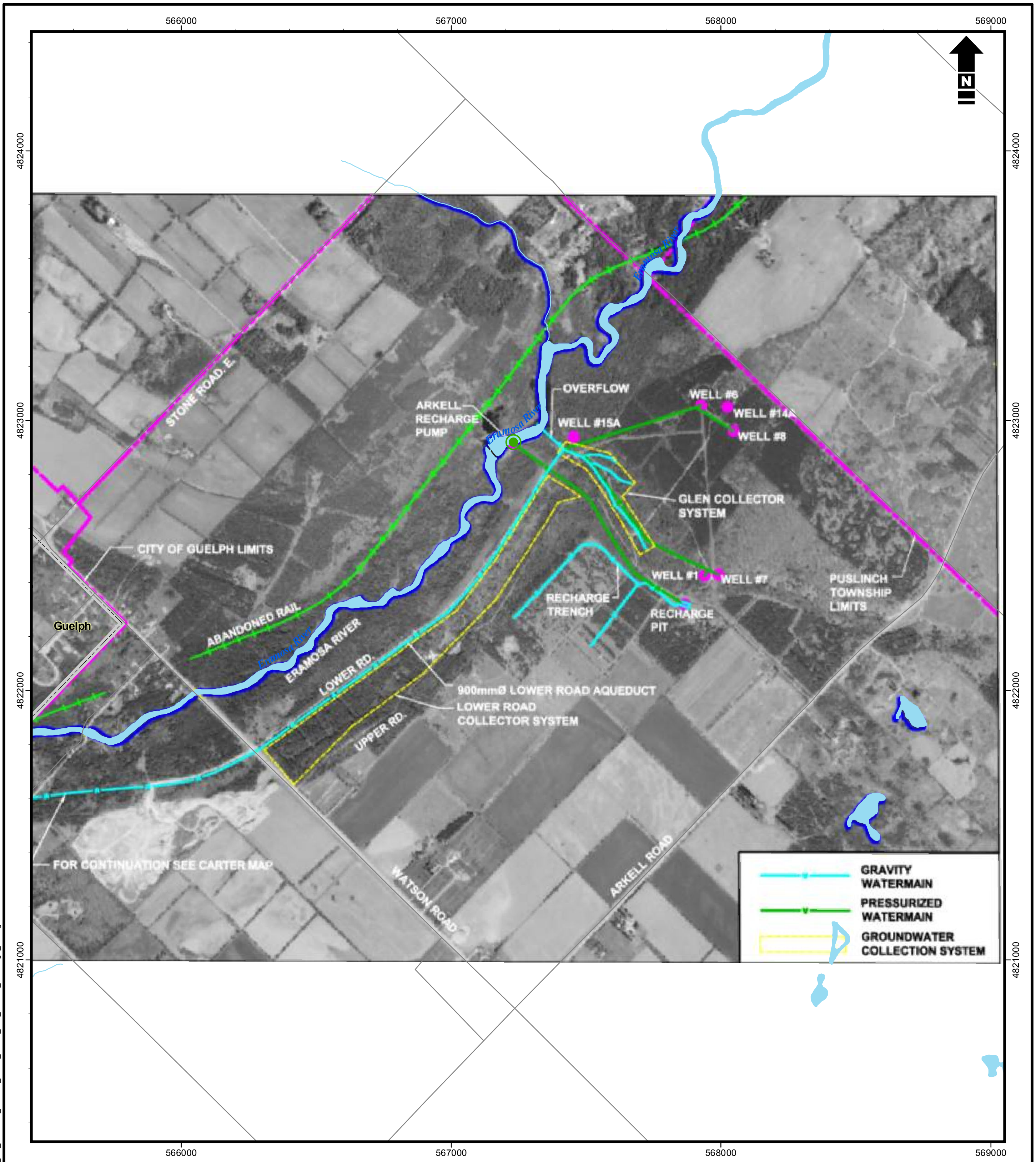

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Community
Water Body
Watercourse
Major Road
River Intake
Municipal Well

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Metres
NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Eramosa Surface Water Intake and Artifical Recharge Configuration

Date: 06 Mar 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

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Figure 3-4

As noted earlier, the Eramosa River subwatershed is located on the eastern portion of the Grand River Watershed near the City of Guelph, Township of Guelph/Eramosa, Puslinch Township, and the Region of Halton. The Eramosa River discharges into the Speed River within the City of Guelph, which then discharges into the Grand River in the City of Cambridge.

The Eramosa River Intake consists of a pump attached to a concrete platform approximately 6 m from the southern river bank. A 2 m high concrete weir is located approximately 90 m downstream of the intake, creating an impoundment near the intake structure. The Eramosa River Intake is a municipal intake as the water pumped from the Eramosa River is used as a municipal supply.

Water withdrawals from the Eramosa River are regulated by a PTTW, which has a number of conditions depending on season, river flow, and water quality. The City of Guelph is permitted to pump water from the intake at the rates listed in Table 3-4, provided that a streamflow of 0.85 m^3/s is maintained past the Guelph Wastewater Treatment Plant, and a streamflow of 0.43 m^3/s is maintained in the Eramosa River.

TABLE 3-4 Seasonal Permitted Water Taking for City of Guelph Eramosa River Intake

Season	Permitted Pumping Rates (m^3/day)
April 15 to May 31	31,822
June 1 to June 30	22,730
July 1 to July 15	18,184
July 16 to August 31	13,639
September 1 to November 15	9,092

Due to pump infrastructure limitations, the pumping rate for the surface water intake is currently limited to a maximum of 9,092 m^3/day throughout the April 15 to November 15 period. If the infrastructure limitations were removed, the surface water intake pumping rate could be increased; however, the final rate would be limited by the infiltration ability of the infiltration pit and trench.

3.2 Municipal Water Demand

As part of the Tier Three Assessment, the Allocated and Planned quantities of water need to be estimated for each existing and planned groundwater well or intake. The Allocated rates are estimated based on the Existing and Committed municipal water demands, and the Planned quantity of water is the amount of water that meets the criteria of a planned system (MOE 2013).

As outlined in the Technical Rules (MOECC 2016) and Technical Guidance Memorandum (MOE 2013), the Existing, Committed, and Planned demand for this assessment needed to be established. The definitions of these terms, as outlined in the revised Technical Guidance Memorandum, are below.

- Existing demand refers to the amount of water determined to be currently taken from each well/intake during the Study Period. For this Tier Three Assessment, the Existing demand was estimated as the average annual pumping during 2008 for the City of Guelph and 2009 to 2010 for Rockwood and Hamilton Drive. Maximum monthly and maximum daily demands should also be estimated for the Study Period based on historical trends (MOECC 2016).

- Committed demand is an amount greater than the Existing demand that is necessary to meet the needs of the approved Settlement Area within the Official Plan. The portion of this amount that is within the Current Lawful PTTW Taking is part of the Allocated rates. Any amount greater than the Current Lawful PTTW Taking is considered part of the Planned quantity of water.

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

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

For the municipal supply systems in the City of Guelph, Rockwood, and Hamilton Drive, none of the demands associated with these wells are considered to be Planned demand; thus, there was no Planned quantity of water to consider.

3.2.1 Existing Demand - City of Guelph

The Existing pumping rates for the City of Guelph in this Tier Three Assessment were calculated as the average annual pumping rates from the 2008 calendar year (Table 3-5). The total Existing demand of the City of Guelph water supply system is approximately 47,700 m^3/day. This compares to a maximum total permitted amount of approximately 132,600 m^3/day; however, the sustainable capacity of the system, as evaluated by the Water Supply Master Plan (Earth Tech et al. 2006) and the City of Guelph Water Services Division, is approximately 89,900 m^3/day (Table 3-5). Within any year, maximum daily demands can be much higher than average daily demands due to outdoor water use, industrial use, or other municipal water uses. The estimated sustainable capacity may be affected by climatic conditions (i.e., drought), well interference, and well efficiency such that the total capacity may not be always available.

TABLE 3-5 Municipal Water Demand - City of Guelph

Municipal Well	Aquifer	Rates (m³/day)		
		Maximum Permitted	Estimated Capacity[1]	Existing Demand (Average 2008)
Glen Collector	Overburden	25,000	6,900	6,500
Arkell 1	Overburden/ Contact Zone	3,273	2,000	730
Arkell 14	Upper to Middle Gasport	28,800[4]	28,800	Not applicable[3]
Arkell 15	Upper to Lower Gasport			Not applicable[3]
Arkell 6	Upper to Middle Gasport			3,774
Arkell 7	Upper to Middle Gasport			3,689
Arkell 8	Upper to Middle Gasport			3,694
Burke	Guelph to Middle Gasport	6,546	6,500	5,385
Calico	Upper Gasport	5,237	1,100	748
Carter Wells	Guelph	6,547	5,500	2,004
Clythe Creek	Reformatory Quarry to Lower Gasport	5,237	3,000[2]	Not applicable[3]
Dean Ave.	Upper to Middle Gasport	2,300	1,500	1,215
Downey Rd.	Upper to Middle Gasport	5,237	5,100	3,940
Edinburgh	Upper to Middle Gasport	3,000	-	Not applicable[3]
Emma	Upper to Middle Gasport	3,100	2,800	2,273
Helmar	Upper to Middle Gasport	3,273	1,500	500
Membro	Upper to Middle Gasport	6,050	6,000	3,036
Paisley	Upper to Middle Gasport	3,200	1,400	762
Park 1 and 2	Upper to Middle Gasport	10,300	8,000	5,897
Queensdale	Guelph to Upper Gasport	5,237	2,000	702
Sacco	Guelph to Middle Gasport	1,640	1,150[2]	Not applicable[3]
Smallfield	Guelph to Lower Gasport	1,964	1,400[2]	Not applicable[3]
University	Upper Gasport	3,300	2,500	1,648
Water Street	Upper to Middle Gasport	3,400	2,700	1,184
Total		**132,641**	**89,850**	**47,681**

Notes:
[1] Estimated Sustainable Rates from Water Supply Master Plan ((Earth Tech et al. 2006), up to the maximum permitted rate
[2] Sustainable Rate estimated by City of Guelph Water Services Division
[3] Wells not pumped during 2008 due to water quality or maintenance concerns
[4] Each well is individually permitted up to 9,504 m^3/day; however, the combined permitted rate is 28,800 m^3/day.

3.2.2 Existing Demand - Rockwood and Hamilton Drive

Existing municipal demand for the Rockwood and Hamilton Drive wells was calculated based on the average demand from 2009 to 2010 for each municipal well (except Rockwood Well 4, which has not yet started production). This period was selected to align with available municipal water level data and the reference data used to estimate population growth forecasts for the two communities. The use of a 2-year period avoids misrepresenting short-term trends in demand in these small systems that might occur over a single year but are not representative of average conditions (e.g., a well shutting down for maintenance). Existing municipal demand rates for Rockwood and Hamilton Drive are provided in Table 3-6.

TABLE 3-6 Municipal Water Demand - Rockwood and Hamilton Drive

Location	Municipal Well	Aquifer	Rates (m^3/day)	
			Maximum Permitted	Existing Demand (Average 2009 to 2010)
Rockwood	Rockwood Well 1	Middle Gasport	1,965	283
	Rockwood Well 2	Middle Gasport		262
	Rockwood Well 3	Upper to Middle Gasport	1,310	422
	Rockwood Well 4	Upper to Middle Gasport	1,310	n/a
Hamilton Drive	Cross Creek	Upper to Middle Gasport	812	87
	Huntington	Upper to Middle Gasport	916	92
		Total	6,313	1,146

Note:
n/a - rate not available. Rockwood Well 4 is not yet in operation.

3.2.3 Existing Plus Committed Demand and Allocated Rates - City of Guelph

According to the Technical Guidance Memorandum (MOE 2013), the Committed demand represents the additional quantity of water over and above the Existing demand that is required to meet the future water demand in the City of Guelph. The Allocated rate represents the sum of the Existing and Committed demands.

The City of Guelph recently finalized its *Water Conservation and Efficiency Strategy Update* (WC&ES; RMSi 2009), updating the City of Guelph's long-term water demand estimates. The WC&ES estimated an average-day water demand (without considering additional water conservation efforts) for the year 2031 to be 71,595 m^3/day to meet the forecast population (175,000 residents) and water demand assumptions within the WC&ES. This demand represents the target total allocated demand for the City of Guelph's water supply system or a target Committed increase in demand of 23,914 m^3/day (50% increase) over Existing demand (47,681 m^3/day).

Two different sets of Allocated rates were developed for individual wells and the Glen Collector to accommodate the following: 1) average conditions and 2) low water (drought) conditions and the impact of decreased pumping from the Eramosa Intake on the yield from the Glen Collector. While average annual discharge from the Glen Collector is greater than 6,900 m^3/day, modelling and operational experience indicate that discharge during very dry conditions can fall below 2,000 m^3/day. When discharge falls below 6,900 m^3/day, the Allocated pumping rates at other wells are increased to meet the 2031 demand.

The first set of Allocated rates (average conditions) was estimated as follows:

1. Initial Allocated rates were estimated for each well based on the total target Allocated rate of 71,595 m^3/day from the WC&ES.

2. Safe additional available drawdown was calculated at each well. Safe additional available drawdown is defined as the additional depth that water within a pumping well could fall and still maintain that well's Allocated pumping rate. It is calculated as the additional drawdown that is available beyond the drawdown created by the existing conditions pumping rate. Appendix F provides a detailed discussion of the calculation of safe available drawdown for the municipal wells examined in this assessment.

3. The groundwater flow model was simulated during average conditions and drought conditions, and drawdown at each well was compared against the safe available drawdown.

4. Where simulated drawdown was found to be greater than safe available drawdown at a well, the Allocated rate for that well was decreased, and there was a corresponding increase in the Allocated rate at another well.

5. The model was rerun iteratively through steps 3 and 4 (above) until the drawdown at each well was within the limits set by the safe available drawdown. The final model was then run in steady-state with the total pumping rate from all wells and the Glen Collector meeting the 2031 demand requirement.

The Allocated rates (for 2031) for each well and the Glen Collector under average conditions, estimated using the above approach, are summarized in Table 3-7. The sum of these rates for the City of Guelph's drinking water system is 73,450 m^3/day. This rate exceeds the target total Allocated rate provided by the WC&ES for the average-day water demand in 2031 by 1,855 m^3/day (compare to 71,595 m^3/day) and adds a level of conservatism to the final Allocated demand estimate under average conditions. This is a Committed increase in demand of 25,769 m^3/day (54% increase) over Existing demand (47,681 m^3/day).

The second set of Allocated rates under drought conditions were required to compensate for a decrease in discharge from the Glen Collector during low water periods. These Allocated rates were estimated as follows:

1. Results from the assessment of average conditions (above) were reviewed to identify wells with the highest capacity and available drawdown. A maximum Allocated rate was specified for each well with additional capacity (highlighted in Table 3-7).

2. Discharge to the Glen Collector was calculated from the groundwater flow model over a 10-year drought period (1960 to 1970). Figure 3-5 illustrates the simulated monthly discharge from the Glen Collector combined with monthly pumping rates at the Eramosa Intake and delivered to the

recharge system. This figure illustrates that the simulated rate of flow at the Glen Collector varies depending on the amount of artificial recharge introduced from the Eramosa Intake pumping on a monthly basis and over the long term. On a monthly basis, when simulated groundwater discharge fell below 6,900 m^3/day, the Allocated pumping rate for selected wells with additional capacity was increased proportionally to accommodate for the loss in water supply from the Glen Collector.

3. The groundwater flow model was simulated over the 10-year drought period (1960 to 1970) with selected wells pumping higher rates in months where Glen Collector discharge was low. Figure 3-6 illustrates the monthly flow from the Glen Collector along with monthly pumping rates across each of the quadrants, increased where needed to accommodate for reduced discharge into the collector.

4. The model was rerun iteratively through steps 2 and 3 (above) until the drawdown at each well was within the limits set by the safe available drawdown and the total pumping rate from all wells, and the Glen Collector met the 2031 demand requirement

Table 3-7 summarizes the set of Allocated rates determined for each of the City of Guelph and Glen Collector wells under drought conditions, using the methodology described above. The total Allocated demand for the water supply system under drought conditions is 73,442 m^3/day and conservatively exceeds the 2031 target provided by WC&ES (compare to 71,595 m^3/day). This represents a Committed increase in demand by 25,761 m^3/day (54% increase) over Existing demand (47,681 m^3/day).

TABLE 3-7 Allocated Rates - City of Guelph

Well Name	Rates (m^3/day)				
	Existing Demand (Average 2008)	Maximum Permitted Demand	Estimated Capacity[1]	Allocated (2031) Demand	
				Average Conditions	Drought Conditions
Arkell 1	730	3,273	2,000	1,400	1,400
Arkell 14	*0*	28,800[3]	28,800	*3,300*	*4,400*
Arkell 15	*0*			*3,300*	*4,400*
Arkell 6	*3,774*			*4,900*	*5,300*
Arkell 7	*3,689*			*4,900*	*5,300*
Arkell 8	3,694			4,900	4,900
Burke	*5,385*	*6,546*	*6,500*	*6,000*	*6,300*
Calico	748	5,237	1,100	1,100	1,100
Carter Wells	*2,004*	*6,547*	*5,500*	*4,000*	*4,400*
Clythe Creek	0	5,237	3,000[2]	2,200	2,200
Dean Ave.	1,215	2,300	1,500	1,500	1,500
Downey Rd.	*3,940*	*5,237*	*5,100*	*5,100*	*5,200*
Edinburgh[4was]	0	3,000	0	0	0
Emma	*2,273*	*3,100*	*2,800*	*2,100*	*2,400*

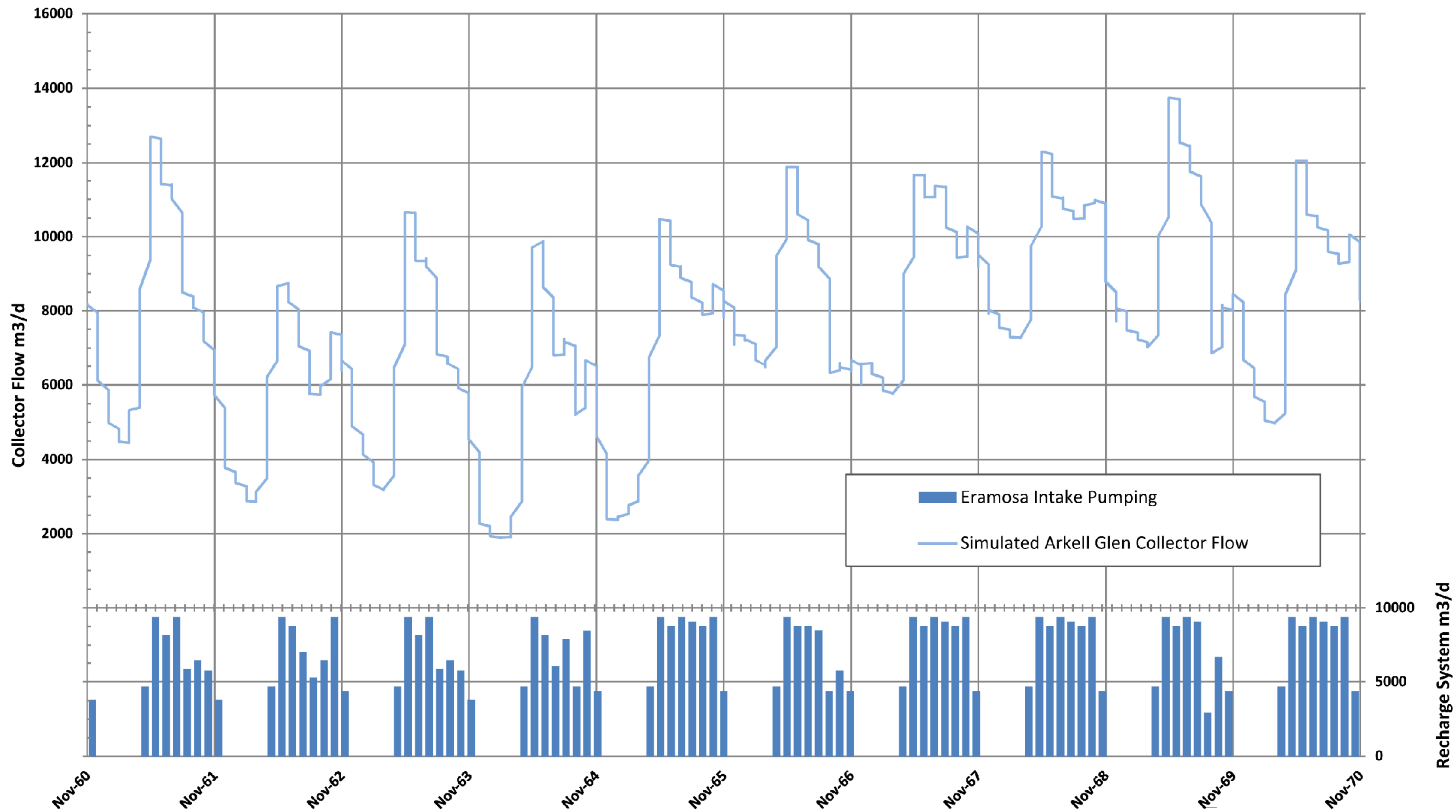
Well Name	Rates (m^3/day)				
	Existing Demand (Average 2008)	Maximum Permitted Demand	Estimated Capacity[1]	Allocated (2031) Demand	
				Average Conditions	Drought Conditions
Helmar	*500*	*3,273*	*1,500*	*1,100*	*1,200*
Membro	*3,036*	*6,050*	*6,000*	*4,200*	*4,300*
Paisley	*762*	*3,200*	*1,400*	*800*	*1,000*
Park 1 & 2	*5,897*	*10,300*	*8,000*	*6,400*	*6,900*
Queensdale	702	5,237	2,000	2,000	2,000
Sacco	0	1,640	1,150[2]	1,150	1,150
Smallfield	0	1,964	1,400[2]	1,400	1,400
University	1,648	3,300	2,500	2,500	2,500
Water Street	*1,184*	*3,400*	*2,700*	*2,300*	*2,400*
Total (Wells)	41,181	107,641	82,950	66,550	71,550
Glen Collector	*6,500*	*25,000*	*6,900*	*6,900*	*1,892*
Total	47,681	132,641	89,850	73,450	73,442

Notes:
[1] Estimated Sustainable Rates from Water Supply Master Plan (Earth Tech, et al. 2006), up to the maximum permitted rate
[2] Sustainable Rate estimated by City of Guelph Water Services Division
[3] Each well is individually permitted up to 9,504 m3/day; however, the combined permitted rate is 28,800 m^3/day.
[4] The City of Guelph is not planning on using Edinburgh due to water quality concerns.

The estimates of Allocated demand under average and drought conditions (Table 3-7) represent the average-day demands and are less than the estimated capacity of the total system (89,850 m^3/day) and maximum permitted taking (132,641 m^3/day). Maximum-day water demands (due to increased outdoor water use, industrial use, or other municipal water uses) may be 34% higher (i.e., peaking factor of 1.34) than the estimated average-day water demand amount, according to projections in the WC&ES (RMSi 2009). It is important to consider these short-term extremes in pumping when assessing a well's ability to accommodate additional demand. To assess whether the water supply system can operate at maximum-day (peaking) requirements under target Allocated conditions, the following formula is used:

$$\textit{Maximum-Day Demand} = \textit{Target Allocated Rate x Peaking Factor}$$
$$\textit{Maximum-Day Demand} = 71{,}595\ m^3/day \times 1.34 = 95{,}937\ m^3/day.$$

This maximum-day demand is less than the total permitted capacity (132,641 m^3/day) of the water supply system, but greater than the estimated capacity (89,850 m^3/day) of the system. It is anticipated that the deficit (6,087 m^3/day) between the estimated system capacity and maximum-day demand would be offset during these short periods by the volume of water available in storage. The City of Guelph's drinking water system has the capacity to store 59,200 m^3 of water using five underground storage reservoirs and three water towers (City of Guelph 2014), providing additional supplies for almost 10 days during these periods. Further, the rates that comprise the estimated system capacity represent the sustainable rates over the long term. Over a short-time frame, during periods of extreme water use, the wells would be able to accommodate an even greater demand close to their permitted rates.



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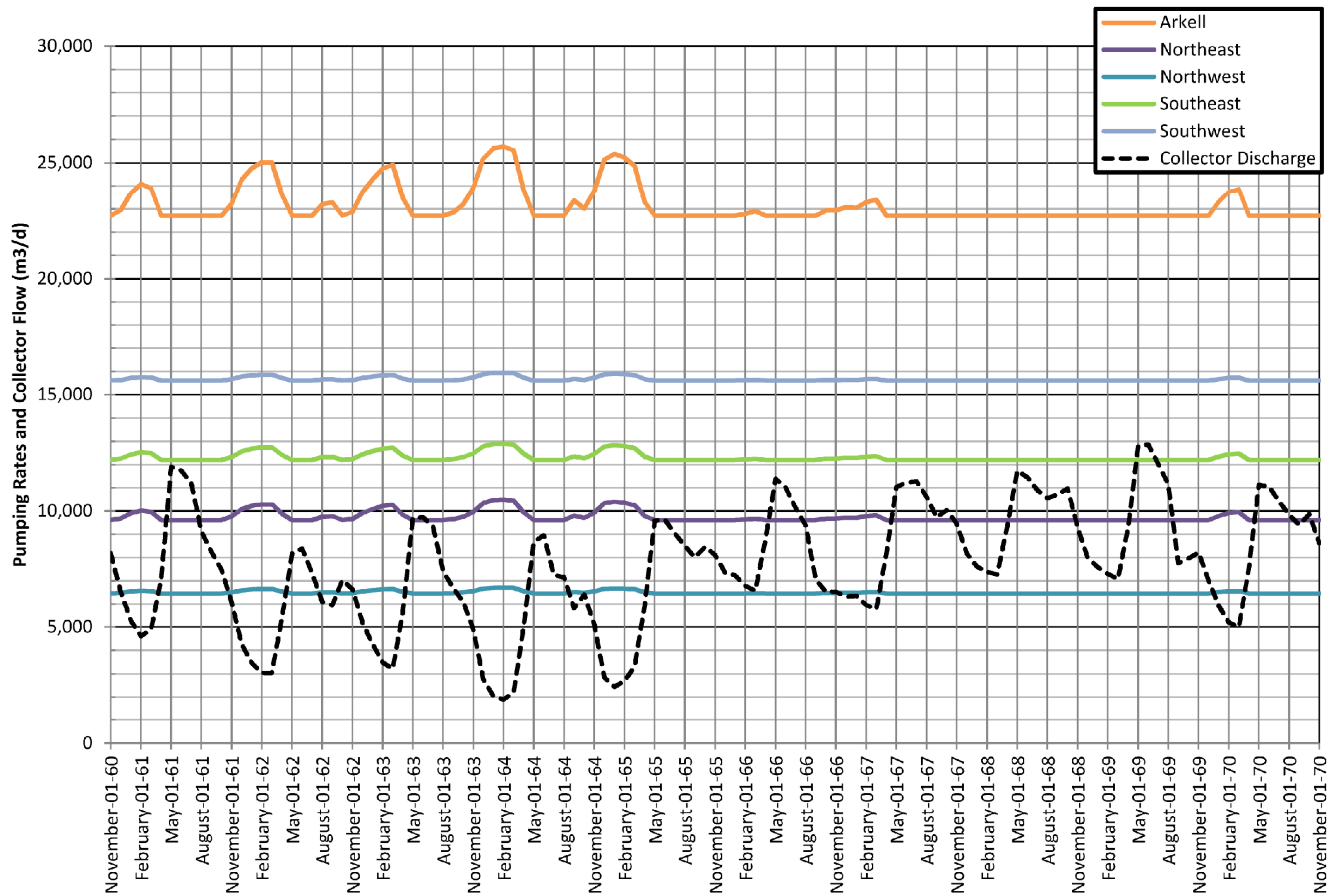
Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Simulated Monthly Discharge from Glen Collector and Pumping from Eramosa Intake

Date: 06 Mar 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

Figure 3-5



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Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Simulated Monthly Discharge from Glen Collector and Total Pumping by Quadrant

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Figure 3-6

3.2.4 Existing Plus Committed Demand and Allocated Rates - Rockwood and Hamilton Drive

For the Township of Guelph/Eramosa's municipal water supply systems in Rockwood and Hamilton Drive, none of the demands associated with these wells are considered to be Planned demand. As a result, the Allocated water supply needs of both communities will solely be from the increase in pumping related to the Committed demands. The Allocated rates estimated for Hamilton Drive were determined using water consumption forecast estimates from a water use study completed for the Township of Guelph/Eramosa (Watson and Associates Economists Ltd. 2011). These estimates represent the Committed demand forecasted until the year 2020, which is an increase in demand relative to that observed in 2010. The Allocated rates estimated for Rockwood were determined using water use forecasts that would be required to reach the build-out of Rockwood in 2026 (Burnside 2013).

The increase in pumping from Existing to Allocated rate was estimated to be 6 m^3/day (an increase of 3%) for the Hamilton Drive water supply system, and 940 m^3/day (an increase of 97%) for the Rockwood water supply system.

Table 3-8 summarizes the final set of Allocated rates (Existing plus Committed demands) for each well in Rockwood and Hamilton Drive. These rates were used for both average and drought conditions in the Risk Assessment scenarios. In Rockwood, the total Allocated rate was estimated to be 1,907 m^3/day, whereas that for Hamilton Drive was estimated to be 185 m^3/day. For both systems, the total Allocated rate is well below the total permitted rate.

TABLE 3-8 Allocated Rates - Rockwood and Hamilton Drive

Municipal Well	Existing Demand (Average 2009 to 2010)	Allocated Rates (m^3/day) Average or Drought Conditions
Rockwood		
Rockwood Well 1	283	396
Rockwood Well 2	262	367
Rockwood Well 3	422	572
Rockwood Well 4		572
Total	967	1,907
Hamilton Drive		
Cross Creek	87	90
Huntington	92	95
Total	179	185

For the purposes of the Risk Assessment scenarios, the increase in pumping associated with the Committed increase was distributed equally among the two wells in Hamilton Drive (i.e., 3 m^3/day/well). For Rockwood, the total Allocated rate was distributed according to recommendations provided by Burnside (2015b), with 40% distributed to Rockwood wells 1 and 2 combined, 30% to Rockwood Well 3, and 30% to Rockwood Well 4. Safe additional available drawdown was calculated for each well to define the additional depth that the water level can decline in each well and still maintain each well's Allocated rate. This calculation is discussed in detail in Appendix F.

3.3 Non-municipal Water Demand

3.3.1 Permitted Groundwater Users and Consumptive Demand - Study Area

In addition to the municipal water takers within the Study Area, there are also a number of large permitted water takers within the Study Area with MOECC permits. Figures 3-1 and 3-2 illustrate the locations of these non-municipal groundwater PTTW holders in the Study Area, and in the smaller area of interest, respectively (as obtained from the *Permit to Take Water Database* [MOE 2008])

Consumptive groundwater demands for permitted, non-municipal water users were determined using reported pumping rates, or estimated pumping rates in the absence of reported actual rates. The use of consumptive demands prevents the overestimation of pumping in the Study Area that would take place if only maximum permitted rates were considered. Estimated pumping rates were generated by combining the permitted rate with the months of expected active pumping and a consumptive factor. Monthly water use estimates were derived by identifying the months where water taking is expected to be active, based on the purpose of that taking, and combining this with the maximum permitted withdrawal and the maximum permitted days per year as specified in the PTTW database. Consumptive factors (Kinkead Consulting and AquaResource 2009) are subsequently applied to determine the proportion of pumped water that is not returned to the original source in a reasonable amount of time. Groundwater takings are typically 100% consumptive (i.e., consumptive factor of 1), since wastewater is seldom returned to the groundwater system, but rather discharged to surface water systems. Other water uses, such as for irrigation, have a consumptive factor less than 1 where some water would percolate beneath the evaporative root zone and return to the groundwater system. Appendix B2 ("Consumptive Groundwater Demand") describes the complete method followed to estimate consumptive groundwater demands for the non-municipal permitted water takers within the Study Area and the details of all the permits are provided therein.

The estimated consumptive demands are subject to various levels of uncertainty related to the following:

- the maximum permitted rate, which often exceeds the permit holder's requirements and may be derived from the capacity of the pumping equipment rather than the requirements of the user
- the lack of details in the PTTW database with regards to seasonal water demand requirements
- inaccuracy of the spatial location of the water taking sources

- the omission of potentially significant water takings due to historic takings that are "grandfathered" and do not require a permit

- outdated information in the PTTW database where the database is not current with respect to the MOE's actual permitting activities

- the ambiguity in the allocation of a single permitted rate when that rate applies to the operation of multiple wells or sources

Table 3-9 summarizes the permitted rates and consumptive demands by water use sector for the whole Study Area. The maximum permitted use totals 351,032 m^3/day while the estimated consumptive water demand for the Study Area is 63,092 m^3/day. As the consumptive demands are considerably lower than the permitted rates, it was a critical step to estimate these rates and use them in the groundwater flow model rather than applying the permitted rates.

TABLE 3-9 Summary of Permitted Rates and Consumptive Demands by Water Use Sector for Study Area

Specific Purpose	Max Permitted Rate (m^3/day)	Percentage of Total Permitted Takings	Consumptive Demand (m^3/day)	Difference (Max Permitted - Consumptive) (m^3/day)
Pits and Quarries	191,710	52	20,356	171,353
Aggregate Washing	82,716	22	3,124	79,592
Aquaculture	16,564	5	15,072	1,492
Golf Course Irrigation	17,913	5	3,068	14,845
Communal	10,893	3	5,512	5,381
Other - Industrial	10,246	3	4,472	5,774
Other - Agricultural	5,894	2	610	5,284
Field and Pasture Crops	5,475	1	415	5,060
Bottled Water	5,057	1	3,093	1,964
Sod Farm	4,696	1	239	4,457
Groundwater	2,183	1	1,853	330
Other - Water Supply	2,178	1	267	1,911
Fish Ponds	1,962	0	2	1,960
Campgrounds	1,785	0	448	1,337
Food Processing	1,760	0	311	1,449
Other - Remediation	1,483	0	960	523
Mall / Business	1,316	0	1,316	0
Other - Dewatering	899	0	213	686
Heat Pumps	885	0	821	64
Nursery	328	0	46	282
Brewing and Soft Drinks	553	0	0	553
Manufacturing	529	0	529	0

Specific Purpose	Max Permitted Rate (m^3/day)	Percentage of Total Permitted Takings	Consumptive Demand (m^3/day)	Difference (Max Permitted - Consumptive) (m^3/day)
Other - Institutional	137	0	137	0
Cooling Water	110	0	53	57
Construction	100	0	8	92
Schools	100	0	83	17
Other - Commercial	64	0	52	12
Irrigation	60	0	32	28
Total	351,032	100	63,092	303,011

Note:
Permits were current as of the Study Period and obtained from the *Permit to Take Water Database* (MOE 2008)

Tables 2 to 7 in Appendix B2 outlines the specific details of each permit in shown on Figure 3-2 including the permit number, the location of the water use, the general and specific purpose for the permit, the source of water, the maximum permitted water taking, the average annual consumptive demand, and whether it is used in the model as a flux boundary condition (i.e., well).

After the consumptive water demand was estimated for each non-municipal permitted well, the data was further analyzed to select wells that should be simulated in the groundwater flow model. Wells with zero average annual consumptive demands and PTTW sources designated as springs were not included in the model as specified flux boundaries (i.e., wells). Additionally, some water takers located close to the model boundaries were excluded (or partially accounted for through recharge reductions) as they caused numerical instabilities due to the proximity with the model boundary. The impact of excluding these water takers on the regional model results is interpreted to be negligible as the boundaries are located at a sufficient distance from the municipal water supply wells of the City of Guelph and the Township of Guelph/Eramosa (Rockwood and Hamilton Drive) and are unlikely to influence the model predictions.

The Guelph Dolime Quarry was explicitly modelled using a specified head boundary condition as detailed in Appendix B.

A detailed review of the permits identified in Puslinch Township also revealed two non-municipal water demands that were not current as of the Study Period (2008 for the City of Guelph, and 2009 to 2010 for the Township of Guelph/Eramosa); thus, they were removed from the model. The first permit, PTTW 02-P-2064 (Kraus Nurseries), is an expired permit for a property in Waterdown, not Puslinch. It was represented in the model at a rate of 39 m^3/day. The second permit, PTTW 99-P-2132 (Kats Okashimo Fish Farm), was not renewed in 2009, and a site discussion with the current tenant suggested that the well has not been pumped for at least 12 years (Harden 2015). This permit was represented in the model at a rate of 1,636 m^3/day. Both water takings were removed from the Tier Three Assessment model.

3.3.2 Permitted Water Users and Consumptive Demand - Upper Speed River Groundwater Assessment Area

The Upper Speed River Groundwater Assessment Area was delineated as part of the Grand River Watershed Tier Two Integrated Water Budget and Subwatershed Quantity Stress Assessment report (AquaResource 2009a, 2009b). As part of the current study, the subwatershed stress is recalculated using the Tier Three Assessment water budget results. Permitted water users (as of the Study Period; *Permit to Take Water Database* [MOE 2008]) within the Upper Speed River Groundwater Assessment Area are shown in Table 3-10, along with the maximum permitted and the average annual consumptive demand rates. These are summarized in Table 3-11 according to water use sector. Within the Upper Speed the maximum total permitted non-municipal water use is 32,262 m^3/day while the estimated consumptive demand is 12,934 m^3/day.

TABLE 3-10 Non-municipal Permitted Water Demand within the Upper Speed Groundwater Stress Assessment Area

Permit No.	Easting (NAD83)	Northing (NAD83)	Specific Purpose	Maximum Permitted Rate (m^3/day)	Average Annual Consumptive Demand (m^3/day)
00-P-2417	567174	4837007	Other - Agricultural	655	111
00-P-2417	566898	4836647	Other - Agricultural	655	111
0147-6K9RKS	562971	4822422	Other - Remediation	23	10
0147-6K9RKS	562968	4822422	Other - Remediation	13	0
0147-6K9RKS	562971	4822424	Other - Remediation	13	7
0147-6K9RKS	562963	4822429	Other - Remediation	10	0
0147-6K9RKS	563000	4821986	Other - Remediation	7	7
0147-6K9RKS	563024	4821986	Other - Remediation	7	7
01-P-2004	557025	4823001	Groundwater	328	152
01-P-2236	557700	4835799	Golf Course Irrigation	589	167
01-P-2236	557700	4835800	Golf Course Irrigation	2,182	618
0882-6FTHMA	566388	4816161	Other - Water Supply	656	10
0882-6FTHMA	566425	4815893	Other - Water Supply	65	0.3
0882-6FTHMA	566318	4816054	Other - Water Supply	130	10
1065-5VFQ9K	564140	4815443	Brewing and Soft Drinks	553	0
1204-62XKAF	562403	4822865	Cooling Water	110	53
1528-6GTN6M	557917	4822988	Other - Remediation	299	88
1528-6GTN6M	557809	4823006	Other - Remediation	15	0.1
1528-6GTN6M	557836	4822990	Other - Remediation	15	0.1
1787-6C8RLU	562478	4820358	Other - Agricultural	737	126
1787-6C8RLU	562551	4820377	Other - Agricultural	525	26
1787-6C8RLU	561928	4819232	Other - Agricultural	1,309	0
2202-6X9QTU	565845	4845183	Aquaculture	2,620	1,783
2202-6X9QTU	566032	4845329	Aquaculture	654	0
3024-6CQJZ5	565174	4820242	Golf Course Irrigation	882	77

Permit No.	Easting (NAD83)	Northing (NAD83)	Specific Purpose	Maximum Permitted Rate (m^3/day)	Average Annual Consumptive Demand (m^3/day)
3036-6QPKHE	560000	4823000	Other - Institutional	137	137
4366-6BTRUX	563512	4821997	Heat Pumps	816	816
5081-6GEPMB	560760	4827800	Other - Water Supply	130	2
5081-6GEPMB	560520	4828020	Other - Water Supply	130	2
5336-6C8R2N	563398	4821157	Field and Pasture Crops	110	16
5336-6C8R2N	563010	4820588	Field and Pasture Crops	175	25
5336-6C8R2N	563036	4821307	Field and Pasture Crops	252	35
6480-74BKR4	568384	4847833	Bottled Water	1,113	499
6800-72CLQH	558858	4823140	Other - Industrial	1,635	105
7175-6LCQ2M	574049	4832866	Golf Course Irrigation	238	9
7240-65YKTN	559873	4819122	Pits and Quarries	13,750	7,888
93-P-2103	565004	4819478	Golf Course Irrigation	540	8
99-P-2070	561092	4820909	Groundwater	46	6
99-P-2070	561018	4820862	Groundwater	46	11
99-P-2070	560985	4820923	Groundwater	46	6
99-P-2070	560982	4820975	Groundwater	46	8
			Total	32,262	12,934

Note:
Permits were current as of the Study Period and obtained from the *Permit to Take Water Database* (MOE 2008)

TABLE 3-11 Summary of Permitted Rates and Consumptive Demands for Upper Speed Groundwater Stress Assessment Area (by water use sector)

Specific Purpose	Maximum Permitted Rate (m^3/day)	Percentage of Total Permitted Takings	Consumptive Demand (m^3/day)	Difference (Maximum Permitted - Consumptive; m^3/day)
Pits and Quarries	13,750	43	7,888	5,862
Golf Course Irrigation	4,431	14	878	3,553
Other - Agricultural	3,880	12	374	3,507
Aquaculture	3,274	10	1,783	1,491
Other - Industrial	1,635	5	105	1,530
Bottled Water	1,113	3	499	614
Other - Water Supply	1,111	3	24	1,087
Heat Pumps	816	3	816	0
Brewing and Soft Drinks	553	2	0	553
Field and Pasture Crops	537	2	75	462
Groundwater	512	2	183	330
Other - Remediation	402	1	120	282
Other - Institutional	137	0	137	0
Cooling Water	110	0	53	57

Specific Purpose	Maximum Permitted Rate (m^3/day)	Percentage of Total Permitted Takings	Consumptive Demand (m^3/day)	Difference (Maximum Permitted - Consumptive; m^3/day)
Total	32,262	100	12,934	19,327

4 TIER THREE WATER BUDGET

The Tier Three Assessment aims to provide an improved estimate of the water budget components included in the hydrologic cycle within the Study Area. The surface water and groundwater flow models developed for the Tier Three Assessment were used to estimate average annual values for the various components of the hydrologic cycle. The GAWSER and FEFLOW models are separate and independent models linked through groundwater recharge; recharge is simulated by the GAWSER streamflow-generation model as a model output, and then is used as a model input parameter in the FEFLOW groundwater model.

The combined results of the water budget models produce an improved conceptualization of the hydrologic and hydrogeologic flow systems. The following sections quantify and outline the water budget components within the Study Area.

4.1 Groundwater Flow

The following section outlines the water budget model results relating to groundwater in the Study Area.

4.1.1 Groundwater Recharge

Figure 4-1 illustrates groundwater recharge rates applied in the FEFLOW groundwater flow model as specified flux boundary conditions. Groundwater recharge is greatest (533 mm/year) on hummocky regions associated with the Paris and Galt moraines (which are underlain by sands and gravels) and recharge is least (0 mm/year) where groundwater discharges to some wetlands. Groundwater recharge is also lower within the urban areas where there is a greater percent imperviousness associated with roads, parking lots, and buildings.

4.1.2 Water Table Surface

Figure 4-2 illustrates the elevation of the water table surface simulated by the calibrated steady-state groundwater flow model. The water table generally mimics the ground surface topography and is strongly influenced by surface water features. The shallow groundwater divide along the boundary with the Credit River Watershed generally coincides with the surface water divide. The shallow groundwater