City of Guelph Source Protection Project

FINAL Groundwater and Surface Water Vulnerability Report

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1.0 Introduction

In the fall of 2005, the Province of Ontario introduced Bill 43, the Clean Water Act (the "Act") to protect drinking water at the source as part of an overall commitment to human health and the environment. Protecting "source water" is the first step in a multi-barrier approach to ensure the quality and sustainability of our drinking water supply. A focus of the government's legislation is the production of locally-developed, science-based assessment reports and source protection plans. The assessment reports identify the risks to be addressed in the source protection plans. The assessment reports will be prepared by teams of representatives from the watershed community working together at the local level (e.g., municipalities, conservation authorities, water users, and land owners).

One of the key objectives of the assessment report is to describe the vulnerability of groundwater and surface water drinking sources. The groundwater vulnerability assessment identifies the vulnerable areas; characterizes the relative vulnerability of the municipality's aquifers as high, medium or low; and assigns vulnerability scores to regions within the vulnerable areas, with the highest score representing areas with the highest vulnerability. The surface water vulnerability assessment identifies vulnerable areas where there is a potential that contaminants entering those areas may migrate towards a drinking water intake; and assigns vulnerability scores to vulnerable areas, with the highest scores representing areas with the highest vulnerability.

In June 2007, the City of Guelph (the City) retained a team led by AquaResource Inc. (AquaResource) working with Stantec Consulting Ltd. (Stantec) to complete a study to assess groundwater and surface water vulnerable areas and vulnerability scoring, and to complete work relating to the identification of threats to water quality and water quantity. This contract was extended in 2009 after the Ontario Ministry of the Environment (MOE) published its Technical Rules (MOE, 2009), which provided revised detailed instructions regarding the water quality vulnerability and threats assessment under the Clean Water Act.

1.1 CITY OF GUELPH WATER SUPPLY

The City of Guelph has 115,000 residents (2006 Statistics Canada data) and it is one of the largest cities in Canada to rely almost exclusively on groundwater for its potable water supply. The population is projected to reach 169,000 by the year 2031 (City of Guelph, 2008). The groundwater supply system comprises 23 groundwater wells distributed throughout the City as shown on Figure 1. In 2008, 18 of the production wells and the shallow groundwater collection system were operated on a near continuous basis and four were removed from the system due to water quality or maintenance concerns. In addition to the groundwater supply wells, the City operates the groundwater collection system located at the Arkell Spring Grounds. This collection system consists of the Glen Collector System which collects shallow groundwater from the overburden through a series of perforated pipes. The yield from the Glen Collector System varies seasonally according to fluctuations in the water table elevation. To enhance the supply of water into the collection system, the City operates the Eramosa River intake and an Artificial Recharge System at the Spring Grounds. Between April 15 and November 15, water is pumped from the Eramosa River and released into an infiltration pit and trench, where it recharges the shallow overburden aquifer supplying the Glen Collector.

1.2 CLEAN WATER ACT (2006)

The Ontario Government introduced Bill 43, the Clean Water Act, 2006 (the "Act") to protect drinking water at the source as part of an overall commitment to human health and the environment. The Act received Royal Assent on October 19, 2006 establishing a framework for the development and implementation of Source Protection Plans across Ontario.

Source Protection is a watershed-based, locally-driven program that uses scientifically sound methods for assessing risks to drinking water and is an approach to decision-making that emphasizes information sharing, consultation, and involvement by interested members of the watershed communities. Under the Act, Source Protection Plans are developed on a watershed basis. To facilitate efficient use of resources and coordination of Source Protection planning, regulations under the Act group individual conservation authorities into Source Protection Regions. The Act mandates that Source Protection Plans be developed to address threats to all municipal residential drinking-water systems within these Source Protection Regions.

The framework for Source Protection, as set out in the Act, requires the development of a watershed-based Assessment Report. This Assessment Report, to be prepared by the Source Protection Authority, includes a watershed characterization, a water budget, municipal water supply strategies (aligned with drinking water systems), a groundwater and surface water vulnerability assessment, a threats assessment and issues evaluation, and water quality and quantity risk assessment studies. Upon completion of the Assessment Reports, Source Protection Plans will be developed for the Source Protection Regions. The Source Protection Plan will outline locally based risk management measures to reduce or to prevent risks to drinking-water supplies, and include a recommended implementation strategy.

Source Protection Teams are required to undertake a series of studies to prepare an Assessment Report; these studies are outlined in the Province's Draft Guidance Modules. The Province released the following guidance documents intended to provide recommendations on the delineation of vulnerable areas and the development of vulnerability maps:

- ASSESSMENT REPORT: Draft Guidance Module 3, Groundwater Vulnerability Analysis (MOE, 2006a); and
- ASSESSMENT REPORT: Draft Guidance Module 4, Surface Water Vulnerability Analysis (MOE, 2006b).

The Province's Technical Rules for the Assessment Report (MOE, 2009) provide the detailed Director's Rules giving legal definitions of vulnerable areas, vulnerability scoring, and the assessment of water quality threats. The above Guidance Modules were developed for guidance purposes only and are not necessarily consistent with the requirements of the Technical Rules.

1.3 RELATED STUDIES

The City has completed numerous studies that contribute to the current knowledge and understanding relating to the hydrology, hydrogeology, and vulnerability of its drinking water supplies. The most relevant studies to the City's wellhead protection area mapping and groundwater vulnerability assessments are summarized in the following subsections.

1.3.1 <u>Earlier Studies</u>

The City of Guelph began a series of detailed hydrogeological investigations in the 1990's to better understand the groundwater resource. It was recognized in 1991 that the information on the City's water supply system was incomplete and in some cases no longer accurate. A comprehensive study was initiated in late 1991 to collect the additional information needed to adequately define the water resource. This study required testing of municipal wells for extended periods of time and it was, therefore, determined that only a portion of the system could be 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 Speed/Eramosa Rivers forming the boundaries. The study was completed on a quadrant-by-quadrant basis by Jagger Hims Limited (Jagger Hims, 1995, 1998a, 1998b, 1998c). The first quadrant evaluated was the northeast quadrant in 1993 followed by the northwest in 1994, southwest in 1995, and southeast in 1996/1997.

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

A summary of the groundwater resource was prepared as part of the City of Guelph Water Supply System Study in 1999 (Gartner Lee, Jagger Hims, and Braun, 1999). A multi-layered MODFLOW groundwater flow model was developed as part of this study and was used to delineate two-year, five-year, ten-year, and steady-state capture zones based on the geologic and hydrogeologic conceptualization of the time. This study also provided recommendations to the City relating to the management of drinking water supplies.

1.3.2 Guelph-Eramosa Township Groundwater Study

The Guelph-Eramosa Township Groundwater Study was completed in 2003 by Gartner Lee Ltd (2003a). The objective of the study was to assemble relevant data and information that could be used to develop a long-term plan to manage both the quantity and quality of the groundwater resources within the Township, and specifically the Township production wells. As part of the study, a finite-difference groundwater flow model was used to map wellhead protection areas for existing and proposed Township water supply wells. The study also included characterization of the susceptibility of the aquifer to surface contamination, and preparation of a potential contaminant sources inventory within the Township wellhead protection areas based on land use information.

1.3.3 Arkell Spring Grounds Groundwater Investigation

The City's use of the Arkell Spring Grounds as a source of water dates back to 1908. The spring source was supplemented by four high capacity wells (i.e., three completed in the bedrock and one completed in the overburden) installed within the Arkell Spring Grounds between 1963 and 1966. In recognition of the need to locate additional water supply sources to meet the growing demands of the municipality, the City retained Gartner Lee Limited (2003b) to undertake an investigation in the Arkell Spring Grounds to evaluate its potential as a source of additional groundwater supply. This area was selected because of the potential for high groundwater yields from the bedrock aquifer.

This study included several long-term pumping tests with extensive groundwater and surface water monitoring. The groundwater flow model, developed by Gartner Lee (2003b), was used to predict aquifer drawdown under steady-state pumping conditions, to estimate changes in groundwater-surface water interactions, and to delineate capture zones.

1.3.4 Guelph- Puslinch Groundwater Protection Study

The Guelph-Puslinch Groundwater Protection Study was completed in 2006 (Golder, 2006a). This study included the development of a numerical groundwater flow model (using a finite-element code) to delineate capture zones for the municipal wells. The study also included regional groundwater characterization, groundwater susceptibility (vulnerability) mapping, a regional contaminant source inventory (threats database), and a groundwater use assessment.

The groundwater flow model developed for this study spans 1,340 km^2, covering the entire City of Guelph and a relatively large area surrounding the City. The model is based on the finite-element method using FEFLOW (Diersch, 2006), a proprietary simulation code, for the groundwater flow analyses. Several aspects of the conceptual model developed for the Guelph-Puslinch Groundwater Protection Study have been incorporated into the model developed for this study, including zones of hydraulic parameters.

1.3.5 Wellington County Groundwater Protection Study

The County of Wellington Groundwater Protection Study (Golder, 2006b) was initiated in 2003 to refine the regional scale mapping completed in the first round of MOE-funded groundwater studies in 2001/2002. The updated study focused on areas susceptible to groundwater contamination, as well as wellhead protection areas. The study also focused on formulating a groundwater protection strategy for the County of Wellington by merging hydrogeological maps across the County.

One of this project's deliverables was a regional potential contaminant sources database. This database was prepared in a similar format to that of the Guelph-Puslinch Groundwater Protection Study.

1.3.6 City of Guelph Source Protection Project

In June 2006, the City retained a team, led by AquaResource Inc. (AquaResource) and included Stantec Consultants (Stantec) and S. S. Papadopulos and Associates, Inc (SSPA), to conduct a Groundwater Study and an Intake Protection Zone Study. Two reports were produced, including an evaluation of Groundwater Vulnerability Threats (AquaResource, 2007a) and an evaluation of Surface Water Vulnerability (AquaResource, 2007b).

This study, funded by the Province under the Clean Water Act program, developed preliminary wellhead protection areas and groundwater vulnerability maps. Wellhead protection areas delineated in this study were based on the groundwater model developed by Golder Associates (2006a). Intake protection zones developed in this study were based on a combination of in-field dye tracer tests and numerical modelling. The groundwater and surface water assessments were completed in accordance with the MOE's preliminary guidance documents on groundwater and surface water vulnerability and threats assessment. This work forms the basis of the vulnerability assessment provided in this report.

1.3.7 Southwest Quadrant Class Environmental Assessment (SWQ-EA)

A current study of the Southwest Quadrant being completed by Golder and AECOM is exploring ways to best use the existing groundwater aquifer by investigating the potential to increase the capacity of existing wells and install a new well(s) in the study area. The study will also develop a testing and monitoring program to determine the long-term water yield capacity and assess environmental impacts. This project is being developed as a Municipal Class Environmental Assessment under Ontario's Environmental Assessment Act and is expected to be completed in 2009/10.

1.3.8 Tier Three Local Area Risk Assessment

The City is completing a Tier Three Local Area Risk Assessment (Tier Three) which is also required under the Clean Water Act. The purpose of this study, being conducted by AquaResource (in progress), is to assess the longer-term sustainability of the City's wells from a water quantity perspective, and to identify any significant threats to water quantity. A major component of this study is the development of a detailed three-dimensional groundwater flow model of the City's aquifer system. The Tier Three model has been developed with more extensive local hydrogeologic data and characterization than was available for the Guelph-Puslinch Groundwater Protection Study. In particular, new data includes a series of new boreholes and groundwater monitoring wells installed by the City as well as recent work completed by the Ontario Geological Survey (OGS). The revised conceptual model, as represented in the numerical model, is based on ongoing investigations and interpretations by the OGS (Brunton, 2008). The OGS has refined the conceptual model of bedrock geology and tied in the geological layer definitions with more regionally standardized interpretations from across Ontario and Western New York State. As part of the Tier Three project, new interpretations were made relating to the depth and thickness of geological layers at high quality boreholes located in the study area. New knowledge gained from this interpretation was also transferred to the geological interpretation throughout the study area to arrive at a new set of model layers. This revised interpretation is described in detail as part of the Tier Three Conceptual Model Report to be released in draft form in 2010.

The updated numerical groundwater flow model has been calibrated with water level monitoring data collected from multi-level monitoring wells installed by the City over the past five years, as well as, several pumping tests carried out in some wellfields. A report describing the development of this model is to be released in 2010.

As a result of the improvements incorporated in the Tier Three groundwater flow model, the City chose to use it to delineate the wellhead protection areas, or WHPAs, needed for the Groundwater Vulnerability Assessment and Water Quality Threats Assessment.

1.4 CONTENTS OF THIS REPORT

This report discusses the methodology followed to delineate vulnerable areas and complete vulnerability scoring for the City of Guelph's groundwater wells and surfaced water intakes. It includes the following sections:

Section 1. Introduction.

Section 2. Groundwater Vulnerability (Municipal Wells). This section includes the delineation of wellhead protection areas (WHPAs), the aquifer vulnerability maps, and the assignment of vulnerability scores within WHPAs.

Section 3. Surface Water Vulnerability. This section includes the delineation of intake protection zones (IPZs) and assignment of vulnerability scores within IPZs for the Eramosa River intake.

Section 4. Groundwater Vulnerability (Carter Wells). This section includes the delineation of the WHPA-E and WHPA-F vulnerable areas for the City's Carter Wells, which are designated a GUDI (Groundwater Under Direct Influence) of surface water system.

Section 5. Conclusions and Recommendations.

Section 6. References.

2.0 Groundwater Vulnerability (WHPA-A, B, C, D)

2.1 INTRODUCTION

Groundwater is an essential resource for the City of Guelph. Guelph takes most of its drinking water from wells located in what has historically been referred to as the Guelph–Amabel bedrock aquifer. Figure 1 shows the locations of these wells which extend through the overburden deposits and into the deep bedrock. Wells are placed around the City in locations where the aquifer is known to be productive. In 2008, the average daily water demand of 50,000 m^3 was met from these wells.

Contamination of groundwater can occur as a result of a wide range of activities. Improper waste disposal, leaking septic tanks, former industrial sites, urban runoff, road salts, and other sources can lead to poor groundwater quality if not managed properly. Once the groundwater is contaminated, it may not be suitable for drinking water or it may require expensive treatment processes to remove the contaminants.

The City has recognized the value of its water resources and has established several planning policies that support its groundwater protection program, to ensure the quantity and quality of this resource is protected. The City's Official Plan describes policies for the protection, conservation, and enhancement of water supply and water resources in the City. When implementing policies for the protection of groundwater drinking water supplies, municipalities generally begin with the delineation of wellhead protection areas or WHPAs. A WHPA is generally referred to in the planning context and is derived by delineating scientifically-based 'capture zones' for a municipal well. A capture zone is the projection onto the land surface of the portion of the three-dimensional volume through which groundwater travels towards a water supply well within a defined period of time. For example, a 10-Year capture zone represents the area, as projected to ground surface, within which groundwater would migrate to a municipal well within a period of 10 years.

Groundwater vulnerability maps are prepared to identify land areas where contamination originating at ground surface may be more or less likely to enter an underlying aquifer. The maps are developed based on a combination of geological data, interpreted hydrogeological conditions, and a conceptual model which provides a prediction of vulnerability based on this information. When maps of WHPAs are overlain with the vulnerability maps, the land areas that have the highest potential to introduce contamination to a municipal drinking water supply can be identified, if that contamination is introduced at the ground surface.

2.1.1 Clean Water Act: Groundwater Vulnerability

The Technical Rules (MOE, 2009) provide three general steps in completing the vulnerability assessment for groundwater supplies. These steps are summarized below, with additional detail provided in the subsections that follow:

1) Delineate wellhead protection areas;
2) Create Vulnerability Maps; and,
3) Complete Vulnerability Scoring.

2.1.1.1 Wellhead Protection Areas

The first step in the groundwater vulnerability assessment is the delineation of wellhead protection areas (WHPAs). The Clean Water Act treats WHPAs as regulated vulnerable areas, and these areas will be treated with specific policies within the Source Protection Plan. The Technical Rules (MOE, 2009) developed in support of the Clean Water Act require that the following wellhead protection areas for drinking water wells be delineated:

1) WHPA-A: the surface and subsurface area centered on the well with an outer boundary identified by a radius of 100 metres;
2) WHPA-B: the surface and subsurface areas within which the time-of-travel to the well is less than or equal to two years but excluding WHPA-A;
3) WHPA-C: the surface and subsurface areas within which the time-of-travel to the well is less than or equal to five years but greater than two years; and
4) WHPA-D: the surface and subsurface areas within which the time-of-travel to the well is less than or equal to twenty-five years but greater than five years.

Other vulnerable areas considered in the assessment include: Highly Vulnerable Aquifers and Significant Groundwater Recharge Areas. These vulnerable areas are not considered in this report but they will be defined at a later date by the Lake Erie Source Protection Authority.

2.1.1.2 Vulnerability Mapping

The relative vulnerability within a wellhead protection area is characterized as high, medium, or low. This categorization is intended to reflect the susceptibility of the aquifer(s) in the vulnerable areas to surface (or near surface) sources of contamination.

2.1.1.3 Vulnerability Scoring

A vulnerability score is then calculated within a wellhead protection area based on the category of the wellhead protection area and the relative vulnerability. Where necessary, the vulnerability score is modified to reflect the presence, or potential presence, of constructed preferential pathways which could allow contaminants of concern at surface to bypass natural protective layers above the aquifers. The vulnerability scores range from 2 to 10, where a score of 10 represents the highest vulnerability.

2.2 DELINEATION OF WELLHEAD PROTECTION AREAS

2.2.1 Capture Zone Delineation Methodology

A groundwater flow model is a simplification of a very complex natural system used to simulate the movement of groundwater through soil and bedrock. When developed and applied for groundwater vulnerability analysis, groundwater flow models are used to delineate capture zones using particle-tracking techniques which estimate the path and trajectory of hypothetical particles of water for given time periods. Particle-tracking techniques are used to estimate the directions and paths that groundwater may actually travel and thus can be used to estimate the land areas within which groundwater may migrate towards a well.

The capture zone delineation methodology includes several components that include:

- Application of a calibrated groundwater flow model;
- Selection of appropriate municipal pumping rates;
- Selection of appropriate porosity values; and
- Numerical particle-tracking techniques.

The above components are discussed further in the following sub-sections.

2.2.1.1 Tier Three Groundwater Flow Model

The City is completing a Tier Three Local Area Risk Assessment required under the Clean Water Act. The purpose of this study is to assess the longer-term sustainability of the City's wells from a water quantity perspective and to identify any significant threats to water quantity. A major component of this study is the development of a detailed three-dimensional groundwater flow model of the City's aquifer system. For the City of Guelph, the numerical groundwater flow model is being developed by AquaResource in partnership with Golder Associates as part of the Tier Three Local Area Risk Assessment. This model is being developed using the FEFLOW finite-element groundwater flow model software consistent with the Guelph-Puslinch study (Golder, 2006a).

The Tier Three groundwater flow model has been developed with more extensive local hydrogeologic data and characterization than was available for the Guelph-Puslinch Groundwater Protection Study (Golder, 2006a). The revised conceptual model, as represented in the numerical model, is based on ongoing investigations and interpretations by the Ontario Geological Survey (Brunton, 2008). The OGS is currently undertaking a project to systematically map and delineate discrete bedrock aquifers with carbonate strata along the Niagara Escarpment region of Southern Ontario. This project has implications for the City of Guelph's geological model. The dolostone aquifers forming the City's water supplies sub-crop between Guelph and the Niagara Escarpment and these formations are being re-characterized as part of the OGS project. The following table summarizes the revised conceptual model layers compared to those used in previous studies.

Table 1: Revised Geologic Conceptual Model

Revised Conceptualization Formation/Member		**Previous Conceptualization Formation/Member**	
Overburden		Overburden	
Guelph Formation		Guelph Formation	
Eramosa Formation	Reformatory Quarry Member	Amabel Formation	Eramosa Member
	Vinemount Member		
Goat Island Formation	Ancaster / Niagara Falls Members		Wiarton / Colpoy / Lions Head Members
Gasport Formation	Gothic Hill Member		
Irondequoit / Rockway / Merritton Formations			
Cabot Head Formation		Cabot Head / Reynales Formation	

The Ontario Geologic Survey has refined the conceptual model of bedrock geology and tied in the geological layer definitions with more regionally standardized interpretations from across Ontario and Western New York State. For example, the City's primary source of drinking water has been from what has historically been referred to as the Amabel Formation. The Amabel Formation has now been subdivided into the Gasport, Goat Island, and Eramosa Formations; consequently the City's water supply aquifer is now referred to as the Gasport Formation. Another change with this conceptual model is with the conceptualization of the aquitard overlying the Gasport Formation. In previous conceptual models, the aquitard was referred to as the Eramosa Member of the Amabel Formation. The refined conceptual model now refers to the Vinemount Member of the Eramosa Formation as being the most significant aquitard in the area of the City. The thickness and nature of the aquitard throughout the City is characterized fairly well, but the hydrogeologic nature of this member is not well characterized outside of the City.

The updated numerical groundwater flow model is based on the conceptual model developed as part of the Guelph-Puslinch Groundwater Protection Study (Golder, 2006a). The model area for the Tier Three has been increased from that of the Guelph-Puslinch Study, as shown on Figure 2, and extends to the Grand River in the West and North, and to the Niagara Escarpment in the East. The Grand River represents a physical groundwater flow boundary and the Gasport Formation extends up to, but not east of, the Niagara Escarpment. The Tier Three model is slightly smaller than the Guelph-Puslinch model at the southern edge of the boundary, and this interpretation was based on revised mapping of bedrock groundwater levels. The differences between these boundaries at the southern are not expected to have an influence on the analysis completed for the City.

The updated numerical groundwater flow model has been calibrated with water-level monitoring data collected from the City's multi-level monitoring wells and data from several pumping tests carried out in some wellfields. A draft report for this model is expected to be available in 2010.

Groundwater recharge for the model area, is specified across the top surface of the model; it is defined by Hydrologic Response Units (HRUs) developed using the GAWSER streamflow generation model (Schroeter and Associates, 2004). This model was also refined as part of the Tier Three Local Area Risk Assessment.

The City chose to use the Tier Three groundwater flow model to delineate the WHPAs needed for the Groundwater Vulnerability Assessment and Water Quality Threats Assessment since it represents the most up-to-date and comprehensive interpretation of the geology and hydrogeology of the area. AquaResource is developing a detailed report, to be completed in 2010, that fully documents and describes the Tier Three model.

The Tier Three model was developed and calibrated to represent the influence of the Dolime Quarry, located between the University and Queensdale municipal wells. The quarry dewatering removes approximately 8,000 m^3/day from the bedrock aquifer and has a significant influence on groundwater flow in the area. The City assumes that at some time in the future the quarry will cease operations and will therefore stop dewatering the bedrock aquifer. At that time, water levels in the quarry will respond and the City's pumping wells will intercept and capture groundwater in the vicinity of the quarry. To reflect this future situation and based on a recommendation from the Peer Reviewer and the Lake Erie Source Protection Authority, the influence of the quarry's dewatering has been removed from the Tier Three model for the capture zone delineation task.

2.2.1.2 Municipal Pumping Rates

The City's drinking water wells are capable of meeting a higher demand than the current average-day water demand of 50,000 m^3/day. 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. Table 2 lists the wells currently considered part of the City's planned system. These wells are organized into four quadrants, following the spatial organization introduced in the 1990 Quadrant Studies. This table includes four wells (i.e., Clythe Creek, Edinburgh, Smallfield, and Sacco) which are currently not pumped due to water quality concerns. The wells have not been abandoned and remain as part of the City's planned system as they could be used in the future with appropriate levels of treatment. Table 2 summarizes both the average daily pumping rate and the estimated capacity of each of the City's wells. These estimated capacities are generally consistent with those reported in the Water Supply Master Plan (EarthTech et al., 2007); where the estimated capacities are not consistent with the Water Supply Master Plan, they are noted.

As shown in Table 2, the total estimated capacity of the City's wells is nearly 90,000 m^3/day. Estimated well capacities were derived as part of the City's Water Supply Master Plan (EarthTech et al., 2007) based primarily on operational experience and monitoring data collected at the wells. The estimates of well capacity do not include the potential for well interference and also do not consider impacts to ecological features (e.g., cold water streams, wetlands). This total estimated well capacity includes both wells that require treatment (i.e., Clythe Creek, Smallfield, and Sacco) and wells that require additional approvals (i.e., Arkell 14 and 15) before they can be brought into service. In addition, the estimated capacity may be affected by climatic conditions (i.e., drought), well interference, and well efficiency such that the total capacity may not be available at all times of the year.

Table 2: Pumping Rate Summary (m^3/day)

City of Guelph Quadrant	Well/Collector Name	Average Day Rate (2008)	Estimated Capacity[1]	WHPA Delineation Rate (80% of Capacity)
Northeast	Clythe Creek	N/A[3]	3,000[2]	2,400
Northeast	Emma	2,273	2,800	2,240
Northeast	Helmar	500	1,500	1,200
Northeast	Park #1/#2	5,897	8,000	6,400
Northwest	Calico	748	1,100	880
Northwest	Paisley	762	1,400	1,120
Northwest	Queensdale	702	2,000	1,600
Northwest	Sacco	N/A[3]	1,150[2]	920
Northwest	Smallfield	N/A[3]	1,400[2]	1,120
Southeast	Arkell 1	730	2,000	1,600
Southeast	Arkell 14	N/A[4]	4,680[2]	3,744
Southeast	Arkell 15	N/A[4]	4,680[2]	3,744
Southeast	Arkell 6	3,774	6,500	5,200
Southeast	Arkell 7	3,689	6,500	5,200
Southeast	Arkell 8	3,694	6,500	5,200
Southeast	Arkell Glen Collector	6,500	6,900	6,900[5]
Southeast	Burke	5,385	6,500	5,200
Southeast	Carter (In/Out)	2,004	5,500	4,400
Southwest	Dean Ave	1,215	1,500	1,200
Southwest	Downey Road	3,940	5,100	4,080
Southwest	Edinburgh[6]	0	0	0
Southwest	Membro	3,036	6,000	4,800
Southwest	University	1,648	2,500	2,000
Southwest	Water Street	1,184	2,700	2,160
	Total	**47,681**	**89,910**	**73,308**

Notes: [1] Estimated Sustainable Rates from Water Supply Master Plan (2006)
[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] Additional approvals needed before wells can be pumped.
[5] 100% of the estimated pumping capacity is used for the Arkell Glen Collector in the WHPA delineation.
[6] No current plans to use the Edinburgh Well

The average day water demand for 2008 is approximately 50,000 m^3/day including residential and ICI (industrial, commercial, and institutional) water consumption. Guelph's 2008 population was approximately 120,000. The City recently finalized its Water Conservation and Efficiency Strategy Update or WC&ES (Resource Management Strategies Inc., 2009) updating the City's long-term water demand estimates. The WC&ES estimated average-day water demand for the year 2031 to be 72,535 m^3/day for the residential population growth (169,000) and ICI water demand assumptions within the WC&ES (Note that maximum-day water demands may be higher by 30 percent of more). This projected average demand can be met using 80% of the estimated capacity for the City's wells and 100% of the capacity for the Arkell Glen Collector, as shown in the right most column of Table 2. These calculated rates are used as the basis for WHPA delineation.

The model also incorporates pumping rates from other permitted water takings in the modelled area. One of the largest non-municipal water takings is the Dolime Quarry, located between the University and Queensdale municipal wells. The quarry dewatering removes approximately 8,000 m^3/day from the bedrock aquifer and has a significant influence on groundwater flow in the area.

The groundwater flow model was calibrated using average 2008 pumping rates and monitoring data reflective of that period.

2.2.1.3 Porosity

Groundwater flow models provide estimates of the Darcy flux, or flow rate of groundwater per unit cross-sectional area through porous media (i.e., overburden or rock). To estimate the linear groundwater velocity, representing the speed at which a particle of water might travel, this flux is divided by the effective porosity of the porous media. Effective porosity differs from the total porosity of a porous media and is typically much smaller than the total porosity. While a porous media may have a high proportion of pore space, many of those pores may not be connected, particularly in the case of fractured bedrock aquifers, and as a result, those unconnected pores do not act as pathways for groundwater to travel. The effective porosity is meant to represent the fraction of pore space that is connected providing a path for groundwater to travel from one point to another.

The estimated effective bedrock porosity has a significant impact on the size of delineated time-of-travel capture zones (e.g., the 2-year, 5-year, and 25-year time-of-travel) because the calculated linear velocity is inversely proportional to the specified “effective” porosity value. Consequently, it is typical to use a lower estimate of effective porosity when defining capture zones for WHPAs to ensure that those areas are conservatively large enough to account for uncertainty in the parameter estimates.

Effective porosity cannot be measured directly in the field and can only be estimated indirectly based on observations of the movement of dissolved chemicals in similar hydrogeological environments. Estimates of effective porosity for this project are derived from field observations in Cambridge, Ontario in addition to estimates made by other professionals practicing in the Guelph area.

Flow and porosity data were collected as part of a bedrock hydrogeological study in the limestone aquifer in Cambridge, Ontario. These studies included the use of televiewer logs, flow profiles, tracer tests and packer tests to identify flow horizons and estimate porosity in the Guelph and Gasport Formation bedrock (bedrock production aquifers in the Orangeville area). The studies concluded that fractures are the most important features contributing to the overall transmissivity of the bedrock aquifer, but areas with higher concentrations of vuggy or secondary porosity also provide localized higher transmissivity zones. Four tracer tests were conducted in Cambridge, Ontario (Beak Consultants et al., 1995; Lotowater, 1997), and analysis of the tracer test results estimated the effective porosity range for use in a groundwater flow was 0.07% to 11% (Duke Engineering and Services, 1998). From these results, however, the most realistic estimate of porosity for capture zone delineation is 3.9%, based on a tracer test that is completed over a relatively long distance (i.e., 250 m). Other tests were completed over shorter distances (i.e., 10 m) where volume of fractured bedrock is not large enough to constitute a reasonably sized sample of the aquifer. Duke Engineering and Services Inc. (1998) also conducted numerical and analytical modelling using a dual porosity code (SWIFT-II) to show that effective porosity of 3% provided a reasonable approximation of dual porosity at the spatial and temporal scale of typical capture zones.

Various other estimates of effective porosity have been used for capture zone delineation in the Guelph Area. The Guelph-Puslinch Groundwater Study (Golder, 2006a) used an estimate of 5% effective porosity for the contact zone and production zone and 1% effective porosity in other bedrock units. The Arkell Spring Grounds Groundwater Supply Investigation (Gartner Lee, 2003b) used the same estimates.

Finally, the Wellington County Groundwater Study (Golder Associates, 2006b) assumed a porosity for all bedrock units of 5%.

Error! Reference source not found. Table 3 summarizes the porosity values applied in the model to delineate capture zones. These values were selected in consultation with the City staff and are considered to be low estimates which will result in capture zones that are conservatively large. The values referenced as the 'Base Case' are used to delineate capture zones. The values referenced to as 'Sensitivity Analysis' are used to demonstrate how the capture zones may change using estimates of effective porosity that are higher but remain within the range of professional uncertainty.

Table 3: Specified Porosities

Geologic Unit	Base Case	Sensitivity Analysis
Bedrock (Except Production Zone)	1%	3%
Production Zone (Middle Gasport)	3%	10%
Overburden/Bedrock Contact Zone	3%	3%
Overburden	20%	20%

The base case estimate of effective porosity for bedrock layers is 1%, which is consistent with the previous studies in Guelph and is conservatively lower than the 3% estimate for Cambridge in the Gasport Formation (Duke Engineering and Services, 1998). The base case estimate of effective porosity for the production zone is 3%, which is conservatively lower than the 5% estimate used in previous Guelph studies. The base case estimate of 3% for the contact zone is also considered conservatively low considering the range of weathered materials present.

A sensitivity analysis is described later in this section to demonstrate the influence of the effective porosity estimates on capture zones. For this analysis, the effective porosity of the bedrock layers, except production zone) is equal to 3%, which is similar to the value estimated in Cambridge (Duke Engineering and Services, 1998). The effective porosity for the production zone is 10%, which is reasonable when considering the cavernous nature of this zone throughout the City.

2.2.1.4 Particle-tracking

The Tier Three groundwater flow model was used to estimate capture zones based on forward and reverse particle-tracking within the FEFLOW model. Particle-tracking is carried out by releasing hypothetical particles of water into the three dimensional space contained in the groundwater flow model, and using an algorithm to compute the path that those particles would travel. Backward particle-tracking releases particles that are tracked backwards in time through the saturated groundwater flow field to the water table, and forward particle-tracking releases particles that are tracked forward in time to the location where groundwater is discharged from the model (e.g., a pumping well).

Particle-tracking using a numerical model such as FEFLOW is not an exact computation and it is possible for errors to be introduced into the solution in areas of coarse mesh discretization as well as in areas of high contrast in hydraulic conductivity. Several considerations were incorporated into the development of the FEFLOW model to minimize particle-tracking errors where possible, including:

- The size of finite elements near and including pumping wells was reduced;
- The size of finite elements near rivers and streams was reduced; and
- The Vinemount aquitard was subdivided into three layers to minimize numerical smoothing of groundwater velocities within the aquitard due to the large velocity contrasts expected between it and the adjacent units and allowing for the predominantly vertical flow through the aquitard to be reflected in computed pathlines.

Capture zones were delineated using a combination of backward and forward particle-tracking. For backward particle-tracking, particles were released at multiple levels within all screened layers along the well, and also in the layers above and below the screen. At each level approximately 100 particles were released in three circles around each well at distances from the well determined by the size of the surrounding finite-elements. The distances ranged from 15 m to 270 m with the average being 90 m around the municipal wells. Particle tracks were calculated to steady state with time markers at 2-year, 5-year, 10-year, and 25-year periods.

Forward particles were also released at ground surface and at the top of the Gasport aquifer layer to identify any potentially captured areas not included within the area delineated using backwards particle-tracking. Forward particles were also released at the end points of some of the backward particle-tracking paths to confirm that the forward and backward paths were the same.

2.2.2 Results - Capture Zones

Figure 3 illustrates the 2-year, 5-year, 10-year, 25-year and steady-state capture zones for all municipal wells delineated using the Tier Three model and the WHPA Delineation Pumping Rates listed in Table 2. Figure 4 illustrates the 2-year, 5-year, 10-year, 25-year capture zones at a finer scale. As described previously, the capture zones are delineated under a future scenario with the Dolime quarry no longer pumping water from the Guelph and Gasport formations. Under this scenario, groundwater that is currently captured by the quarry's dewatering system is captured by the City's municipal wells in the vicinity of the quarry.

As shown on Figure 3 and Figure 4, a large land area within the City's municipal boundaries is contained within the 2-year or the 5-year capture zones. These results suggest that a contaminant introduced into the water supply aquifer within the City may be withdrawn at a municipal well within a 5-year time period. In general, the capture zones illustrated on Figure 3 and Figure 4 are similar to those using the Guelph-Puslinch groundwater flow model (AquaResource, 2007a).

The steady-state capture zones, shown on Figure 3, identify long thin areas to the north of the City where groundwater ultimately travels to the City's wells. Groundwater within areas to the north of the City not included within these capture zones discharges to surface water. Numerically, these areas have been confirmed by both forwards and backwards particle-tracking; however, there is uncertainty with respect to the configuration of the steady-state capture zones. This uncertainty is generally due to the simplified conceptual model as well as the limited amount of good quality calibration data, particularly to the north of the City.

2.2.2.1 Northwest Quadrant Wells

Figure 5 illustrates the capture zones computed for the Calico, Paisley, Queensdale, Sacco and Smallfield Wells in the Northwest Quadrant. The capture zones for these wells indicate that groundwater is captured from the north and northwest direction. While the 2-year, 5-year, and 10-year capture zones follow relative flow paths that trend to a northerly direction, the 25-year capture zones illustrate rather abrupt changes in groundwater flow direction and this may reflect the uncertainty of the model predictions.

2.2.2.2 Northeast Quadrant Wells

Figure 6 illustrates the capture zones for the Emma, Park, Helmar and Clythe Creek Wells in the Northeast Quadrant. In general, these wells pump a large volume of water and produce a capture zone that encompasses a large portion of the northeastern part of the City capturing groundwater flowing from the north.

2.2.2.3 Southwest Quadrant Wells

Figure 7 illustrates the capture zones for the Membro, Water Street, Dean, University and Downey Wells in the Southwest Quadrant. This figure shows that the groundwater that is ultimately pumped by the wells in the central part of the City travels between and through the capture zones of wells in the other quadrants. The actual shape and nature of the capture zones for these wells is subject to uncertainties in the conceptual model and will depend on pumping conditions at other wells. Except for the areas within the centre of the City, near the pumping wells, the shape and configuration of the capture zones for these wells should be considered relatively uncertain as compared to wells in the other quadrants.

2.2.2.4 Southeast Quadrant Wells

Figure 8 illustrates the capture zones for the Arkell Wells and the Burke and Carter Wells in the Southeast Quadrant. The capture zones for the Arkell Wells reflect the large amount of water pumped by these wells and extend to the north, east, and southeast. The influence of regional groundwater discharge to Blue Springs Creek to the northeast and the Eramosa River to the north is seen in the 5-year, 10-year, and 25-year capture zones.

The Carter Wells are completed in the shallower Guelph formation. The Carter Wells, which have been designated as groundwater under the direct influence of surface water (GUDI), have a very small area of influence with nearly the entire capture zone having a 2-year time-of-travel. The Burke Well, which derives portions of its water from both the Guelph and Gasport Formations, has a slightly larger capture zone oriented south-easterly towards the Galt/Paris Moraine.

2.2.3 Sensitivity Analysis – Capture Zones

As described above, effective porosity is one of the key parameters associated with the estimation of travel time using particle-tracking techniques. It is also a difficult parameter to estimate particularly in fracture-dominated bedrock aquifers. In addition to the effective porosities used to estimate the capture zones presented in the previous section, Table 3 lists effective porosity estimates that are approximately a factor of three higher but within the range of acceptable uncertainty based on a limited amount of field tests and professional judgment. The impact of using these higher estimates of porosity will be to reduce the calculated linear groundwater flow velocity by approximately a factor of three.

Figure 9 illustrates the influence of these porosity estimates for the 2-year and 5-year capture zones as compared to the base case. As expected, the size of the computed capture zones when increasing the porosity is reduced appreciably. Figure 10 illustrates the influence of these porosity estimates for the 10-year and 25-year capture zones as compared to the base case.

While Figure 9 and Figure 10 both illustrate that the size of the capture zones is very sensitivity to the porosity estimates, the results all indicate that regardless of the porosity used, nearly all of the land within the City is contained within the 10-year and 25-year capture zone and therefore there is a potential for contaminants that enter the groundwater system within the City to migrate to one the City's wells at some time in the future. Given the need to follow precautionary principles, it is appropriate to base the delineation of wellhead protection areas on the smaller estimates of porosity with the knowledge that the actual porosity in the City may vary ranging from values that are very small in some areas to being larger in others.

2.2.4 Results – Wellhead Protection Areas

The capture zones illustrated in Figure 3 and Figure 4 are based on calibrated model parameters and porosities that are considered to be conservative and therefore more protective of the water supply system. However, the model is a necessary simplification of a relatively complicated system. There remains uncertainty with respect to the conceptual model and specifically with the role of fractures or other bedrock aquifer features within the City that may influence the nature and shape of the capture zones as represented in these figures. In developing wellhead protection areas, the impacts of uncertainty are accounted for by adjusting the model's estimated capture zones to reflect the potential for groundwater to be captured by the City's wells. These adjustments are illustrated on Figure 11 and are summarized as follows:

- The areas contained within the 25-year capture zone boundary are simplified and broadened by approximately 200 m around its outer extents to reflect the area where there is a potential for dissolved chemicals introduced into groundwater to migrate to the City's groundwater wells.
- The boundaries of the 2, 5 and 10-year capture zones are simplified and broadened by approximately 100 m to reflect the potential for groundwater within that area to be captured by the City's groundwater wells.
- The areas within the City between the capture zones for some of the City's wellfields were originally estimated to only be within the 10-year or the 25-year capture zones (e.g., between Arkell and Burke/Carter); however, based on the impact of uncertainty on groundwater flow velocities and directions in the fractured bedrock aquifer, these areas are included within the 2-year and 5-year capture zones.

2.2.4.1 Uncertainty

As described previously, there are uncertainties associated with the delineation of time-of-travel based capture zones and WHPAs, and where possible these uncertainties been incorporated into this analysis to delineate conservative WHPAs boundaries that are likely to encompass all areas that contribute to the City's drinking water wells. While these areas are delineated using the best information and interpretation available, the exact time-of-travel associated with dissolved contaminants cannot be estimated exactly, and will likely never be able to be estimated with high precision based on the reality of subsurface hydrogeology, particularly in a fractured rock environment. The development of groundwater protection policies that can be applied over the broader landscape is prudent to address this uncertainty; these policies should be focused on land areas that have a reasonable likelihood to be contained within the capture zone for a municipal supply well.

While there are uncertainties, the reliability of the recommended WHPAs is supported by the applicability of the calibrated model. The groundwater flow model is calibrated using model parameters that reflect hydraulic field tests and have values that are within expected ranges for the various hydrogeological units. Vertical hydraulic gradients simulated in the City are similar to those observed at the City's monitoring wells supporting the characterization of the aquifers and aquitards.

In general, the uncertainty of the capture zone predictions is lower within the City where high quality monitoring data supports the model's estimated groundwater levels and hydraulic gradients. Outside of the City there is less high quality monitoring data and aquifer levels are not lowered as a result of pumping.

The approach followed to develop capture zones recognizes the role of uncertainty by using conservative estimates of porosity and by conservatively adjusting those boundaries when delineating WHPAs. The model parameters having the highest amount of uncertainty affecting the City's capture zones are summarized below:

- Bedrock aquifer porosity. The true effective porosity of the Gasport Formation and the 'Production Zone' is uncertain. The effective porosity (i.e., that which controls travel time in groundwater) is a function of bulk rock porosity, fracture connectivity, and matrix diffusion. The actual value of this parameter may range within an order of magnitude or more and this value may be highly variable spatially and with depth. There are no water quality data or tracer tests in the City that can be used to support the estimated travel times. This uncertainty translates directly to the uncertainty associated with capture zone travel time.
- Characterization of Vinemount Member Aquitard. Although the thickness of the Vinemount Member Aquitard is well defined in the vicinity of the City of Guelph, it is not characterized to the same level of detail outside of the City. Furthermore, the hydraulic properties of the aquitard can only be estimated by indirect methods (e.g., model calibration). Variations in extent, thickness,

and permeability may have an effect on the degree of hydraulic connection between shallow aquifers and the Gasport Formation aquifer. Furthermore, high observed sodium and chloride concentrations in the municipal aquifer may indicate that the aquitard is not a complete barrier to contamination and areas may exist within the City where shallow groundwater may flow, over a period of time, into the water supply aquifer. The high sodium and chloride concentrations may have also been introduced into the aquifer by migrating along either open well bores or along the casings of older wells.

- Hydraulic Conductivity of Gasport Formation. The hydraulic conductivity of the Gasport Formation varies spatially and with depth; this will have an effect on the actual capture zones. The 'Production Zone' is characterized as a high permeability layer within the City but is meant to represent disconnected sequences of one or more permeable features that are observed at generally the same depth across the City. The characterization of this unit has evolved to include numerous areas with varying hydraulic conductivities and while the level of detail of this characterization improves with additional field studies and model calibration, the influence of having this unit characterized as a single layer on capture zones is uncertain.

2.3 GROUNDWATER VULNERABILITY MAPPING

The City of Guelph obtains most of its groundwater from the Gasport Formation aquifer, which is located at a depth of up to 50 m within the City. While the aquifer may be considered to be well protected due to this depth and the presence of the Vinemount Member aquitard, some areas of the aquifer are contaminated within the City from historical industrial activities and other areas show impact from ongoing road salting activities; therefore demonstrating that the aquifer is vulnerable. The ability for the Vinemount Member to act as a complete confining unit with respect to contamination is not clear. In the northwestern area of the City, the Smallfield wellfield has been impacted by Trichloroethylene (TCE). TCE and other chemicals have also been observed at some of the City's wells (e.g., Edinburgh, Emma) where the Vinemount aquitard is present, suggesting that the aquifer is vulnerable in spite of the aquitard. It is possible, however, that the chemicals have been introduced into the aquifer from man-made pathways and not solely through the aquitard.

The vulnerability of an aquifer to contamination is defined as the tendency or likelihood for a contaminant introduced on the ground surface to reach an aquifer of interest. A groundwater vulnerability map identifies where contamination may be more or less likely to enter an underlying aquifer.

In general, aquifers that are unconfined or have little protective overburden cover are more susceptible to contamination than those that have a substantial amount of fine-grained overburden protection due to the attenuation capacity of fine-grained material. Deep aquifers that are confined by thick layers of fine-grained overburden or tight bedrock would be defined as having low vulnerability to contaminants at surface when compared to a water table aquifer that consists of sand and gravel from ground surface.

2.3.1 Background

The Ministry of Environment's Guidance Module for Groundwater Vulnerability (MOE, 2006a) outlines the several approaches for developing maps of relative aquifer vulnerability:

- Basic Hydrogeological Assessment. This is a qualitative approach where subjective consideration is given to the available hydrogeological information (e.g., geological maps, cross-sections, existing groundwater quality) and the relative vulnerability of the aquifer(s) assessed. It relies on local experience by a qualified hydrogeologist, but does not directly involve numerical calculations or modelling.
- Aquifer Vulnerability Index (AVI) or Similar Index Approach. This is an index approach where spatial calculations are completed with the available hydrogeological data and mapping products (e.g., overburden soil type and thickness, depth to aquifer, etc.) to produce an index or numerical

score that reflects the relative amount of protection provided by the physical features that overlie the aquifer.

- Groundwater Intrinsic Susceptibility Index (GwISI). This is a specific indexing approach that takes advantage of the existing Water Well Information System (WWIS) database within the Province to produce an index or numerical score for each well in the database. The index considers the overburden soil type and thickness above the aquifer, and the static water level in the well. This index value is then interpolated between the well locations to produce a complete spatial assessment (i.e., a map) of the intrinsic vulnerability of the aquifer(s).
- Surface to Aquifer Advection Time (SAAT). In this approach, an estimate is made of the vertical travel time from the ground surface (or near ground surface) to the top of the aquifer (or top of the water table in an unconfined aquifer). Unlike the previous methods, the intrinsic vulnerability is expressed in units of time (e.g., years) rather than a subjective (generic) index value.
- Surface to Well Advection Time (SWAT). In this approach an estimate is made of the time it takes for water to travel from the ground surface down to a well. This is essentially equivalent to the SAAT, plus the time it would take for a particle to travel through the aquifer from the top of the aquifer to the well screen.
- Detailed Hydrogeological Assessment. This approach involves a higher level of field data collection and evaluation than is incorporated into the basic hydrogeological assessment or indexing methods described above. For example, it could include detailed water quality sampling and assessment and/or numerical modelling methods to evaluate the relative intrinsic vulnerability of the aquifers.

As part of the Guelph-Puslinch Groundwater Protection Study (Golder, 2006a), aquifer vulnerability mapping was completed using a modified version of the MOE's Groundwater Intrinsic Susceptibility (GwISI) method (MOE, 2001). As described above, the GwISI method is an indexing approach that estimates an index or numerical score for individual boreholes or water wells, and interpolates these values across the broader landscape. The assessment evaluated the vulnerability of the different municipal groundwater aquifers based on the travel time for contaminants to travel from ground surface through the subsurface to the underlying contributing (municipal) aquifers.

As part of this study, Golder (2006a) produced intrinsic vulnerability maps for individual aquifers that have classes of high, medium or low vulnerability. In the City of Guelph, this included shallow overburden aquifers, intermediate to deep overburden aquifers, the Guelph Formation aquifer, and the Amabel Formation aquifer. The zones of medium to high vulnerability were then propagated upwards from the bedrock aquifer, through the intermediate overburden aquifer, to the shallow overburden aquifer to ensure that zones of medium to high vulnerability mapped at depth were not mapped with a lower vulnerability in an overlying aquifer. In addition, Golder (2006a) used Quaternary mapping to help refine the vulnerability of the shallow overburden aquifer such that areas mapped as surficial sands and gravels were classed as highly vulnerable regardless of the vulnerability scores at the wells; and assigned a low vulnerability to the Amabel Formation aquifer in areas where the Amabel Formation is overlain by the Eramosa Member. Additional information regarding the vulnerability mapping can be found in the Guelph-Puslinch Groundwater Protection Study (Golder, 2006a).

Based on the occurrences of organic contaminants, and sodium and chloride concentrations in the City's municipal wells, the 2006 Guelph Source Protection Project (AquaResource, 2007a) determined that the Amabel/Gasport aquifer should not be assigned a low vulnerability score, as it was mapped in the Guelph-Puslinch Groundwater Protection Study. Rather, the City chose to use vulnerability mapping for the shallowest bedrock formation when calculating the vulnerability scores. This map is illustrated on Figure 12. While this approach is conservative in many cases, it recognizes that once contamination reaches the top of bedrock in the City, there is always a potential that it could migrate to the aquifer through bedrock fractures or other preferential pathways.

The AquaResource (2007a) study conducted an assessment of the Surface to Well Advection Time (SWAT) method for mapping aquifer vulnerability. The SWAT method involves the use of forward particle-tracking techniques to estimate the trajectory and time-of-travel for water to travel from the water table to a well. Figure 13 illustrates the results of this analysis performed by AquaResource (2007a). The figure illustrates the starting point of imaginary particles released at the water table and assigns a colour to those points based on the calculated time-of-travel for those particles to reach a pumping well. As shown on the figure, there are many particles released in the City that are computed to have greater than a 25-year travel time to a municipal well, such as those located immediately east of the Sacco and Smallfield wells. There are also areas within the City having very short (e.g., less than 5 year) travel times to a well, such as those areas near the Arkell wells. Finally, there are large portions of the City where particles released at the water table discharge at the Eramosa or Speed River and are therefore not highlighted on the figure.

This study concluded that the particle-tracking used in the SWAT method was very sensitive to both the configuration and hydraulic conductivity of the production zone and the Eramosa/Vinemount aquitard--both of which have a relatively high uncertainty. In addition, the travel times computed are much different for wells that are drawing water from shallower rock. Finally, the method would not consider areas in shallow overburden bedrock where groundwater discharges to surface water, even though the aquifer beneath is very close to a municipal well and within the two-year time-of-travel computed with backwards particle-tracking. Based on the results of this study, it was concluded that while the technical approach provides insight into the groundwater flow system in the vicinity of a particular pumping well, the SWAT method would not be a reliable and defensible method for delineating the City's vulnerable areas.

2.3.2 Modified GwISI Method

The Groundwater Intrinsic Susceptibility Index (GwISI) is an indexing approach that takes advantage of an existing database of water well records and boreholes to produce an index or numerical score for each well in the database. The index considers the overburden soil type and thickness above the aquifer, and the static water level in the well. The GwISI is calculated by summing the product of the thickness of each geological unit overlying the aquifer with its corresponding K-Factor. The K-Factor is a dimensionless number that is loosely related to the exponent of the vertical hydraulic conductivity of the geological material (in m/s). In effect, the objective in assigning the K-Factor is to relate the degree of protection offered by each respective geological material that overlies the aquifer. Suggested K-Factors for this classification system are provided in the MOE's Guidance Document for Groundwater Vulnerability (MOE, 2006a). These factors were derived from studies conducted in the Oak Ridges Moraine and it is assumed that they are relevant for the City of Guelph area.

While the GwISI method was initially developed to map vulnerability from ground surface to the water table, MOE (2006a) states that the methodology for calculating the ISI remains suitable for the deeper aquifers, with the target depth becoming the top of the respective aquifer. In each of the index approaches, it is assumed that flow to the target aquifer is vertical. The validity of this assumption should be evaluated particularly for deeper aquifers where there may be horizontal travel in overlying aquifers. Many of the City of Guelph's monitoring wells show high vertical gradients, supporting the validity of this approach for the deeper aquifer.

For the GwISI method, index values < 30 would be categorized as "High"; index values ranging from 30 to 80 would be categorized as "Medium"; and index values > 80 would be categorized as "Low". The index value is then interpolated between the well locations to produce a complete spatial assessment (map) of the intrinsic vulnerability of the aquifer(s). As is shown on Figure 12, the interpolated GwISI map provides a general indication of areas having high and low vulnerability. When calculating the GwISI with respect to the top of bedrock, areas having thick overburden tend to have lower vulnerability, as with the Galt/Paris Moraine Area; and areas having thin overburden tend to have higher vulnerability, as with many areas along the Eramosa River where bedrock is close to surface.

The GwISI method applied by Golder (2006a) within the City of Guelph provides for a good regional representation of groundwater vulnerability, but the certainty of this estimation at the local scale may be reduced as a result of the limited reliability of MOE water well records or in areas where the index values have been interpolated from MOE water well records at distance. As an example of a problem with local conditions not being reflected by the interpolation, there are areas within the City where overburden is very thin and this is not reflected by a high vulnerability estimate. As shown on Figure 14, there are many areas along the Speed River and Eramosa River valleys where overburden thickness is less than 5 m and this would result in a high vulnerability score. The Golder (2006a) mapping shows vulnerability to be moderate and sometimes low, and this is due to the process of interpolating from water well record values without regard to better estimates of overburden thickness.

For this current assessment, the GwISI method was modified to use an overburden thickness map created using existing information. The modified method calculates the same index value as the GwISI method at the location of each water well record, but uses additional information provided by a Digital Elevation Model (DEM) in areas where there are no water well records.

The modified GwISI method is summarized as follows:

1) An overburden thickness map (Figure 14) is generated for the study area using a DEM and a top of bedrock elevation surface. This map was compared against point estimates of overburden thickness derived from high quality borehole logs.
2) GwISI is estimated for water well records and boreholes using the regular GwISI technique and published K-Factors. The GwISI index value is then divided by the overburden thickness at the location of each water well record and borehole to calculate an Effective K-Factor.
3) The Effective K-Factor is then interpolated using a ‘natural neighbour’ algorithm across the land area as shown on Figure 15. This map illustrates the general trends of higher and lower permeability soils as reported in the water well record database and higher quality boreholes. It is noted that this map is derived from a combination of sparse high quality data (i.e., high quality boreholes) and more prevalent lower quality data (i.e., water well records). The Effective K-Factor map does provide results that are expected, illustrating lower permeability sediments associated with the Port Stanley Till (yellow and orange) to the north and west of the City and higher quality sediments (blue) located in outwash deposits along key surface water features.
4) For each grid cell, the interpolated Effective K-Factor (Figure 15) is multiplied by the overburden thickness, shown on the map included as Figure 14. This results in the map illustrated on Figure 16 that is referred to as the modified GwISI map. This final step accounts for the influence of variations in overburden thickness in areas where there are no water well records, such as in deeper valleys.

The modified GwISI map (Figure 16) shows many of the same trends as the one prepared using the GwISI method (Figure 12); however, differences are seen along the Eramosa and Speed River valleys where overburden is thin and shallow bedrock is more vulnerable to contamination originating from ground surface. The modified GwISI map also shows lower vulnerability trends along known thick overburden features, such as the Galt/Paris Moraine. These trends are not as well defined in Figure 12.

2.3.3 Transport Pathways

The Technical Rules (MOE, 2009) require that the influence of transport pathways that are anthropogenic in origin be incorporated into vulnerability scoring by increasing the vulnerability score to medium or high vulnerability where these transport pathways are considered to be significant. The 2006/07 Guelph Source Protection Project (AquaResource, 2007a) included an evaluation of preferential pathways and updated the vulnerability mapping to account for these pathways.

The following anthropogenic activities were identified by the City as having a potential effect on the vulnerability of the municipal aquifer:

1) Private wells that may be improperly constructed / poorly maintained;
2) Deep large-diameter municipal sewers that intersect bedrock; and
3) Quarries and gravel pits.

The following sections describe the methodology and results of the preferential pathways study completed as part of the Guelph Source Protection Project (AquaResource, 2007a).

2.3.3.1 Private Wells

In late 2006, Stantec conducted a well survey throughout the City of Guelph as part of the preferential pathways inventory. The objective of the survey was to identify improperly constructed or poorly maintained wells in and around the urban core area of the City that may make it easier for contaminants to be transported to the groundwater.

Figure 12 illustrates the location of bedrock wells in the City. A total of 215 MOE water well records plot in the area of the survey. Of these, 18 wells were observed in the field and matched with MOE water well records, and eight wells were observed but were not matched with MOE water well records. Of the wells that were observed, all appeared to be in good condition, however, the condition of the surface seal was not evaluated as part of this study.

A total of 868 residences received letters as part of a door-to-door survey. Of these, Stantec received 364 responses. Between November 20, 2006 and December 4, 2006, 26 people called the City of Guelph regarding a well on their property in response to the press release and/or radio spot. Stantec reached 13 of the 26 people by phone, using the survey questionnaire to guide the telephone conversation.

A total of 377 responses were received. Of these, 150 reported being unaware of having a well on their property; 212 reported having a well on their property; and 15 did not wish to participate. Of the properties with wells, 169 were reported to be in use, and 43 were not in use. Of the wells that are being used 148 reported their well to be in good condition, 9 reported their well was in poor condition and 12 reported the condition of their well was unknown. Of the wells that are not being used, 12 reported their well to be in good condition, 4 reported their well to be in poor condition, the condition was unknown for 7 wells, 5 were reportedly decommissioned and 15 were reported to be buried.

Based on the survey of Private Wells within the City, AquaResource and the City decided that the quality and quantity of information relating to abandoned wells was not suitable to modify the vulnerability mapping to account for the potential for these wells to act as transport pathways to contaminate the aquifer.

2.3.3.2 Municipal Sewer Infrastructure

The City provided a GIS layer of the municipal sewer infrastructure information including invert elevations of each manhole. The invert elevation data provided was compared to the bedrock elevation map to give an indication of where municipal sewers were likely to intersect bedrock. Figure 17 shows the sanitary and storm sewers which may intersect bedrock. These areas may be more susceptible to the preferential movement of contaminants than shallower infrastructure installed above the bedrock.

2.3.3.3 Quarries and Gravel Pits

Quarries and gravel pits represent a preferential pathway of concern because the overlying protective layers of aquifer are removed, thereby, making the aquifer more vulnerable. One quarry and one gravel pit were identified in the vicinity of Guelph as illustrated on Figure 17. The quarry is a particular concern for the City with respect to its potential to impact the drinking water supply due to the significant dewatering, depth of excavation in the bedrock and its proximity to several municipal wells.

2.3.3.4 Modification to Vulnerability Mapping

Preferential pathways are intended to be accounted for in the refined vulnerability scoring of capture zones and may be used to increase the intrinsic vulnerability index (i.e., from low to moderate or moderate to high) to reflect the higher vulnerability caused by the pathway.

Figure 17 shows the aquifer vulnerability map overlain with the sanitary and storm sewers intersecting bedrock. Adjustments to the intrinsic vulnerability (e.g., high, medium, and low) were made in areas where the bedrock is intersected by sanitary or storm sewers, and in areas where pits and quarries were reported to exist. As noted above, the intrinsic vulnerability was increased one step (e.g., from low to medium, and from medium to high) in the above noted areas. While they are located throughout the study area and may also impact the municipal aquifer vulnerability, the vulnerability scores were not adjusted to account for the presence of improperly abandoned or poorly maintained boreholes.

Figure 18 shows the updated vulnerability in the City of Guelph adjusted from Figure 16 to account for the potential influence of sanitary or storm sewers, and/ or sand and gravel pits or quarries as preferential pathways.

2.4 GROUNDWATER VULNERABILITY SCORING

Groundwater vulnerability scoring is the next step in this process. Having delineated the vulnerable areas and assessed the relative vulnerability of the aquifers within these areas as High, Medium or Low, the vulnerability scoring within each of the vulnerable areas must be completed following the methodology provided by the MOE (2006a) and the Technical Rules (MOE, 2009). The vulnerability scoring is based on the premise that the vulnerability of the aquifer decreases as the time-of-travel to the well increases. Thus, under identical geologic conditions, a higher vulnerability score will be assigned within a 2-year time-of-travel capture zone than a 25-year time-of-travel capture zone.

2.4.1 Methodology

Vulnerability scoring is completed by overlaying the 2-year, the 5-year, and the 25-year time-of-travel capture zones with the intrinsic vulnerability map. Intersecting the classed vulnerability map with the capture zones creates a series of polygons that are assigned a vulnerability score based on the vulnerability and type of WHPA. The following table is provided in the Technical Rules (*Table 2(a): Wellhead Protection Area Vulnerability Scores – ISI or AVI Location Within a Well Head Protection Area*) (MOE, 2009) and specifies the vulnerability score that is applied to areas within a WHPA based on the groundwater vulnerability in that area.

Table 4: Wellhead Protection Area Vulnerability Scores (From Technical Rules (MOE, 2009))

Groundwater Vulnerability Category for the Area	WHPA-A (100 m)	WHPA-B (2-Year TOT)	WHPA-C (5-Year TOT)	WHPA-D (25-Year TOT)
High	10	10	8	6
Medium	10	8	6	4
Low	10	6	4	2

Note: TOT represents time-of-travel.

Figure 19 illustrates the vulnerability scores within the City's WHPAs. The Technical Rules stipulate that significant water quality threats can only be identified in areas where the vulnerability score is 8 or 10 under the regular threats assessment process.

As shown on this figure, vulnerability scores equal to 8 or 10 are located within large portions of the WHPA-A and WHPA-B (2 year time-of-travel) particularly along the Eramosa and Speed River Valleys where overburden is thin. Dissolved organic chemicals have been observed at a number of the City's pumping wells, particularly where the land areas with high vulnerability scores for those wells are associated with industrial or commercial land uses. These occurrences of contamination in the aquifer illustrate the potential that the deep water supply aquifer may be impacted by contamination originating at the ground surface. Historical occurrences of contamination also illustrate that there are areas within the City with high groundwater vulnerability and that the presence of an aquitard should not presume that the groundwater supply is not vulnerable to contamination issues.

2.4.1.1 Northwest Quadrant

Figure 20 illustrates the groundwater vulnerability scoring for the Northwest Quadrant. Much of the areas contained within the 2-year WHPAs from the Sacco, Smallfield, Paisley, and Queensdale wells have a high vulnerability score. Portions of the 5-year WHPA also have a high vulnerability score. These results are consistent with the City's observation of organic contaminants at the Sacco and Smallfield wells which resulted in these wells being identified as having issues and the City removing them from service.

2.4.1.2 Northeast Quadrant

Figure 21 illustrates the groundwater vulnerability scoring for the Northeast Quadrant containing the Emma, Park, Helmar, and Clythe Creek wells. The area northwest of Clythe Creek and northeast of the Emma and Park wells contains the Eastview Landfill, situated on a layer of thick till which is responsible for the low vulnerability in that area. The land areas south of the wells, particularly along the Speed and Eramosa River Valleys, have a high vulnerability as a result of thin overburden. Some of this land area is within the capture zone of the Emma Well where concentrations of dissolved organic chemicals have been increasing since the 1990's.

2.4.1.3 Southwest Quadrant

Figure 22 illustrates the groundwater vulnerability scoring for the Southwest Quadrant containing the Membro, Water, Dean, University and Downey wells. Capture zones for these wells extend into the centre of the City, particularly beneath the Speed River and Eramosa River valleys where overburden is thin and vulnerability is high. Dissolved organic chemicals have been observed in both the Membro and Edinburgh wells.

2.4.1.4 Southeast Quadrant

Figure 23 illustrates the groundwater vulnerability scoring for the Southeast Quadrant containing the Arkell wells and the Carter and Burke wells. The Arkell Well capture zones extend to the northeast and to the southeast into the Galt/Paris Moraine. Groundwater vulnerability is high (e.g., 8, 10) over much of the 2-year capture zone due to relatively thin overburden, particularly along the Eramosa River valley. Capture zones for the Burke and Carter Wells extend southeast into the Moraine. The presence of nitrate in the Carter Wells is consistent with the high vulnerability in the area.

3.0 Surface Water Vulnerability

3.1 INTRODUCTION

The Eramosa River has been a source of drinking water for the City of Guelph for many years. The Arkell Spring Grounds were developed by the City in 1908 to replace the Eramosa River as a source of water supply. Prior to that time, water was pumped directly from the Eramosa River to open reservoirs at the former York Road Pumping Station which is now the site of the current F.M. Woods Water Pumping Station. The development of the Arkell Spring Grounds involved the installation of a collector system to intercept groundwater springs/seeps from the outwash sands and gravels that are exposed along the south valley wall of the Eramosa River. The system also required the construction of an aqueduct to convey the water from the Arkell Spring Grounds to the York Road Water Pumping Station.

In addition its 23 groundwater production wells, the City of Guelph continues to operate the groundwater collection system located at the Arkell Spring Grounds. This collection system consists of the Glen Collector System which collects shallow groundwater from the overburden through a series of small diameter perforated pipes. A similar system, the Lower Road Collection System was taken offline in about 2002 due to water quality concerns. The yield from the Glen Collector System varies seasonally according to fluctuations in the water table elevation. To enhance the supply of water into the collection system, the City operates an Eramosa River intake and an Artificial Recharge System at the Spring Grounds. Between April 15 and November 15, water is pumped from the Eramosa River and released into an infiltration pit and trench, where it recharges the shallow overburden aquifer supplying the Glen Collector. Figure 24 shows the location of the Arkell Spring Grounds and the Eramosa River intake in relation to the Eramosa River subwatershed. Figure 25 illustrates the local detail of the collection system configuration with respect to the Intake and to the Spring Grounds.

This section describes the delineation of intake protection zones (IPZs) for the Eramosa River intake and the assigned vulnerability scores for the IPZs.

3.1.1 <u>Clean Water Act: Surface Water Vulnerability</u>

Similar to the Groundwater Vulnerability Assessment, a Surface Water Vulnerability Assessment is required under the Technical Rules for surface water intakes to delineate both the vulnerable areas for a surface water intake and to assign vulnerability scores for those areas. The Surface Water Vulnerability Assessment delineates land areas which contribute water to a drinking water intake. The assessment uses measurements and calculations to estimate time-of-travel within a river and within buffers around watercourses to delineate land areas where, should a spill occur, the quality of the raw intake water could be compromised.

The Technical Rules (MOE, 2009) require that the following intake protection zones (IPZs) be created for surface water intakes:

1) IPZ-1. A semi-circle of 200 m radius, extending upstream of the intake. The semi-circle is extended 10 m downstream of the intake. Where the area abuts land, a setback of 120 m or the extent of the Conservation Authority Regulated Area is applied. IPZ-1 can be modified based on local hydrodynamic conditions.

2) IPZ-2. The length of river, extending upstream of the intake to a distance equal to a two-hour time-of-travel under bankfull flow conditions. The length of river is buffered at the river bank by 120 metres, or the extent of the Conservation Authority Regulated Area, whichever is greater. The two-hour time constraint is a minimum and may be modified upwards based on the time required for the municipal system in question to respond to an upstream spill.

3) IPZ-3. All watercourses providing water to the intake, buffered to either 120 metres or the Conservation Authority Regulated Area, whichever is greater.

The Technical Rules provide a range of vulnerability scores for IPZ-1, IPZ-2, and IPZ-3 and technical teams are required to consider a series of factors when assigning these scores. These factors include: the percentage of area within the IPZ-2 or IPZ-3 that is composed of land; the land cover, soil type, permeability, and slope; and the hydrological and hydrogeological conditions that contribute water to the area.

Threats within the IPZs would subsequently be identified through a Water Quality Threats Assessment. Threats are identified based on knowledge of land use practices within the delineated IPZ areas. The City of Guelph completed a Water Quality Threats Assessment draft report in March 2010. The Clean Water Act requires the City to develop specific risk-management measures for all significant water quality threats.

3.1.2 Eramosa River Intake

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 in the vicinity of the intake structure. The Eramosa River intake is considered to be a municipal intake, as the water pumped from the Eramosa River is ultimately used as a municipal supply. With respect to the Technical Rules, the Eramosa River intake is being considered as a Type C Intake, as it is "*located in a river and the direction of the flow of the water at the intake is not affected by a water impoundment structure*". While a concrete weir is located downstream of the intake, it does not appear to change the direction of flow at the intake.

The river intake has no remote operations capacity, and therefore, in the event of a spill, the water treatment operator would be required to physically close the intake. For this reason, the City has indicated that a 2-hour response time is insufficient to respond to threats and close the intake. The City feels that a 4-hour response time is more appropriate for the delineation of an IPZ-2 and the management of threats that would fall within this immediate response time requirement.

Water withdrawals from the Eramosa River are regulated by a Permit-to-Take-Water (PTTW), which has a number of conditions depending on season, river flow, and water quality. The conditions are as follows:

- Provided that 0.85 m^3/s of streamflow is maintained past the Guelph Wastewater Treatment Plant,
- And provided that 0.42 m^3/s streamflow is maintained in the Eramosa River,
- Then, the City of Guelph may pump water from the Eramosa River at the rates listed in Table 5.

Table 5: Seasonal Permitted Water Taking for City of Guelph Eramosa River Intake

Season	Permitted Pumping Rates
April 15 to May 31	0.368 m^3/s
June 1 to June 30	0.261 m^3/s
July 1 to July 15	0.211 m^3/s
July 16 to August 31	0.158 m^3/s
September 1 to November 15	0.105 m^3/s

Currently the pumping rate is limited by the current pump infrastructure to 0.105 m^3/s throughout the April 15th to November 15th period.

3.1.3 Watershed Characterization

The City of Guelph's Artificial Recharge System is supplied by the Eramosa River. The Eramosa River subwatershed is approximately 240 km^2 and is located on the eastern portion of the Grand River watershed near the municipalities of the City of Guelph, Guelph-Eramosa Township, 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. In addition to the Arkell weir, there are two significant dam structures on the Eramosa River: the Eden Mills Dam located on the Eramosa River in Eden Mills; and the Rockwood Dam located in the Rockwood Conservation Area.

As shown on Figure 26, the overburden geology within the Eramosa River subwatershed varies and consists of extensive deposits of coarse-grained glaciofluvial ice-contact sand and gravel deposits, with finer-grained tills (Port Stanley Till and Wentworth Till) interspersed. The large percentage of pervious overburden soils and deposits produce a high potential for groundwater recharge, which is reflected in the abundant groundwater resources of the area.

Thirty-six percent of the subwatershed is characterized by hummocky topography associated with the Galt and Paris Moraines. Hummocky areas are characterized by numerous large scale depressions that lack well defined surface drainage systems. The lack of well defined drainage systems and the large scale depressions enhance infiltration by allowing rainfall to infiltrate rather than runoff to nearby surface water features.

Land cover in the Eramosa River subwatershed is shown on Figure 27 and is predominately agricultural; however, this subwatershed has among the highest percentages of forest cover among all subwatersheds within the Grand River watershed (19.9%). The combination of land cover, surficial geology and topography translate to reduced surface runoff relative to other subwatersheds. Figure 27 also illustrates the GRCA's Regulated Areas, which include a number of features, including provincially significant wetlands and regulated floodplains.

The high recharge rates and transmissive shallow aquifers permit large volumes of groundwater to discharge into the Eramosa River and Blue Springs Creek, a tributary to the Eramosa River. Due to the large volumes of groundwater discharge, the Eramosa River has a well sustained flow regime, with much higher low flows than runoff-driven systems. The groundwater discharge in the Eramosa River also supports the spawning and habitat for a number of significant coldwater fisheries.

3.2 IPZ DELINEATION

3.2.1 Dye Tracer Test

As part of the 2006 Guelph Source Protection Project, AquaResource (2007a) conducted a series of dye tracer tests to measure travel time during low flow conditions along the Eramosa River upstream of the Eramosa River intake. Tracer tests are commonly used to characterize the time-of-travel for a possible contaminant to reach a point of interest from an upstream injection point. The tests typically use a non-toxic, conservative, fluorescent dye (usually rhodamine WT), allowing the investigators to study the characteristics of plume migration without harming the environment. As part of the 2006 dye tracer test, a slug of rhodamine WT (water tracing) dye was mixed with water and released into the centre line of the channel at four locations upstream of the intake. Recording instruments (i.e., fluorometers) were stationed downstream of the dye release locations to monitor the concentration of the dye and to capture the dye plume's characteristics, such as time to first detect, time to peak, peak concentration, and time for the plume to be flushed out of the stream. Further descriptions of this test are provided by AquaResource (2007a).

The results of the dye tracer test were used to estimate both the velocity of the leading edge of the dye plume and the time to peak concentration of the dye plume. Under the low flow conditions, equal to approximately 1.8 m^3/s, the time to first detection for all four injection points was greater than the 2-hour minimum travel time suggested within MOE Guidance (MOE, 2006).

3.2.2 Hydraulic Model

The dye tracer test provided an estimate of travel time under the low flow conditions, but did not, however, reflect travel times under higher flows with higher velocities. The study team developed, calibrated, and applied a hydraulic model to 'scale up' the results of the dye tracer test to higher streamflows to estimate travel time under these higher streamflows. Hydraulic models, which are typically used to estimate water surface elevations during flooding, use the physical characteristics of a river to estimate a variety of hydraulic related parameters for a water course, including water depth, water velocity, and time-of-travel.

Recent work carried out by the Grand River Conservation Authority (GRCA), in partnership with Conservation Ontario and MOE, (GRCA, 2005) demonstrated the applicability of hydraulic models in describing low flow hydraulic conditions and the relationship to aquatic habitat.

Due to its widespread use, and previously demonstrated applicability for simulation of low flow hydraulics, HEC-RAS was selected to simulate the hydraulic characteristics of the Eramosa River. HEC-RAS is a simulation program originally designed by, and currently maintained by the US Army Corps of Engineers to perform one-dimensional hydraulic calculations for both natural and constructed channels (USACE, 2002).

The hydraulic model was designed to extend from the weir downstream of the Eramosa River intake up-gradient to the main outlet of Eden Mills Pond to be consistent with the reach of the Eramosa River studied during the dye tracer test. The model was limited to the main channel of the Eramosa River and did not include tributaries (Blue Springs Creek) or side channels.

The 2006 Guelph Source Protection Project included a survey of 26 geomorphic cross sections using a total station along the 4,000 m of river reach. The average cross section spacing was approximately 150 m; however, the downstream reach length between sections varied significantly and locations were chosen to capture the observed hydraulic shifts in channel morphology. The cross sections were focused on in-river geometries, with sections terminating at locations the field crew estimated to represent bankfull stage. In addition to collecting cross section and pebble count information, the survey team also collected continuous channel invert elevation and water surface elevation.

The field studies provided two sets of data to support the HEC-RAS model calibration: the continuous water surface elevation reported during the cross section survey; and the time-of-travel estimates collected during the dye tracer tests. The approach used to achieve the calibrated model involved the adjustment of Manning's 'n' values along the reach until the simulated travel times and water surface elevations were representative of observed values.

3.2.3 Results

Delineation of the IPZs involves a combination of Geographic Information System (GIS) procedures, fieldwork, and numeric hydraulic modelling. The following sections describe the methodology for the delineation of the three different IPZs. The first two (IPZ-1 and IPZ-2) are highlighted on Figure 28 while all IPZs are presented in Figure 29.

3.2.3.1 IPZ-1

As described in Section 3.1.1, the Technical Rules specify that the IPZ-1 is delineated using a 200 m semi-circle extending upstream, centered on the intake. The semi-circle is then extended 10 m downstream of the intake. The Technical Rules also allow the IPZ-1 to be modified based on local hydrodynamic conditions.

Following this, the Eramosa River intake IPZ-1 is delineated based on semi circle with a 200 m radius, centered on the intake, extending upstream. Reflecting the local hydrodynamic conditions present at the intake, the IPZ-1 was extended downstream of the intake to the face of the Arkell weir, rather than the typical 10 m downstream extension.

Where the delineated area abutted land, a setback of 120 m or the Regulated Area, whichever was greater, was used. As the semi-circle abutted land on both sides of the Eramosa River, the IPZ-1 was laterally extended to include the full extent of the Regulated Area.

3.2.3.2 IPZ-2

The IPZ-2 is meant to represent the land area upstream of a surface water intake where, should a spill occur, the municipality would have insufficient time to respond (e.g., shut down intake). While the Technical Rules require this distance to at least be equal to the 2-hour time-of-travel, this can be increased should the municipality decide that additional time is needed to respond to a spill event. City of Guelph Waterworks believes that two hours would be insufficient, with a four to six hour window being preferred.

Based on the dye tracer test, the time-of-travel characteristics predicted by the hydraulic model, and consultation with City of Guelph staff, the IPZ-2 was delineated to extend upstream of the Eden Mills Pond, at the Indian Road bridge crossing. Flow monitoring data indicates that a streamflow equal to 5.6 m^3/s is greater than 95% of all flow conditions that have historically been observed during the normal operation window of the Eramosa River intake (April 15 – November 15). The hydraulic model output and the dye tracer tests indicate that the upstream extent of Eden Mills Pond represents approximately a 6-hour time-of-travel to the Eramosa River intake at a streamflow of 5.6 m^3/s. This time-of-travel includes both the time for water to travel to the intake at these flow conditions (3 hours) and the mixing time for water in the pond (3 hours). It is noted that a bypass structure and channel exists at the upstream portion of Eden Mills Pond. This bypass channel rejoins the Eramosa River downstream of Eden Mills. At a flow rate of 5.6 m^3/s, the bypass structure and channel would likely divert an unknown quantity of flow around Eden Mills Pond, possibly resulting in a shorter travel time than if all flow was contained within the pond and introduces a level of uncertainty into the travel time estimate. Since the overall travel time allowance (6 hours) is significantly above the minimum travel time required under the Technical Rules (2 hours), and at the upper range of the time required by the municipality for adequate response, this level of uncertainty is not significant enough to invalidate the selected limit of the IPZ-2.

The lateral extent of the IPZ-2 is defined as an overland setback from those watercourses that are included within the longitudinal extent of the IPZ-2. The Technical Rules require that the area be based on the greater of a setback of 120 m or the Regulated Area as illustrated on Figure 27. Figure 28 illustrates the extent of the IPZ-2 area based on these criteria.

3.2.3.3 IPZ-3

The third and final intake protection zone was delineated by identifying all watercourses/water bodies that supply water to the Eramosa River intake. This includes any watercourse within the Eramosa River subwatershed, or its tributaries. A lateral setback from the included watercourses was applied, equal to the greater of a 120 m or the Regulated Area.

Figure 29 illustrates the Eramosa River intake IPZ-3 area, in relation to the IPZ-1 and IPZ-2 and the contributing drainage area. The IPZ-3 area contains many wetland areas adjacent to creeks and streams that have a very small topographic gradient, and in some areas have no defined surface water outlets. While the IPZ-3 mapping provided here includes all Regulated Areas adjacent to surface water, parts of these areas may not contribute surface water drainage to the Eramosa River.

3.3 SURFACE WATER VULNERABILITY SCORING

Following the Technical Rules, the surface water vulnerability score is computed by multiplying two factors: the area vulnerability factor, which represents the vulnerability of the intake protection zone; and the source vulnerability factor, which represents the vulnerability of the intake.

The area vulnerability factor is an integer from 1 to 10, where 10 represents the highest vulnerability. As outlined in the Technical Rules, the area vulnerability factor is based on four local attributes as follows:

1) the percentage of land in the IPZ;
2) the land cover, soil type, permeability, and slope;
3) the consideration of transport pathways such as tile drainage, swales and sewer discharge pipes; and
4) for IPZ-3, the proximity of the IPZ-3 to the intake.

The source vulnerability factor is a number expressed to a single decimal, ranging from 0.5 to 1, where 1 represents the highest vulnerability. As outlined in the Technical Rules, the source vulnerability factor is based on three features:

1) the depth of the intake;
2) the distance of the intake from land; and
3) the history of water quality concerns at the intake.

The area and source vulnerability factors and resulting vulnerability scores for the Eramosa River intake are discussed in the following sections.

3.3.1 Area Vulnerability Factor

3.3.1.1 IPZ-1

The Technical Rules state that the IPZ-1 is assigned an area vulnerability factor of 10, as it is closest to the intake, has a higher vulnerability than the IPZ-2 or IPZ-3, and any water quality threats in this area would likely impact the drinking water intake. Therefore, the Eramosa River intake IPZ-1 was assigned an area vulnerability factor of 10.

3.3.1.2 IPZ-2

According to the Technical Rules, an IPZ-2 shall be assigned an area vulnerability factor that is not less than 7 and not more than 9 based on the vulnerability of the area where a higher factor corresponds to a higher vulnerability. The local features within the Eramosa River intake IPZ-2 were taken into account to assign the area vulnerability factor.

As illustrated in Figure 28, the Eramosa River intake IPZ-2 includes mostly land (95%), as opposed to open water (5%), which reduces the potential for direct surface water runoff connection. Overland runoff within the IPZ-2 has the potential to infiltrate into the ground, depending on the land cover, soil properties and hydrologic conditions.

Land cover within the IPZ-2 consists of mainly natural areas (66%), including forests, wetlands and plantations. These natural areas have a high water-holding potential, promote infiltration and reduce direct runoff. A very small area of the IPZ-2 consists of built-up areas, specifically Eden Mills, which represents 3% of the IPZ-2 area. As a result, there is very little urban runoff within the IPZ-2. The remaining area within the IPZ-2 consists of agricultural lands (26%). These areas are generally buffered from the Eramosa River by natural areas and there is a lower potential for the Eramosa River to receive direct runoff from farmers' fields. Overall, the land cover within the IPZ-2 would suggest that the area vulnerability factor should be at the low end of the prescribed range.

A final consideration was given to transport pathways within the IPZ-2. There are no sanitary sewers draining into the IPZ-2. Urban development is very limited in the subwatershed and storm sewer outfalls were not observed along water course. A visual inspection of the Eramosa River was performed by AquaResource in June 2006, and no tile drains were identified along the Eramosa River from the intake to Eden Mills. Vegetated drainage swales and ditches are located and were observed within the village of Eden Mills and along roads crossing the IPZ-2.

Based on the high percentage of land area, low urban drainage, and no transport pathways, the Eramosa River intake IPZ-2 was assigned an area vulnerability factor of 7. This area vulnerability factor is at the low end of the prescribed range of 7 to 9 for the IPZ-2 and this is considered reasonable given the land cover, soils and permeability of the area as well as the very few transport pathways in the area. Based on the vulnerability assessment, the most significant transport pathways in the IPZ-2 would be roadside drainage ditches which cross the Eramosa River, Blue Springs Creek, and several small tributaries.

3.3.1.3 IPZ-3

As stated in the Technical Rules, the IPZ-3 is assigned one or more area vulnerability factors ranging from 1 to 9, but not greater than the area vulnerability factor for the IPZ-2. Therefore, no areas within the IPZ-3 can be assigned an area vulnerability factor greater than 7.

The local attributes were used to assign the area vulnerability factors for the Eramosa River intake IPZ-3. As the Eramosa River intake IPZ-3 includes nearly all land area (95%) with generally consistent soils and hydrological conditions. As the area vulnerability factor can change within the IPZ-3, it is assigned to represent the relative impact of land cover on vulnerability with consideration given to transport pathways.

Land cover within the IPZ-3 consists primarily of natural areas (forests, wetlands, plantations), fringe agricultural areas, and very few built-up areas, namely in Rockwood, Everton, and Glenellen. Built-up areas would represent a higher vulnerability than agricultural and natural areas as they generate more direct runoff, contain possible drinking water threats, and are likely to include more transport pathways. However, ditches in Everton, and storm sewers and ditches in Rockwood, are used to convey stormwater to the river. These ditches and sewers could act as transport pathways for sediment and pollutants. The built-up areas within the IPZ-3 are a minimum of 8 km upstream of the intake, and therefore would not cause as great of a threat as those within the IPZ-2. As a result, all built-up areas within the IPZ-3 are assigned an area vulnerability factor of 5. This recognizes that the built-up areas represents the most vulnerable land within the IPZ-3, but is less vulnerable than similar built-up areas within the IPZ-2.

Agricultural areas and golf courses promote more infiltration and generate less direct runoff than urban areas and therefore were assigned a lower area vulnerability factor than built-up areas. As shown in Figure 27, the agricultural areas are mainly within the contributing areas of smaller tributaries, and around the perimeter of the IPZ-3, but not directly connected to the major water courses. The major water courses are buffered from agricultural runoff by natural vegetated areas. However, these areas contain drinking water threats associated with livestock, fertilizers, and pesticides, and possibly include transport pathways such as tile drains. As a result, the agricultural areas have a higher vulnerability than the natural areas and are assigned an area vulnerability factor of 3.

Natural areas make up the majority of the IPZ-3. These areas have high infiltration rates and very low runoff volumes, due to high permeability soils and bedrock, and hummocky and karst topography. Hummocky topography contains numerous surface depressions which collect and retain overland runoff, resulting in wetlands or kettle lakes that act as closed drainage systems. Karst topography forms sinkholes, caves and underground channels, and provides considerable infiltration capacity as well as potentially high travel times to the river. While they represent potential local transportation pathways, mapping of karst features with connection to surface water is not available and therefore the regional IPZ-3 mapping does not take into account this process. Although they are not mapped, there may be areas where karst features are transport pathways. As the natural areas in the IPZ-3 generally have very low overland runoff, no urban drainage and a low potential to contain drinking water threats, they are assigned the lowest area vulnerability factor of 1.

In summary, areas within the Eramosa River intake IPZ-3 are assigned an area vulnerability factor of 5 for urban areas, 3 for agricultural areas and golf courses, and 1 for natural areas.

3.3.2 Source Vulnerability Factor

The Technical Rules specify that Type C surface water intakes are assigned a source vulnerability factor ranging from 0.9 to 1. While there is no history of water quality concerns with the Eramosa River intake, it is a shallow intake and it is close the shoreline. In addition, surface water from the intake is recharged directly into groundwater through the Arkell Springs infiltration galleries and as a result any contaminant introduced to the intake could be introduced into groundwater very quickly if not observed early enough to shut down the intake. In consideration of the nature of the intake and the potential for contamination to be introduced into the groundwater the Eramosa River intake is assigned a source vulnerability factor of 1.

3.3.3 Vulnerability Score

The vulnerability scores for the IPZ-1, IPZ-2, and IPZ-3 are summarized in Table 6. The scores are calculated by multiplying the area vulnerability factors by the source vulnerability factors discussed in the previous sections.

Table 6: Summary of Vulnerability Scores for Eramosa River Intake IPZs

Intake Protection Zone	Area Vulnerability Factor	Source Vulnerability Factor	Vulnerability Score
IPZ-1	10	1	10
IPZ-2	7	1	7
IPZ-3 Built Up Areas	5	1	5
IPZ-3 Agricultural Areas	3	1	3
IPZ-3 Natural Areas	1	1	1

Figure 30 illustrates the vulnerability scoring for the IPZ-1 and IPZ-2 areas. Figure 31 illustrates the vulnerability scoring for the IPZ-3 area.

4.0 Groundwater Vulnerability – Carter Wells WHPA-E

4.1 INTRODUCTION

The Technical Rules require the delineation of separate vulnerable areas for groundwater wells where the well obtains water from a raw water supply that is groundwater under the direct influence (GUDI) of surface water as determined accordance with subsection 2 (2) of O. Reg. 170/03 (Drinking Water Systems) made under the Safe Drinking Water Act, 2002. These vulnerable areas are classified as WHPAs and described as follows:

1) Area WHPA-E, being the area delineated in accordance with the rules that apply to the delineation of an IPZ-2, as if an intake for the system were located in the surface water body influencing the well at the point closest in proximity to the well; and
2) Area WHPA-F, being the area delineated in accordance with the rules that apply to the delineation of an IPZ-3, as if an intake for the system were located in the surface water body influencing the well at the point closest in proximity to the well.

The Technical Rules provide some additional criteria relating to wells where WHPA-E and WHPA-F areas should or should not be delineated. As an example, a WHPA-F should only be delineated where a specific issue has been identified and that issue is located outside of any other vulnerable area (e.g., WHPA-A, WHPA-B, WHPA-C, WHPA-D or WHPA-E).

The City operates three systems that are considered to be GUDI systems: the Glen Collector system, Arkell 1 Well and the Carter Wells. The Glen Collector system and Arkell 1 Well are influenced by the Eramosa River, and therefore the IPZ-1, IPZ-2, and IPZ-3 areas delineated in the previous chapter are relevant for those systems.

The Carter Wells are located adjacent to Torrance Creek, a small watercourse draining an area of the southeast quadrant of the City of Guelph. The system consists of two bedrock wells located at a distance of approximately 3 m apart. The wells obtain their water from the shallow bedrock which, at this location, consists of the Guelph Formation.

4.1.1 Torrance Creek Subwatershed

Torrance Creek is a tributary of the Eramosa River and drains an estimated 10.6 km^2 of land in the southern part of Guelph and parts of Puslinch Township. Figure 32 illustrates the Carter wells in the southeastern area of Guelph in relation to Torrance Creek and the Torrance Creek subwatershed. Torrance Creek extends 2,900 m upstream of the Carter wells.

The subwatershed is divided by a municipal boundary along Victoria Road, with the City of Guelph on the west side and the Township of Puslinch on the east. Current land use is a mixture of agriculture, recreation (golf courses) and urban uses. The City of Guelph owns 53.5 ha (132 ac) of land surrounding the Carter wells and another 3.8 ha (9.5 ac) parcel near the mouth of the creek, which, other than the Carter wells and associated infrastructure, consists of vacant land. As reported in the Torrance Creek Subwatershed Study (TSH, 1997), there are significant terrestrial features from an environmental perspective including wetland area and upland woodlots. The wetland areas buffer existing urban and rural land uses from the stream and augment base flows. Furthermore, Torrance Creek has been reported to become dry for much of its length during years with low rainfall.

4.1.2 Carter Wells – GUDI Characterization

A source water characterization assessment (A&A, 2002) characterized the Carter Wells as GUDI with effective in situ filtration. These results were sufficient to waive the requirement to provide chemicallyassisted filtration for the wells. Golder (2006c) developed a Microbial Contamination Control Plan (MCCP) for the Carter Wells consistent with MOE requirements. This plan satisfies a number of provincial objectives, including the inventory and ranking of existing and potential sources of contamination and measures to protect the in situ filtration capability of the aquifer.

4.2 WHPA-E AND WHPA-F DELINEATION

4.2.1 Methodology

The methodology followed to delineate the WHPA-E and WHPA-F is the same as that followed to delineate the IPZ-2 and IPZ-3 vulnerable areas and is summarized below:

1) WHPA-E: The WHPA-E extends upstream, from the point in the watercourse closest to the well or the point of surface/groundwater interaction to a distance equal to the two-hour time-of-travel. The two-hour time-of-travel can be modified based on the response time required by the municipality. A lateral setback of 120 m or the extent of a Regulated Area (e.g., Provincially Significant Wetland or Regulated Floodplain), whichever is greater, is applied. It is analogous to the vulnerable areas for surface water intakes as described in the next section. Figure 32 illustrates the Regulated Area in the vicinity of Torrance Creek as mapped by the Grand River Conservation Authority.
2) WHPA-F: The WHPA-F includes all upstream watercourses, with a lateral setback of 120 m or the extent of the Regulated Area, whichever is greater. It is analogous to the vulnerable areas for surface water intakes.

The above methodology was applied to the IPZ-1, IPZ-2, and IPZ-3 for the Eramosa River intake in Chapter 3 of this report and is applied in this section for the Carter Wells.

4.2.2 WHPA-E

While the City did not complete a dye tracer test in Torrance Creek, typical water velocities in neighbouring watercourses during bankflow conditions have been estimated to range from 0.5 m/s to 1.0 m/s (AquaResource Inc., 2007b). Within this range of velocities, the time-of-travel along the 2,900 m reach of Creek would range from 0.8 to 1.6 hours. Based on this rough time-of-travel estimate, it is recommended that the entire length of Torrance Creek be considered within the WHPA-E. It is noted here that while the estimated water velocity is not based on hydraulic calculations, the relatively short length of the Creek warrants having the entire length included within the IPZ-2 area.

Figure 33 illustrates the WHPA-E area, delineated using the greater of a lateral setback of 120 m or the Regulated Area as defined by the GRCA. In the vicinity of Torrance Creek, the Regulated Area represents provincially regulated wetlands.

Nearly all of the land area identified as WHPA-E is already contained within the WHPA-B for the Carter and Burke Wells (see Section 2).

4.2.3 WHPA-F

There is no need to delineate a WHPA-F, as the WHPA-E has been delineated to include all upstream watercourses.

4.3 VULNERABILITY SCORE

The vulnerability score for the WHPA-E is computed by multiplying the area vulnerability factor and the source vulnerability factor as discussed in the previous chapter for intake protection zones.

4.3.1 Area Vulnerability Factor

The Carter Wells WHPA-E consists primarily of land and therefore has a low potential for direct surface water runoff connection.

The WHPA-E is on the outskirts of the City of Guelph, within the Torrance Creek subwatershed. Land cover within the WHPA-E consists of mainly natural areas (61%), including forests, wetlands and plantations. These natural areas reduce direct runoff, promote infiltration and provide buffered areas around Torrance Creek. Current built-up areas represent approximately 8% of the WHPA-E but new subdivisions are proposed on vacant land west of Victoria Road in the subwatershed and will contribute urban runoff into the Creek. The remaining land areas within the WHPA-E consist of agricultural lands and two golf courses (26%). Finally, 5% of the total area of the subwatershed is comprised of surface water. While land areas are somewhat buffered from Torrance Creek by natural areas, land uses are associated with fertilizer and chemical use. Overall, the land cover within the WHPA-E indicates a higher vulnerability when compared to the IPZ-2 for the Eramosa River intake.

With respect to transport pathways, several existing and proposed urban subdivisions discharge or will discharge stormwater into the Creek's wetlands. As discussed in the Torrance Creek Subwatershed Study (TSHI, 1997), stormwater management facilities have been (or will be) designed to fairly strict environmental standards; however, the stormwater discharges do represent transport pathways. Drainage outlets from the golf courses have not been verified in the field.

Based on the role of agricultural land, urban stormwater drainage, and golf courses, with possible transport pathways, the Carter Wells WHPA-E is assigned an area vulnerability factor of 8. This value is reasonable given that the area is more vulnerable than the Eramosa River intake IPZ-2 which was assigned a factor of 7.

4.3.2 Source Vulnerability Factor

While the Technical Rules do not directly specify how to estimate a source vulnerability factor for a WHPA-E, the MOE has indicated that the factors that need to be considered for the source vulnerability factor for a GUDI are the same as for any intake. Given this, Torrance Creek should be considered similar to that of a Type C (River) Intake, and therefore the source vulnerability factor must be between 0.9 and 1. While Torrance Creek is a very small and shallow stream in the vicinity of the Carter Wells, the Carter Wells do not receive all of their water from the Creek. In fact, the wells obtain a large proportion of their supply from the bedrock aquifer and a smaller proportion as infiltration from the Creek as evidenced by continuous water taking even when Torrance Creek has been observed to be dry during drought periods. As a result, if a dissolved contaminant was introduced into the subsurface from Torrance Creek, that contaminant would be diluted by mixing with bedrock groundwater.

The Carter Wells source water characterization assessment (A&A, 2002) concluded that in situ filtration was effective. As a result, microbial contaminants introduced in Torrance Creek would be removed by filtration in the subsurface and would not travel to the well.

As a result of both dilution of dissolved chemicals and filtration of microbial contaminants, the Carter Wells are assigned source vulnerability factor of 0.9.

4.3.3 Vulnerability Score

The vulnerability score of the Carter Wells WHPA-E is calculated by multiplying the area vulnerability factor (8) by the source vulnerability factor (0.9). This results in a vulnerability score of 7.2, rounded to 7, as illustrated on Figure 34.

5.0 Conclusions and Recommendations

5.1 CONCLUSIONS

This study was undertaken by the City of Guelph to meet its requirements under the Clean Water Act relating to the vulnerability of groundwater and surface water supplies. This work is consistent with the Ministry of Environment's Technical Rules (MOE, 2009) for the delineation of wellhead protection areas (WHPAs) for groundwater wells and intake protection zones (IPZs) for surface water intakes and the assignment of vulnerable scores for areas within the WHPAs and IPZs.

5.1.1 Groundwater Vulnerability

5.1.1.1 Vulnerable Areas

Wellhead protection areas (WHPAs) for the City's current and planned wells were delineated using a particle-tracking technique and the groundwater flow model currently being developed in support of the City's Tier Three Local Area Risk Assessment. These WHPAs include the WHPA-A, WHPA-B, WHPA-C and WHPA-D areas as required under the Technical Rules. The WHPAs are estimated based on the City's projected water demand for 2031.

A large portion of the City's land area was found to be contained within the 2-year WHPA (WHPA-B) and most of the land area is contained within the 5-year WHPA (WHPA-C).

There is uncertainty associated with the delineation of time-of-travel based capture zones and WHPAs and therefore the areas are estimated conservatively. While these areas are delineated using the best information and interpretation available, the exact time-of-travel associated with potential contaminants cannot be estimated exactly. The development of groundwater protection policies that can be applied over the broader landscape is prudent to address this uncertainty; these policies should be focused on land areas that have a reasonable likelihood to be contained within the capture zone for a municipal supply well.

5.1.1.2 Vulnerability Mapping and Scoring

Groundwater vulnerability maps are created to identify areas where the groundwater supply aquifer has a high, medium or low vulnerability to contamination from ground surface. For this study a modified version of the Groundwater Intrinsic Susceptibility Index (GwISI) was developed which takes into account a map of overburden thickness in addition to the estimated GwISI value at wells (e.g., water well records, municipal wells). The modified version of the GwISI method is implemented to better represent the influence of areas having low or high overburden thickness where there are few estimates of the ISI value from which to interpolate.

This study creates a GwISI map for the top of bedrock. Although the City's main water supply aquifer is within the Gasport Formation, which is located underneath the Vinemount/Eramosa aquitard, the City does have several wells that are open across the shallower Guelph Formation, or open across both the Guelph and Gasport Formations. Establishing the vulnerability at the top of bedrock is justified from both the precautionary perspective, as well as from field evidence that suggests that where contamination is present at the top of bedrock there is a potential for this contamination to migrate to the water supply aquifer through fractures in bedrock. The presence of sand and gravel pits, bedrock quarries and sanitary or storm sewers near or beneath the top of bedrock surface are also considered when assigning the relative groundwater vulnerability. Where these preferential pathways exist, the groundwater vulnerability is increased from low to moderate, or from moderate to high.

This study follows the MOE's vulnerability scoring methodology as written in the Technical Rules to assign scores to vulnerable areas within the City's WHPAs. The results identify large areas of the City having high vulnerability scores equal to 8 or 10. These areas with high vulnerability are typically located within the WHPA-A (e.g., 100 m) or WHPA-B (e.g., 2-year time-of-travel) areas and have relatively thin overburden. These results are intuitive in that where the bedrock is close to ground surface it is more vulnerable to contamination.

5.1.2 Surface Water Vulnerability

The City operates a surface water intake on the Eramosa River. Water is pumped from this intake on a seasonal basis and introduced into groundwater through an artificial groundwater recharge system at the Arkell Spring Grounds. Similar to the Groundwater Vulnerability Assessment, a Surface Water Vulnerability Assessment is required under the Technical Rules for surface water intakes to delineate both the vulnerable areas for a surface water intake and to assign vulnerability scores for those areas.

5.1.2.1 Vulnerable Areas

Following the MOE's Guidance and the Technical Rules (MOE, 2009) the following vulnerable areas are delineated for the Eramosa River intake:

1) Intake Protection Zone 1 (IPZ-1) - This vulnerable area is based on a semi-circle of 200 m radius, extending upstream of the intake. The IPZ-1 intake is also extended downstream to the Arkell weir/impoundment below the intake. A setback of 120 m or the extent of the Conservation Authority Regulated Area is applied.
2) Intake Protection Zone 2 (IPZ-2) - The IPZ-2 vulnerable area is delineated beginning at the IPZ-1 and extending upstream of Eden Mills to the Indian Road Bridge across the Eramosa River. During high flow conditions, the time-of-travel from this location to the intake is estimated to be approximately 6 hours. Delineation of the IPZ-2 was based on the results of a dye-tracer test scaled up to a higher flow using a hydraulic model. While the Technical Rules require a minimum two-hour time-of-travel criteria, the City prefers that the longer time period be used to represent the IPZ-2 reflecting the amount of time that might be needed for the municipality to respond to an upstream spill.
3) Intake Protection Zone 3 (IPZ-3) - The IPZ-3 vulnerable area is delineated to include all watercourses providing water to the intake, buffered to either 120 metres or the Conservation Authority Regulated Area, whichever is greater. These watercourses include the Eramosa River, Blue Springs Creek, and their tributaries.

The Technical Rules provide a range of vulnerability scores for IPZ-1, IPZ-2, and IPZ-3 and technical teams are required to consider a series of factors when assigning these scores. These factors include: the percentage of area within the IPZ-2 or IPZ-3 that is composed of land; the land cover, soil type, permeability, and slope; and the hydrological and hydrogeological conditions that contribute water to the area.

5.1.2.2 Vulnerability Scoring

Based on the above discussion, Table 7 lists the vulnerability scores assigned as part of this study:

Table 7: Vulnerability Scores for Eramosa River Intake IPZs

Intake Protection Zone	Vulnerability Score
IPZ-1	10
IPZ-2	7
IPZ-3 Built Up Areas	5
IPZ-3 Agricultural Areas	3
IPZ-3 Natural Areas	1

The vulnerability scores reflect both the guidelines provided in the Technical Rules as well as a practical assessment of the relative vulnerability of the lands contributing water to the Eramosa River intake.

5.1.3 GUDI Well Vulnerability

The Technical Rules require the delineation of separate vulnerable areas for groundwater wells where the well obtains water from a raw water supply that is groundwater under the direct influence (GUDI) of surface water as determined accordance with subsection 2 (2) of O. Reg. 170/03 (Drinking Water Systems) made under the Safe Drinking Water Act, 2002.

The City's Carter Wells are considered to be GUDI systems and are located adjacent to Torrance Creek, a small watercourse draining an area of the southeast quadrant of the City of Guelph. The system consists of two bedrock wells located at a distance of about 3 m apart. The wells obtain their water from the shallow bedrock which, at this location, consists of the Guelph Formation.

5.1.3.1 Vulnerable Areas

The Technical Rules require that the WHPA-E and WHPA-F vulnerable areas be delineated for GUDI systems. These areas are analogous to the IPZ-2 and IPZ-3 vulnerable areas and are summarized below:

1) WHPA-E: Based on a rough time-of-travel estimate, it was recommended that the entire length of Torrance Creek be considered within the WHPA-E for the Carter Wells. It is noted here that while the estimated water velocity is not based on hydraulic calculation the relatively short length of the Creek warrants having the entire length included within the WHPA-E area. The WHPA-E is further delineated using the greater of a lateral setback of 120 m or the Regulated Area as defined by the GRCA.
2) WHPA-F: A WHPA-F was not delineated for the Carter Wells, as the WHPA-E includes all of Torrance Creek.

5.1.3.2 Vulnerability Scoring

A vulnerable score of 7 was assigned to the WHPA-E for the Carter Wells.

5.1.4 Uncertainty Factor

The Technical Rules require that an analysis of uncertainty be carried out for the groundwater and surface water vulnerability study, and this analysis should assign an uncertainty factor of "high" or "low" to each of the vulnerable areas. The intent of the Technical Rules is to identify situations where a reasonable amount of additional work could significantly increase the certainty of the vulnerability assessment. While there are various sources of uncertainty as described in this report, the uncertainty factor for the groundwater and surface water vulnerable areas is "low". The results of this assessment are only likely to change with significantly more technical work which may only be achieved with significantly more monitoring over large areas for many years. This conclusion is based on an assessment of several factors to be considered as required under the Technical Rules as listed in the following table.

Table 8: Uncertainty Analysis Factors (Part I.4 Rule 14)

Uncertainty Assessment Factors	**Description**
14(1) The distribution, variability, quality and relevance of data used in the preparation of the assessment report.	The groundwater and surface water vulnerability assessments both rely on a detailed characterization of a large amount of data collected over a long period of time.
14(2) The ability of the methods and models used to accurately reflect the flow processes in the hydrological system.	The groundwater flow model has been shown to reflect groundwater flow processes both regionally and locally within the City by representing both water levels and flows to surface water under pumping conditions. The capture zones delineated in this study are similar to those delineated using other models. The surface water model used to delineate the IPZ's simulated flow velocities similar to those measured using a dye tracer test.
14(3) The quality assurance and quality control procedures applied.	Each step of the model development process relied on data that had been collected and/or reviewed by professional engineers or geoscientists.
14(4) The extent and level of calibration and validation achieved for models used or calculations or general assessments completed.	The groundwater model calibration process included both steady-state and transient datasets and demonstrated that the final parameters derived are both consistent with field observations and those that would be expected based on the conceptual model.
14(5) For the purpose of subrule 13(1), the accuracy to which the groundwater vulnerability categories effectively assess the relative vulnerability of the underlying hydrogeological features.	The groundwater vulnerability categories (e.g., high, medium, and low) effectively assess the relative vulnerability of the underlying hydrogeological features. Many areas within the capture zones of the City's wells are identified as having a high vulnerability and this is consistent with occurrences of various contaminants which continue to be closely monitored by the City.
14(6) For the purpose of subrule 13(4), the accuracy to which the area vulnerability factor and the source vulnerability factor effectively assesses the relative vulnerability of the hydrological features.	The surface water vulnerability categories effectively assess the relative vulnerability of the hydrological features. With respect to the City's Eramosa River intake, much of the IPZ-2 and IPZ-3 areas are contained within rural areas with naturally vegetated wetlands and forests buffering the river and its tributaries.

5.2 RECOMMENDATIONS

The City's technical efforts under the Clean Water Act will continue into the future as the City completes its current work relating to water quality and quantity and as part of the future process of continuous updates and improvement. The recommendations in the following sections are based on knowledge gathered during this study relating to both groundwater vulnerability and surface water vulnerability. The vulnerability scores assigned in this study were used by the City for its Water Quality Threats Assessment, and it is expected that that this assessment will provide a larger number of recommendations to the City with respect to the identification and assessment of threats to drinking water as well as recommendations to the City for the management of these threats.

5.2.1 Groundwater Vulnerability

The groundwater vulnerability assessment includes the delineation of WHPAs, the preparation of groundwater vulnerability maps, and the vulnerability scoring. With respect to the delineation of WHPAs, the City is encouraged to continue its efforts in the future to better understand both the configuration of capture zones and the time-of-travel within these zones. Specific recommendations are as follows:

1) Updates to the Groundwater Flow Model. The City's groundwater flow model was developed as part of the Tier Three Local Area Risk Assessment to represent the current conceptual model of the hydrogeology within and outside of the City. This conceptual model will continue to evolve in the future with the collection of new data as the City studies specific areas in greater detail and, as others, such as the University of Guelph, study the hydrogeology of the area. At intervals consistent with updates to the proposed Source Protection Plan, the City should revise the numerical groundwater flow model and re-evaluate capture zones with the new information as required. Upon completion, the Tier Three report will provide the City with additional recommendations on how to improve the groundwater flow model in the future.

2) Factors Influencing Time-of-Travel Estimates. The time-of-travel estimates used to delineate capture zones and WHPAs are particularly sensitive to porosity estimates. In addition, some of the key assumptions built into the conceptual model, including the high permeability production zone, also have a significant impact on the time-of-travel estimates. The uncertainties associated with porosity estimates and hydraulic conductivity zones will never be eliminated; however, in the future it is expected that the evolution of science and the understanding of the hydrogeology will improve and the City should continue to revise the time-of-travel estimates consistent with the updates to the numerical model.

3) Studies on Aquifer Vulnerability. This study implemented a relatively simple method to map groundwater vulnerability across the study area. The Technical Rules support the concept of implementing new or modified methods to map vulnerability, and there is an opportunity for the City to further develop its mapping of groundwater vulnerability by studying and assessing more information. Additional information would include analysis of groundwater quality in shallow and deep bedrock for parameters such as chloride to identify areas potentially being impacted from shallow groundwater. The City may also revisit the Surface to Well Advection Time (SWAT) approach for mapping of groundwater vulnerability mapping in conjunction with local studies on interactions between shallow and deep groundwater.

5.2.2 Surface Water Vulnerability

This study follows the MOE's Guidance and Technical Rules for completing surface water vulnerability assessments. While there is some uncertainty with respect to the time-of-travel for contaminants to reach the Eramosa River intake, there is certainty relating to the potential for contamination in any area upstream of the intake to reach the intake. In this respect, there are no recommendations with respect to the delineation of intake protection zones.

The vulnerability scoring assigned to the IPZ-1, IPZ-2, and IPZ-3 areas is based on the Technical Rules, however there is considerable latitude given to the City when assigning specific scores to the IPZ-2 and IPZ-3 areas. The scoring methodology used in this study generally reflects the relative vulnerability of these areas, but there may be a benefit for the City to revisit these scores at a later date if the Province publishes further guidance.

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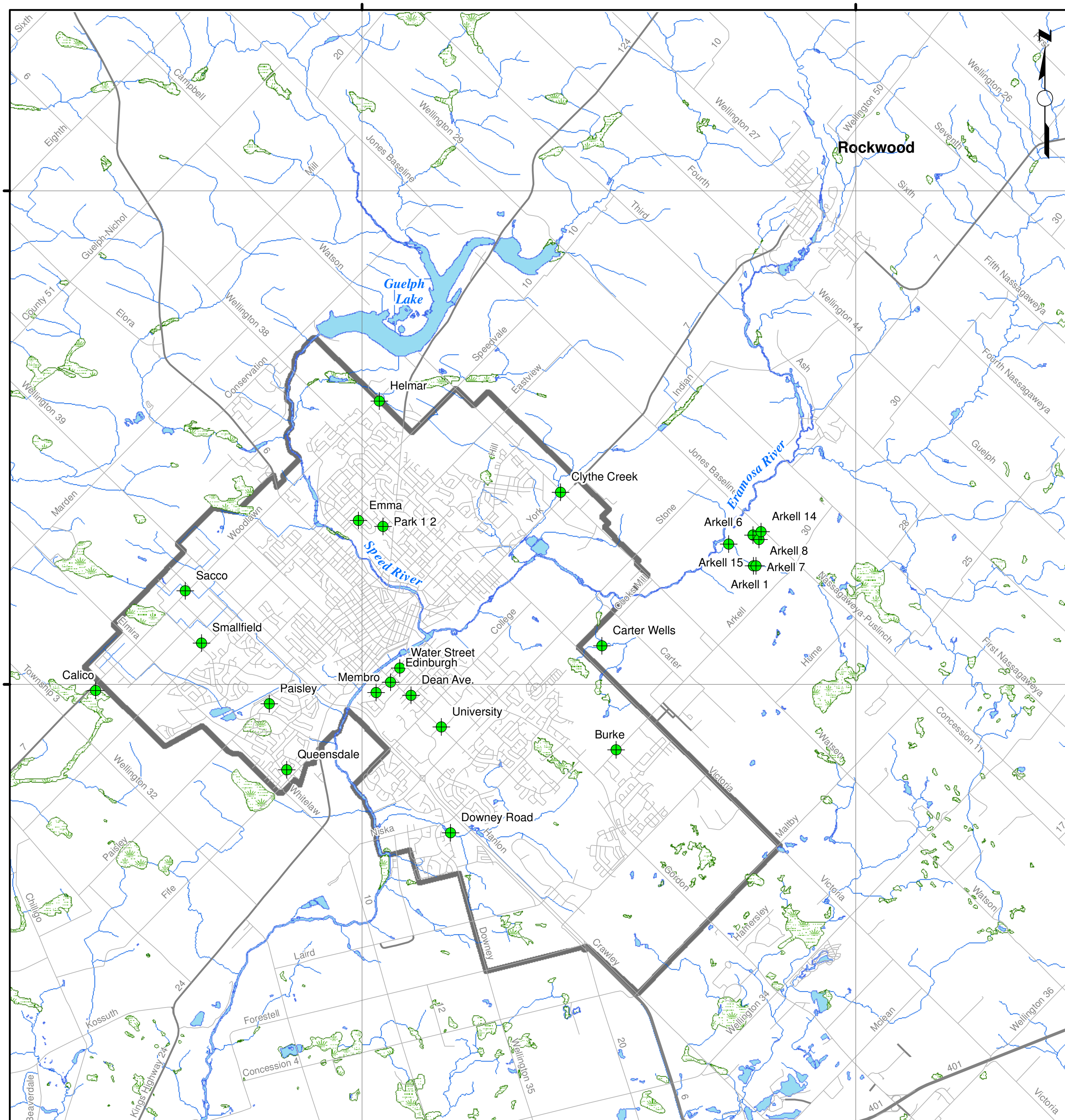

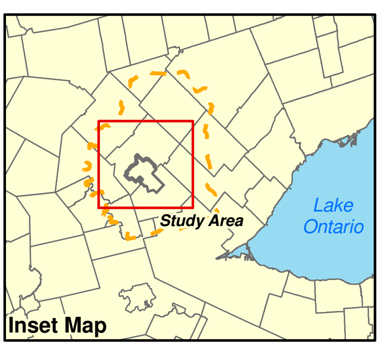

LEGEND

- Water Supply Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary

Scale 1:110,000

0 2.5 5

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83

Map Version: 1; Map Date: 10-Mar-10; Created By: CC

City of Guelph Source Water Protection Project

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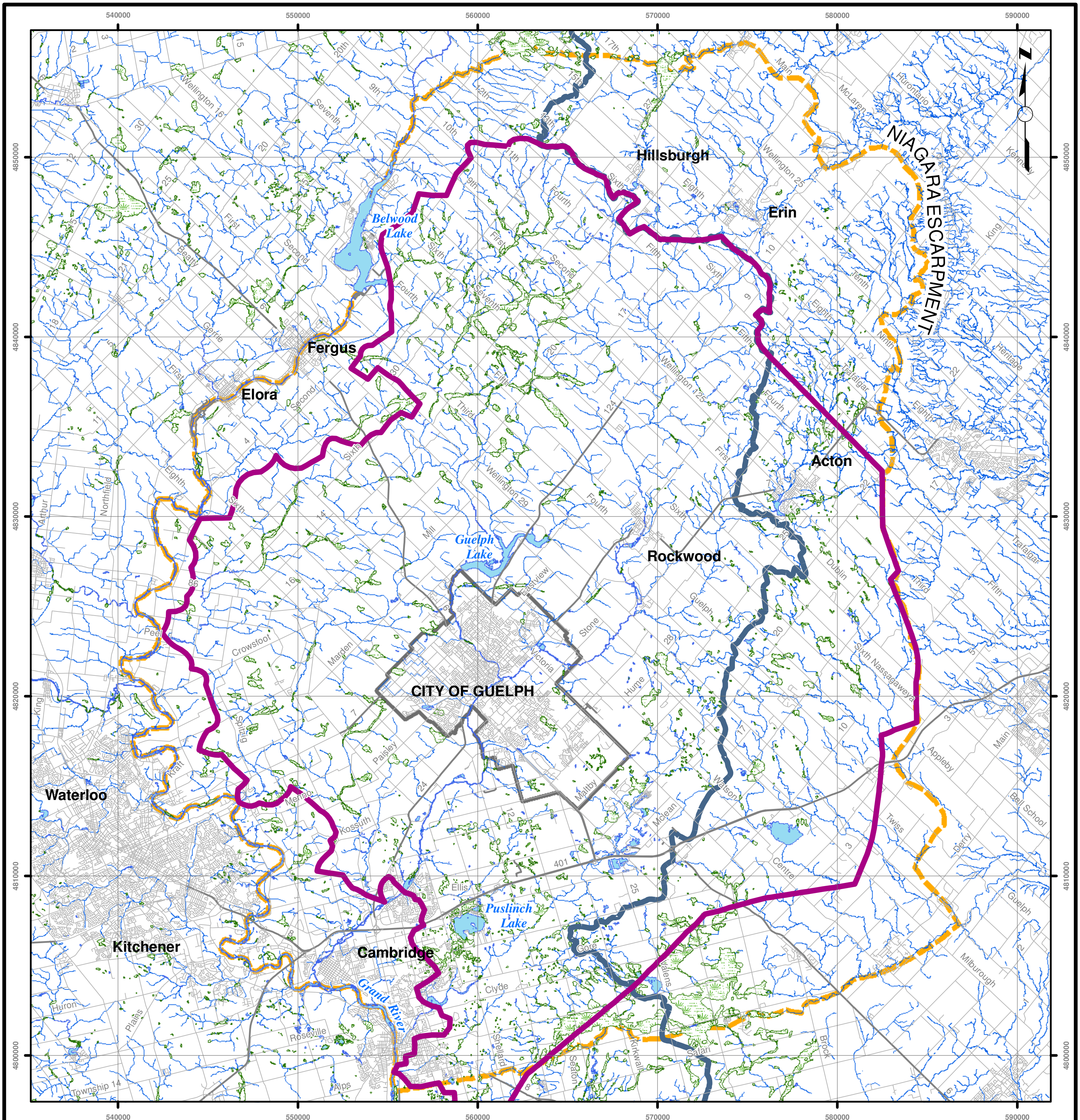
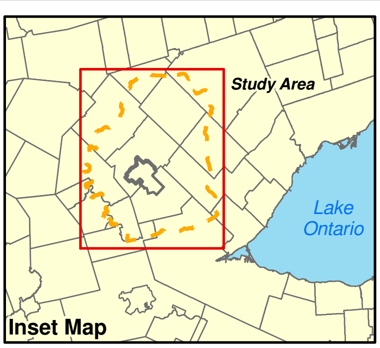
Figure 1.

City of Guelph Pumping Wells





LEGEND

- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- G-P Model Boundary
- Tier Three Model Boundary
- GRCA Watershed Boundary

Scale 1:290,000

0 2.5 5 10 15

Kilometres

REFERENCES:
Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 10-Mar-10; Created By: CC

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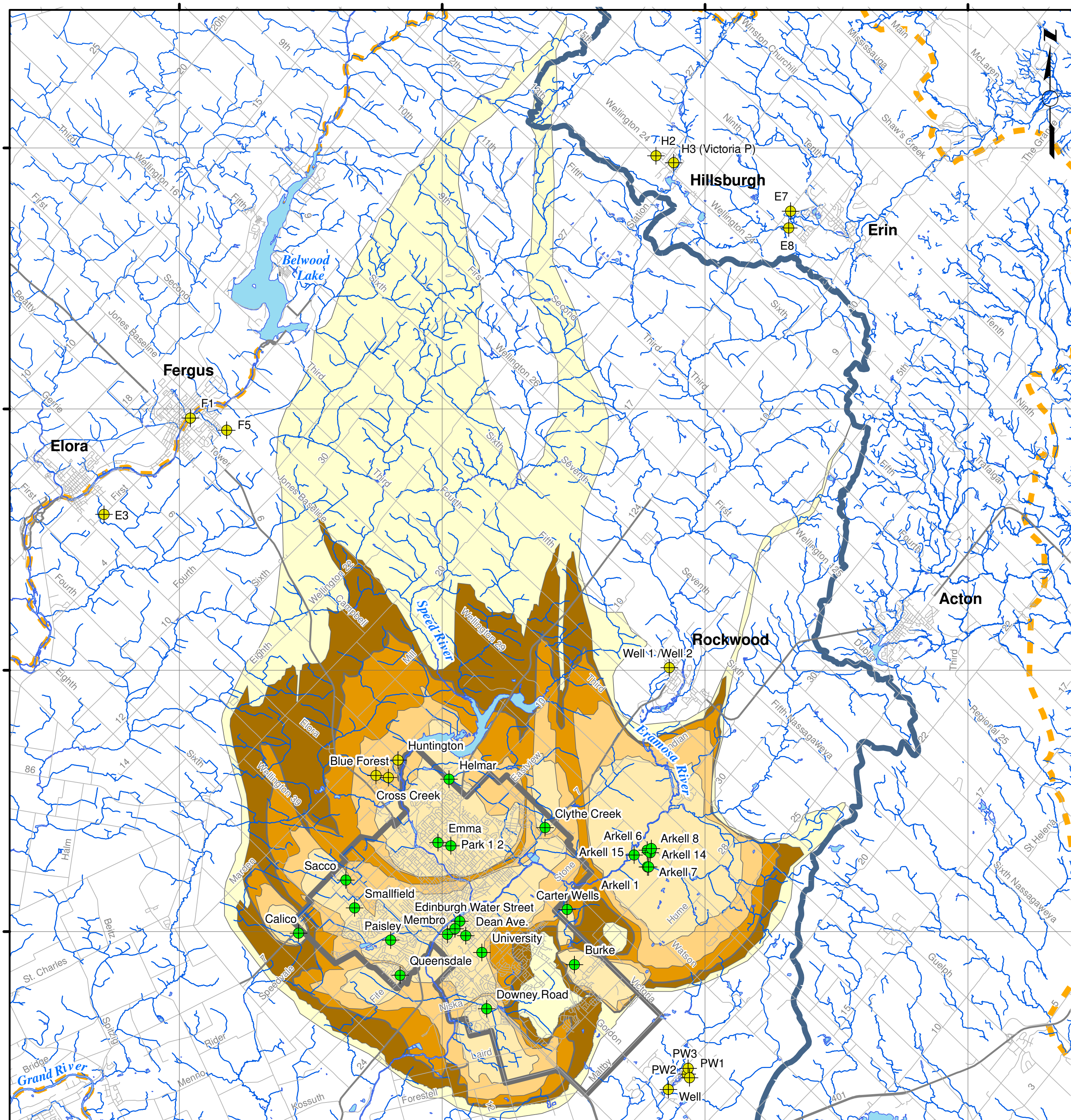
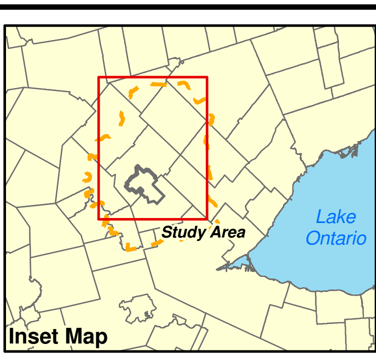
Figure 2.
Groundwater Flow Model Boundaries





LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Open Water
- GRCA Watershed Boundary
- Tier 3 Study Area Boundary
- City of Guelph Boundary

Capture Zones

- 2 year
- 5 year
- 10 year
- 25 year
- Steady State

Scale 1:207,500

0 2.5 5 10

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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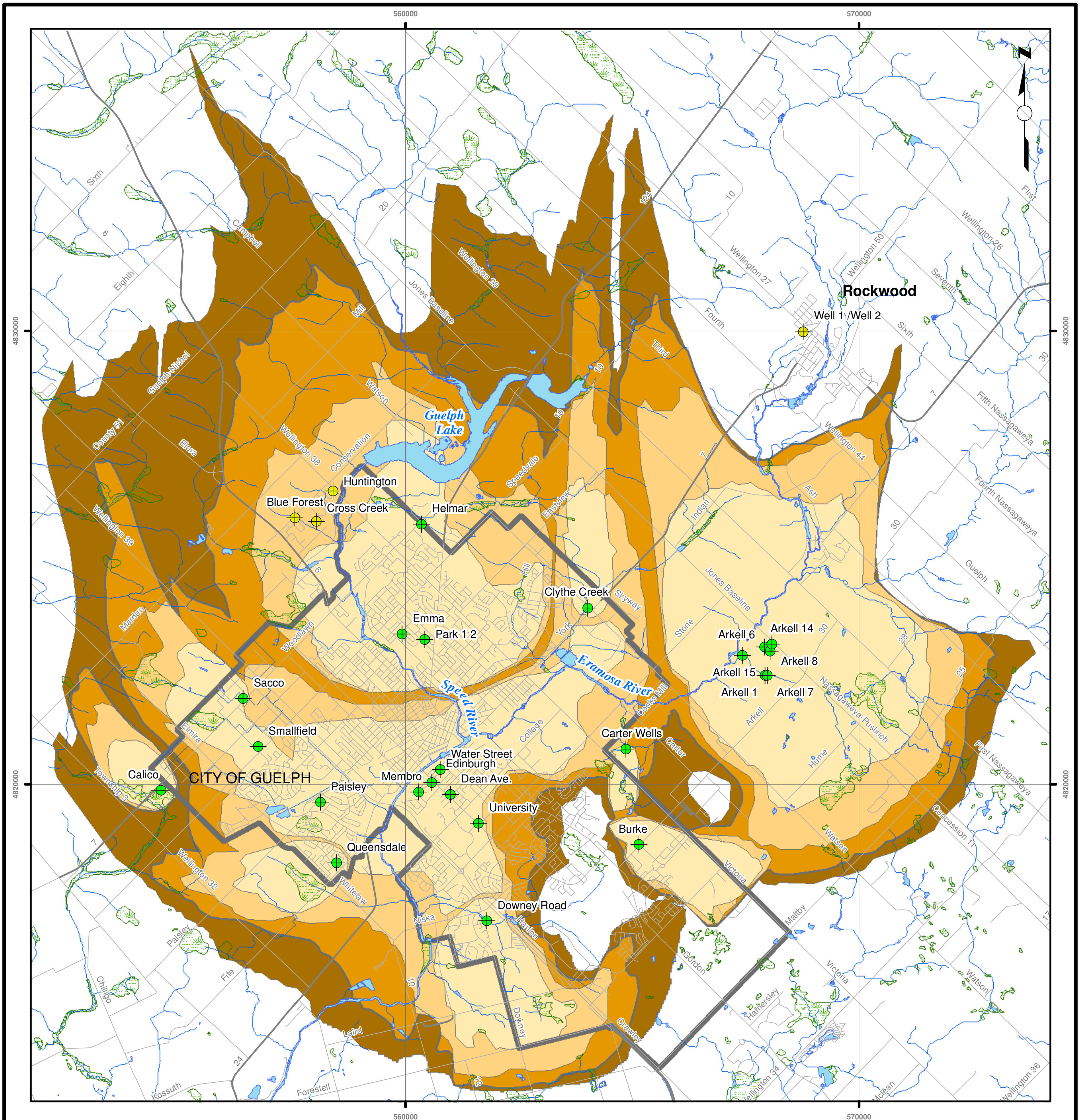
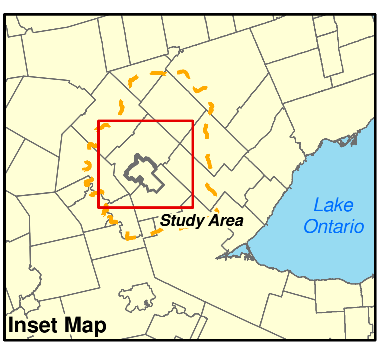
Figure 3.

Capture Zones





LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary

Capture Zones

- 2 year
- 5 year
- 10 year
- 25 year

Scale 1:115,000

0 2.5 5 Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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Map Version: 2; Map Date: 4-Mar-10; Created By: CC

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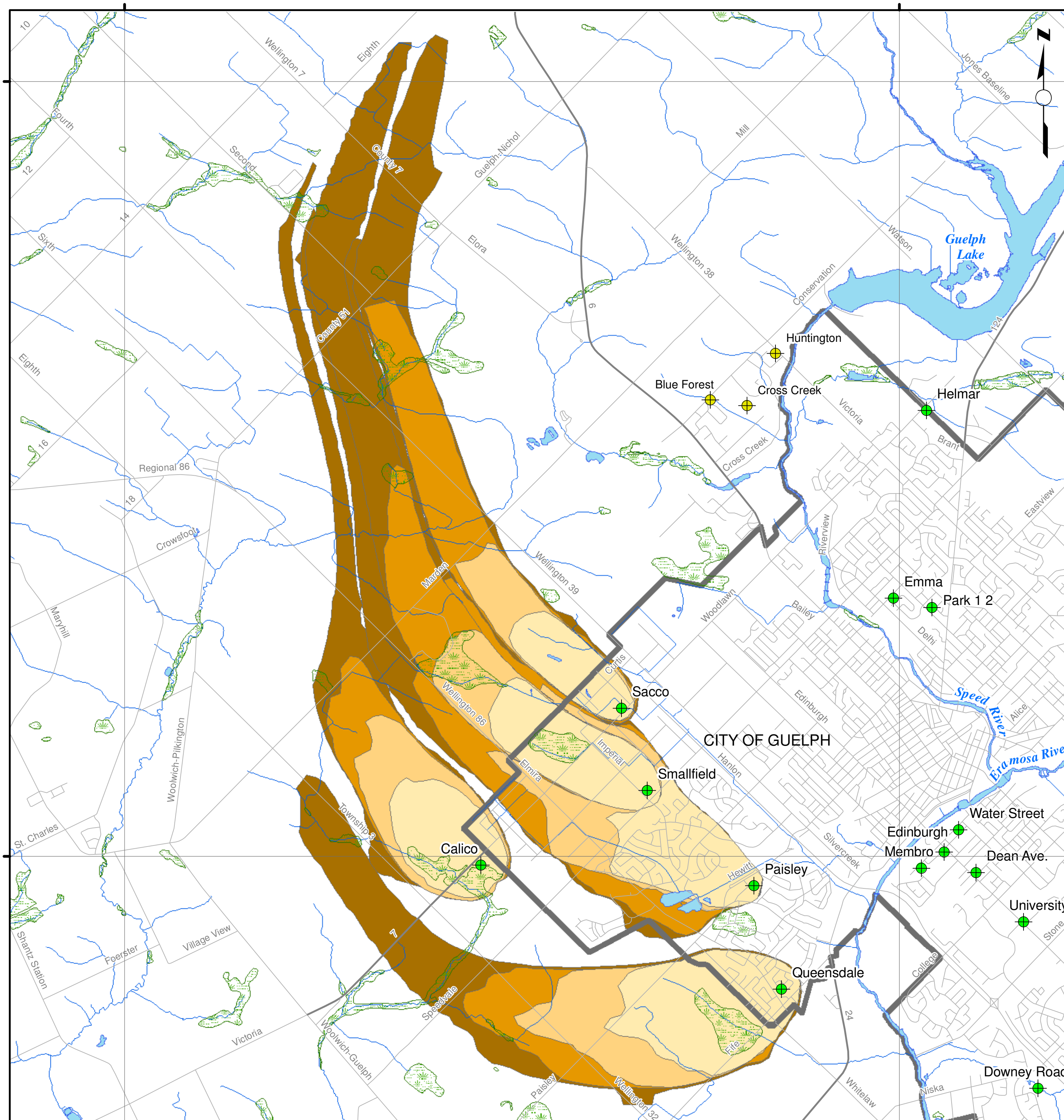
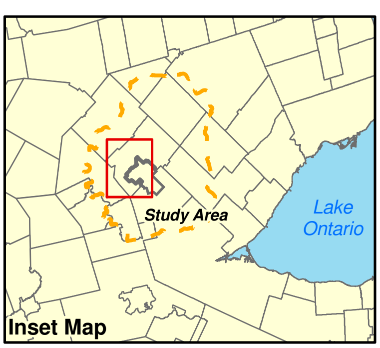
Figure 4.

2,5,10,25 Year Capture Zones





LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary

Capture Zones

- 2 year
- 5 year
- 10 year
- 25 year

Scale 1:70,000

0 1.25 2.5 Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 2; Map Date: 10-Mar-10; Created By: CC

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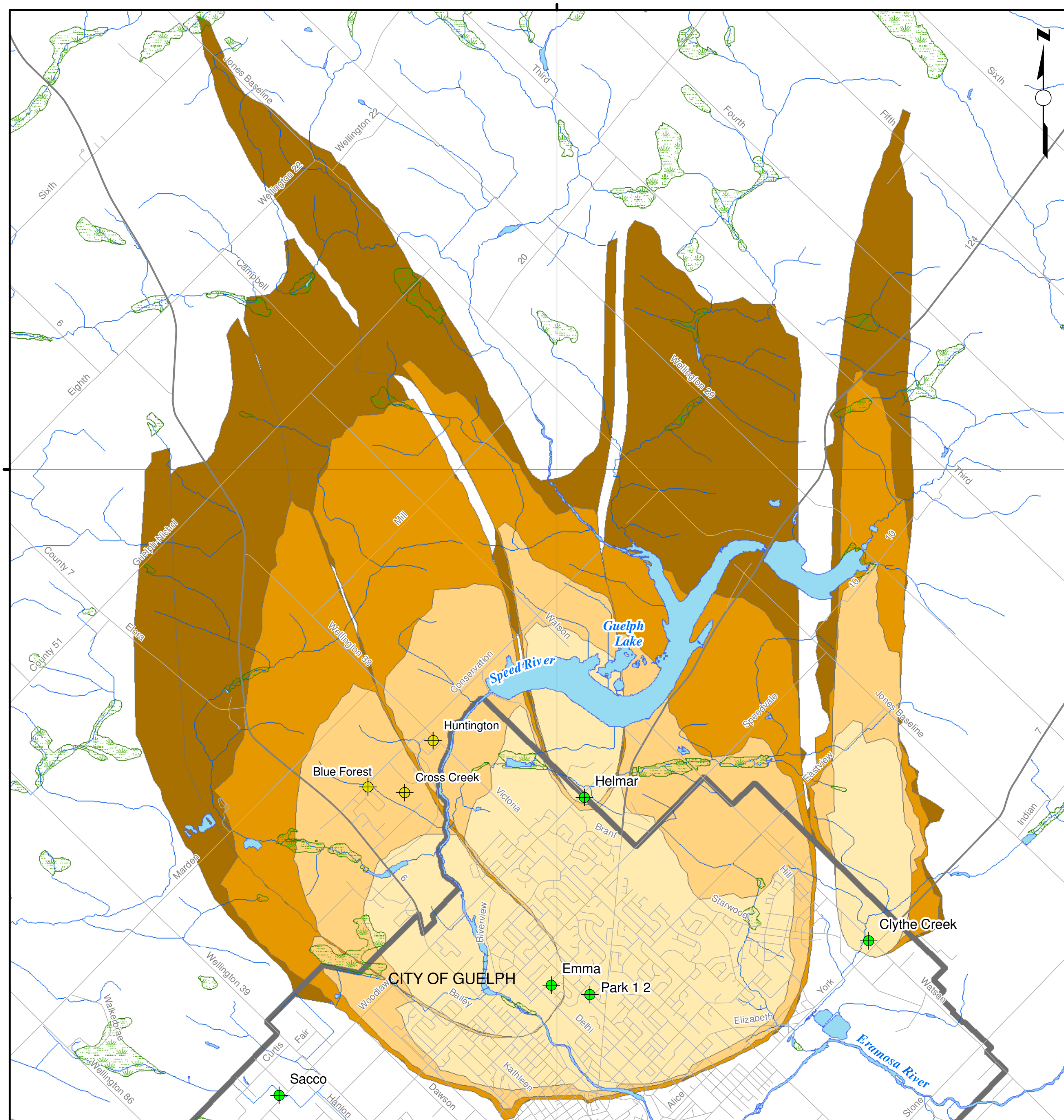
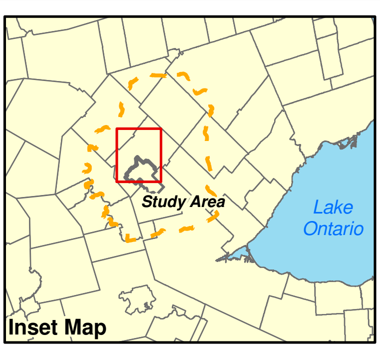
Figure 5.
Capture Zones
Northwest Quadrant

Fig5_CZ_NW.mxd

Project: 2006005_GuelphSourceProtection





LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary

Capture Zones

- 2 year
- 5 year
- 10 year
- 25 year

Scale 1:70,000

0 1.25 2.5

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 2; Map Date: 10-Mar-10; Created By: CC

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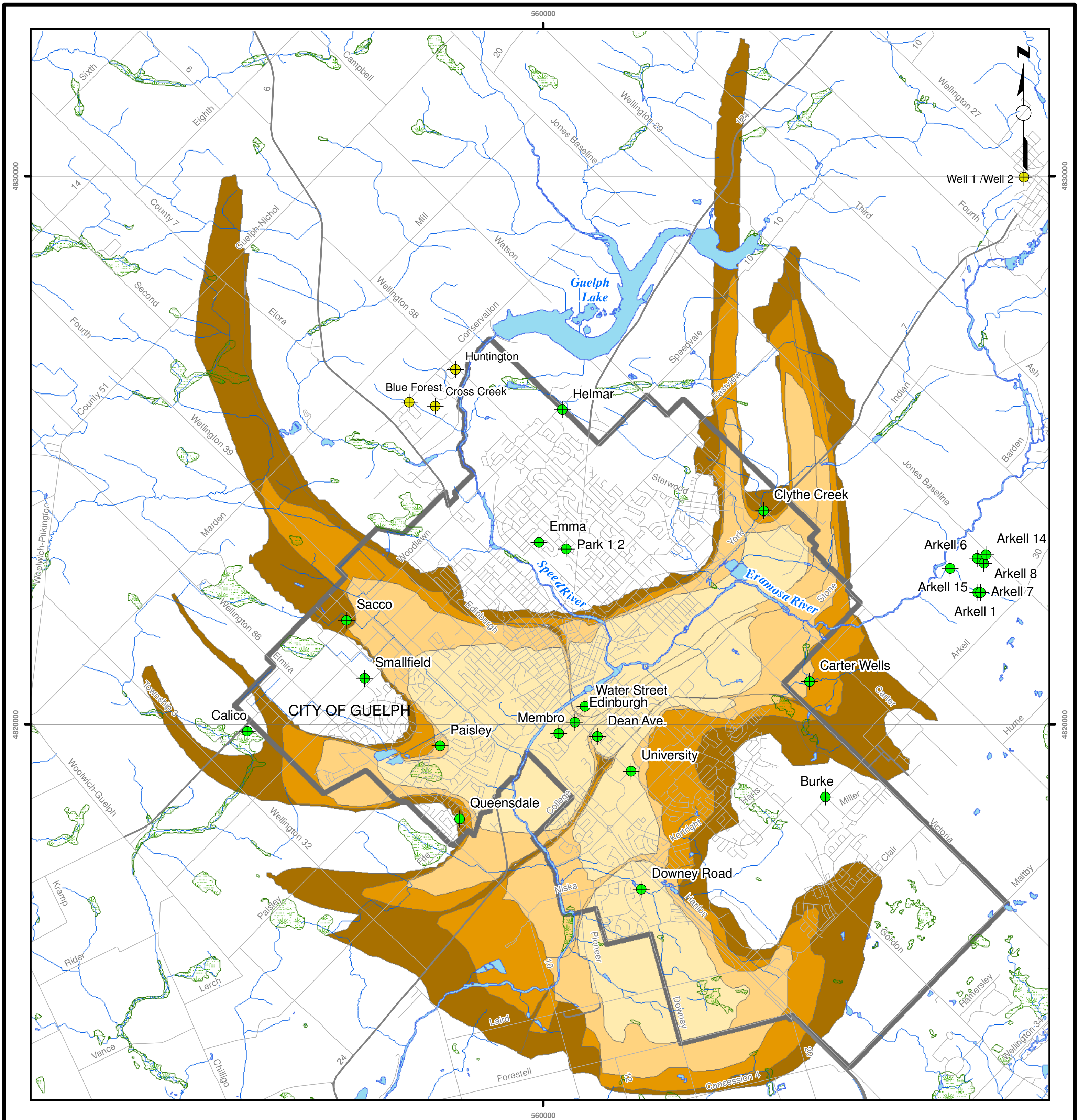
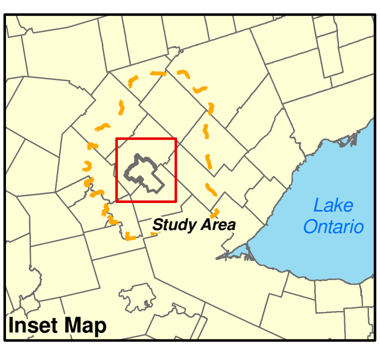
Figure 6.

Capture Zones
Northeast Quadrant





LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary

Capture Zones

- 2 year
- 5 year
- 10 year
- 25 year

Scale 1:95,000

0 1.25 2.5 Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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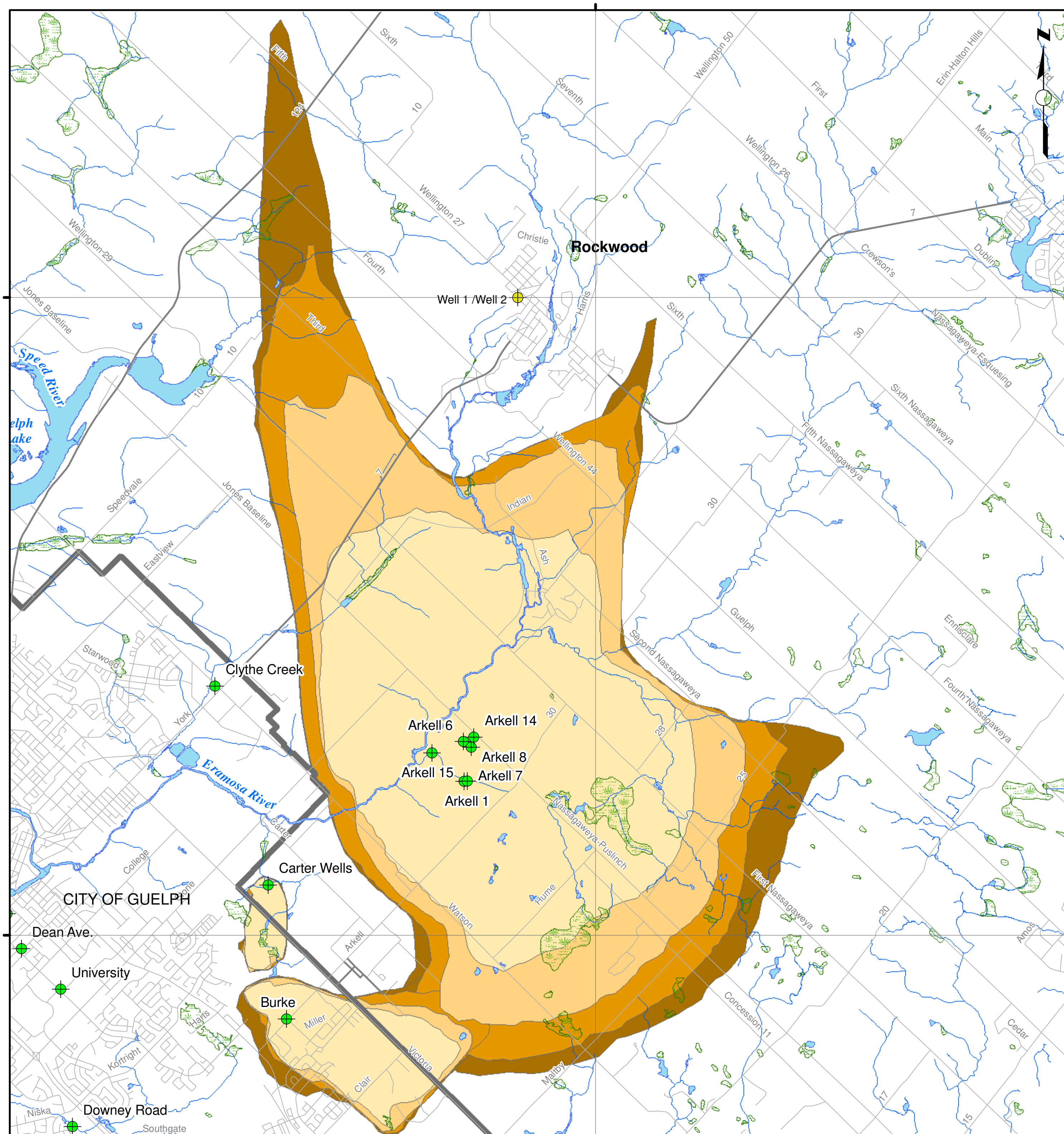
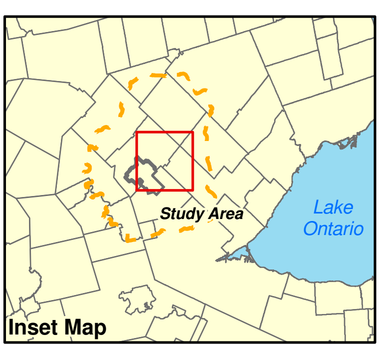
Figure 7.

Capture Zones
Southwest Quadrant

Fig7_CZ_SW.mxd

Project: 2006005_GuelphSourceProtection





LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary

Capture Zones

- 2 year
- 5 year
- 10 year
- 25 year

Scale 1:85,000

0 1.25 2.5 Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 2; Map Date: 10-Mar-10; Created By: CC

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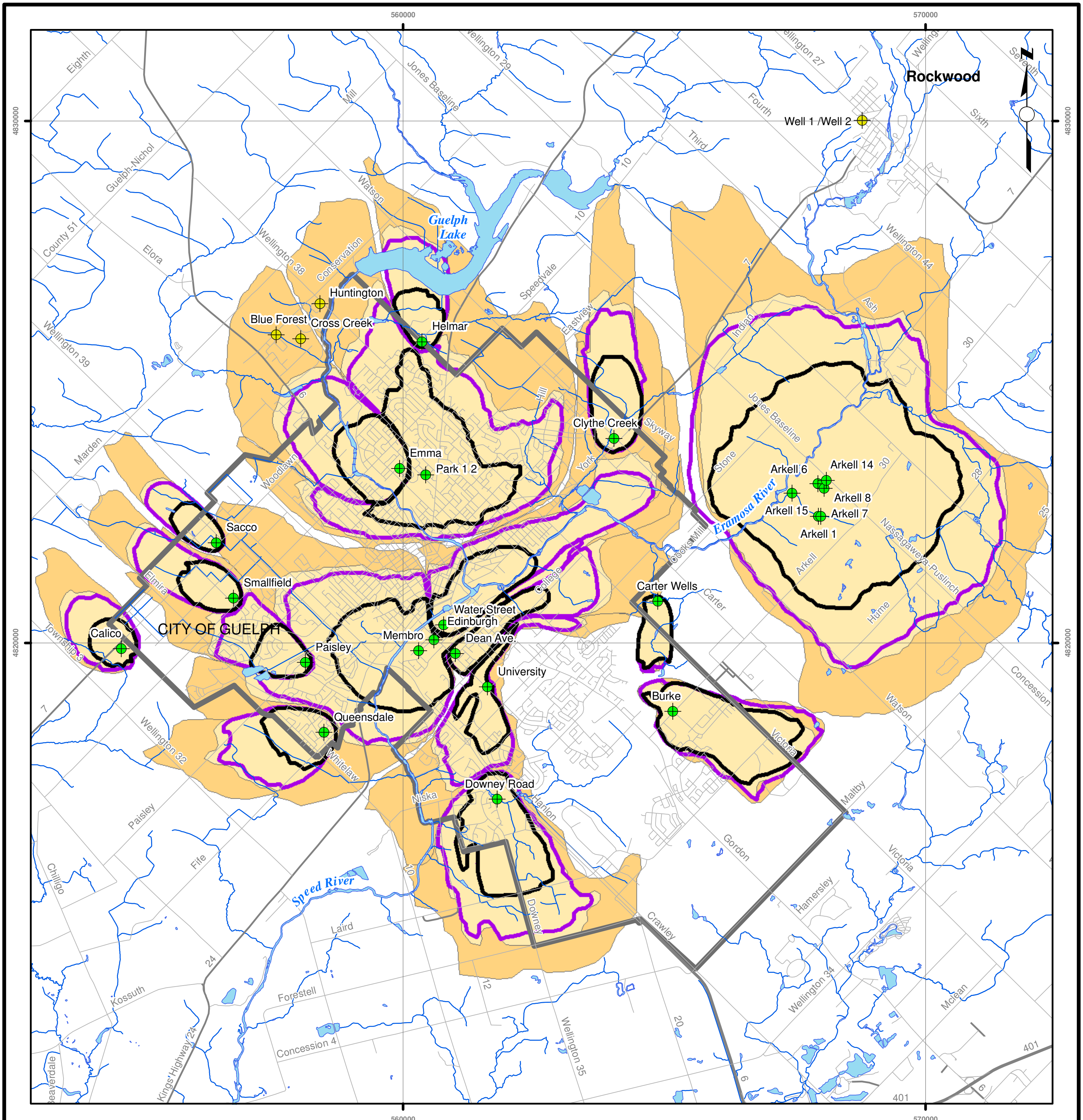
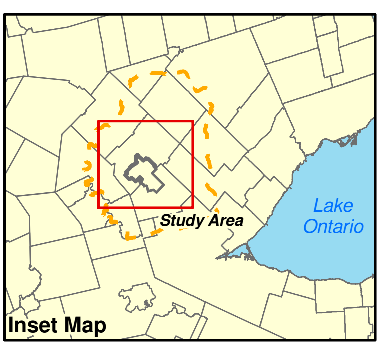
Figure 8.
Capture Zones
Southeast Quadrant





LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary

Capture Zones
- 2 year
- 5 year

Sensitivity Analysis
- 2 year
- 5 year

Scale 1:100,000

0 2.5 5

Kilometres

City of Guelph Source Water Protection Project

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REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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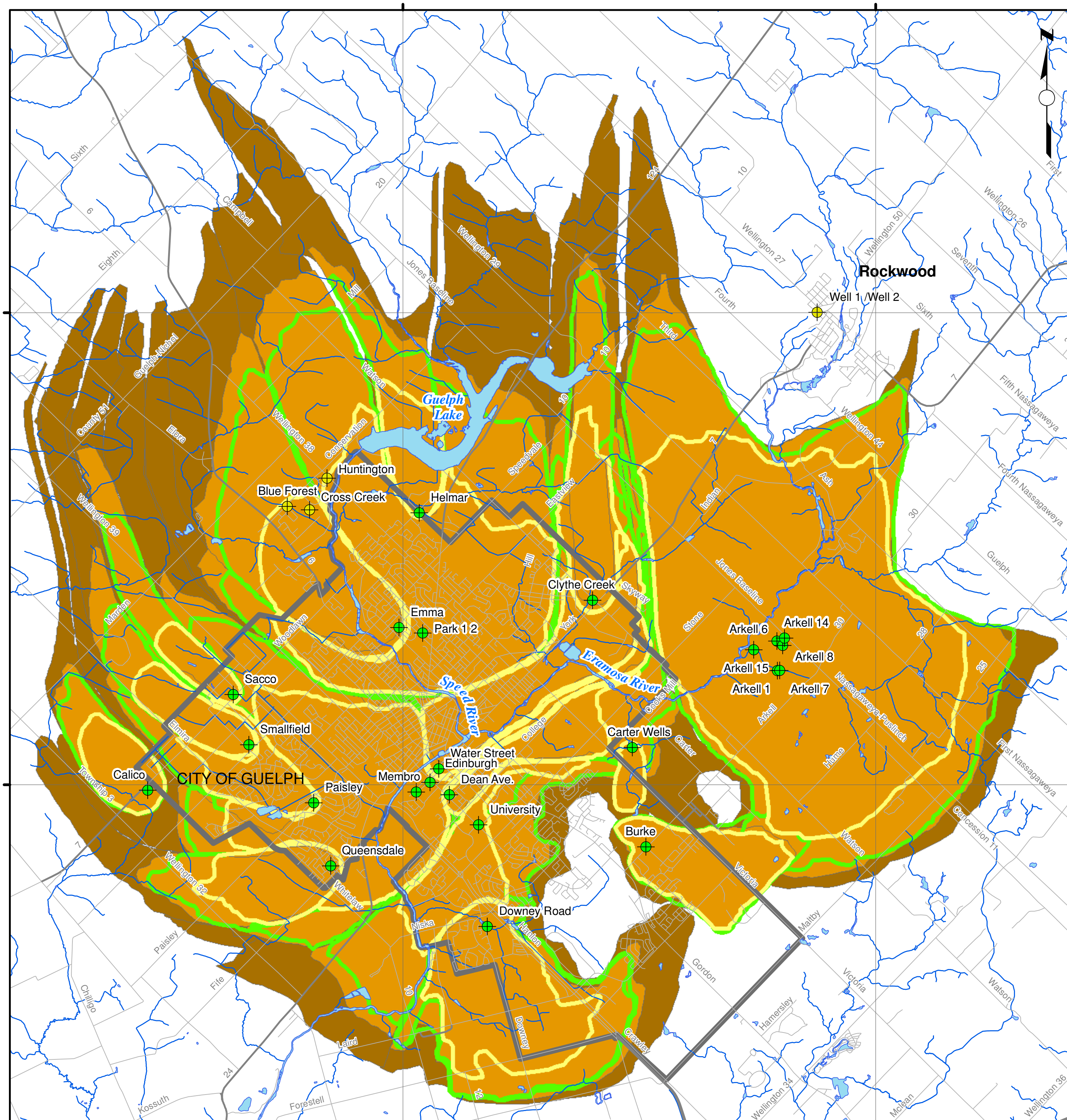
Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 8-Mar-10; Created By: CC

Figure 9.
Sensitivity Analysis
2 Year and 5 Year Capture Zones

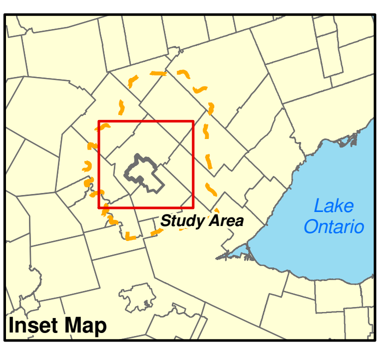


LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary

Capture Zones
- 10 year
- 25 year

Sensitivity Analysis
- 10 year
- 25 year



Scale 1:115,000
0 2.5 5
Kilometres

REFERENCES:
Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 8-Mar-10; Created By: CC

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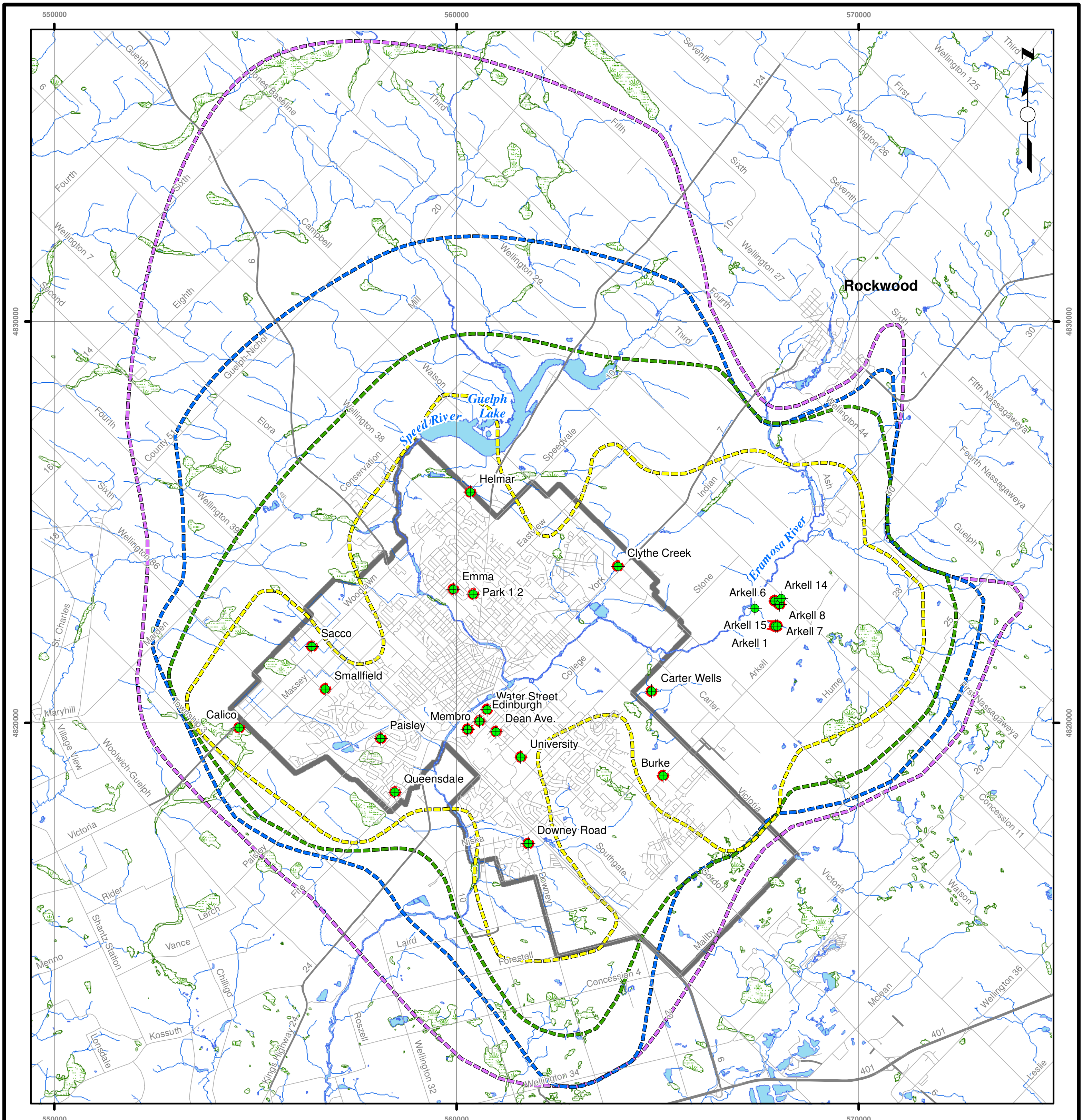
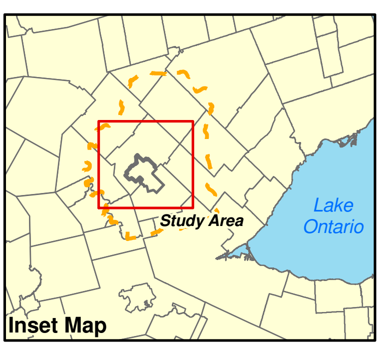
Figure 10.
Sensitivity Analysis
10 Year and 25 Year Capture Zones





LEGEND

- Water Supply Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary

WHPAs

- 100m (WHPA-A)
- 2yr (WHPA-B)
- 5yr (WHPA-C)
- 10yr (WHPA-C1)
- 25yr (WHPA-D)

Scale 1:130,000

0 2.5 5

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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Projection: UTM Zone 17N, NAD 83

Map Version: 2; Map Date: 4-Mar-10; Created By: CC

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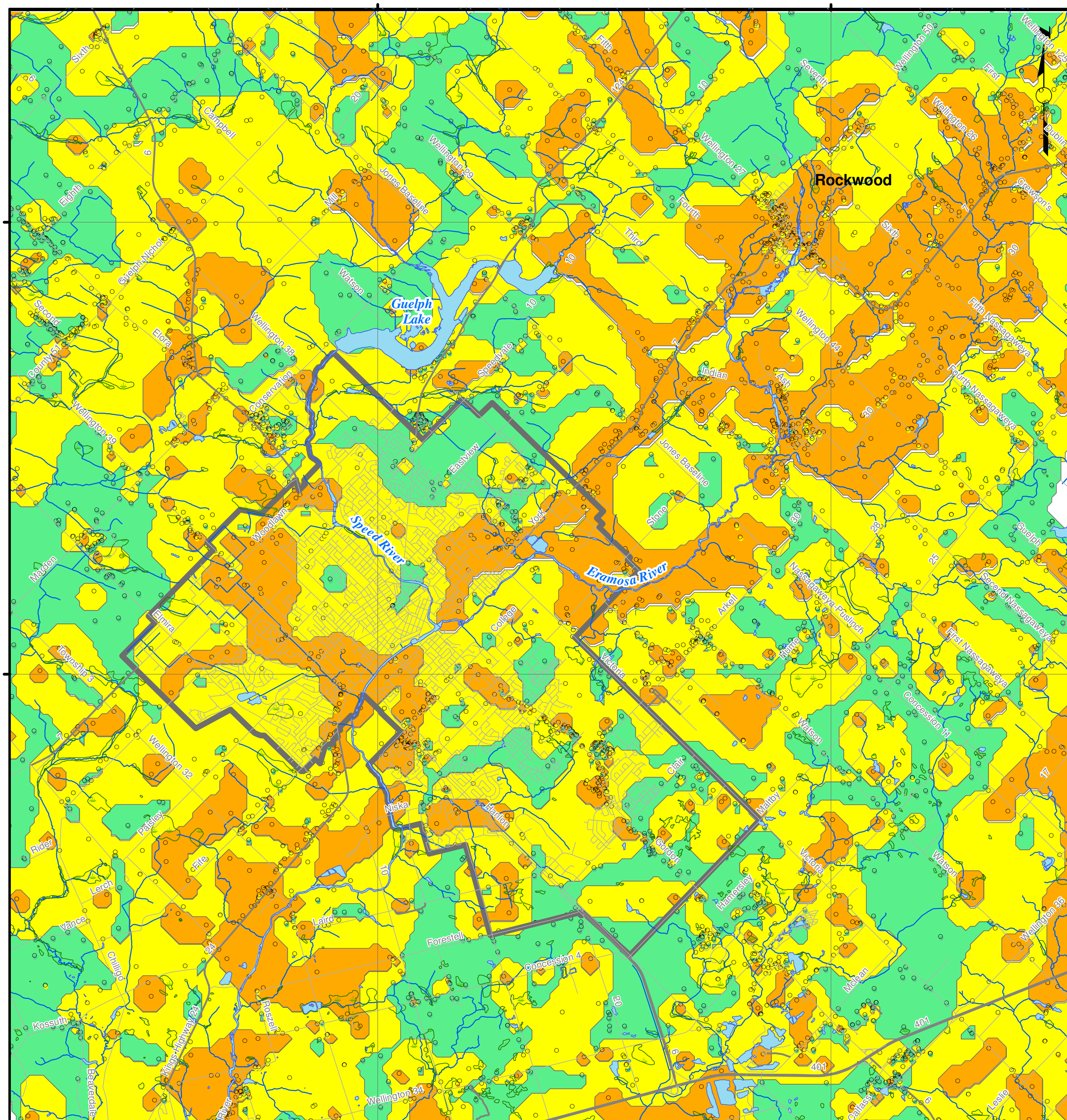
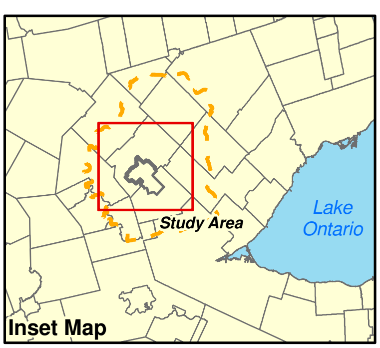
Figure 11.

Wellhead Protection Areas





LEGEND

- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Tier Three Model Boundary
- City of Guelph Boundary

ISI Index

- <30 (High)
- 30-80 (Medium)
- >80 (Low)

Bedrock Wells - ISI Index

- <30 (High)
- 30-80 (Medium)
- >80 (Low)

Scale 1:120,000

0 2.5 5
Kilometres

REFERENCES:
Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 10-Mar-10; Created By: CC

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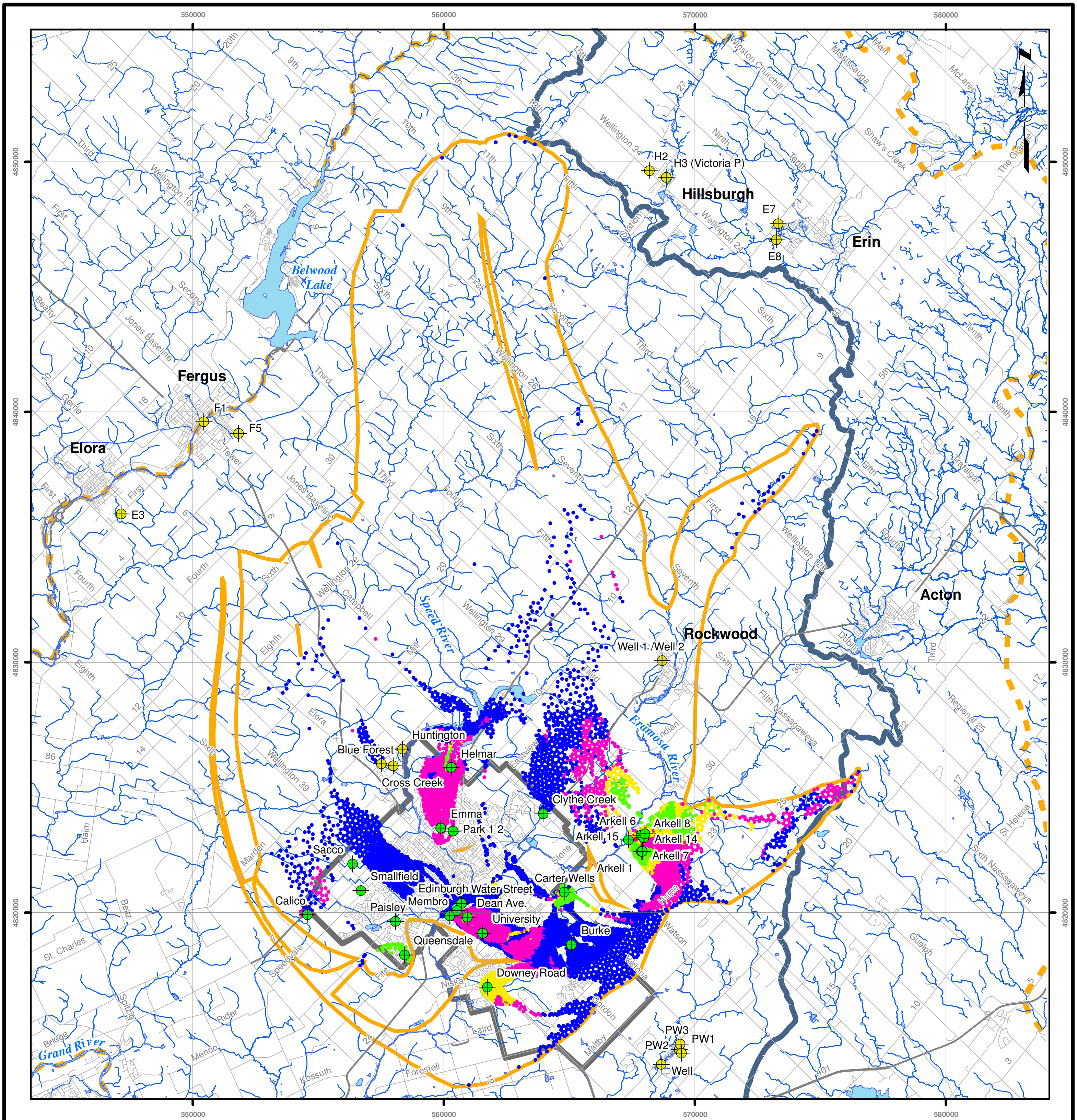
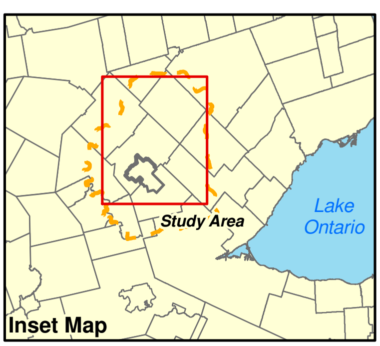
Figure 12.

Bedrock Vulnerability
(G-P-W Groundwater Study)





LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Open Water
- GRCA Watershed Boundary
- Tier 3 Study Area Boundary
- City of Guelph Boundary
- Steady State

Forward Particles

TOT (yrs) to Municipal Well

- < 5
- 5 - 10
- 10 - 25
- > 25

Scale 1:207,500

0 2.5 5 10 Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 9-Mar-10; Created By: CC

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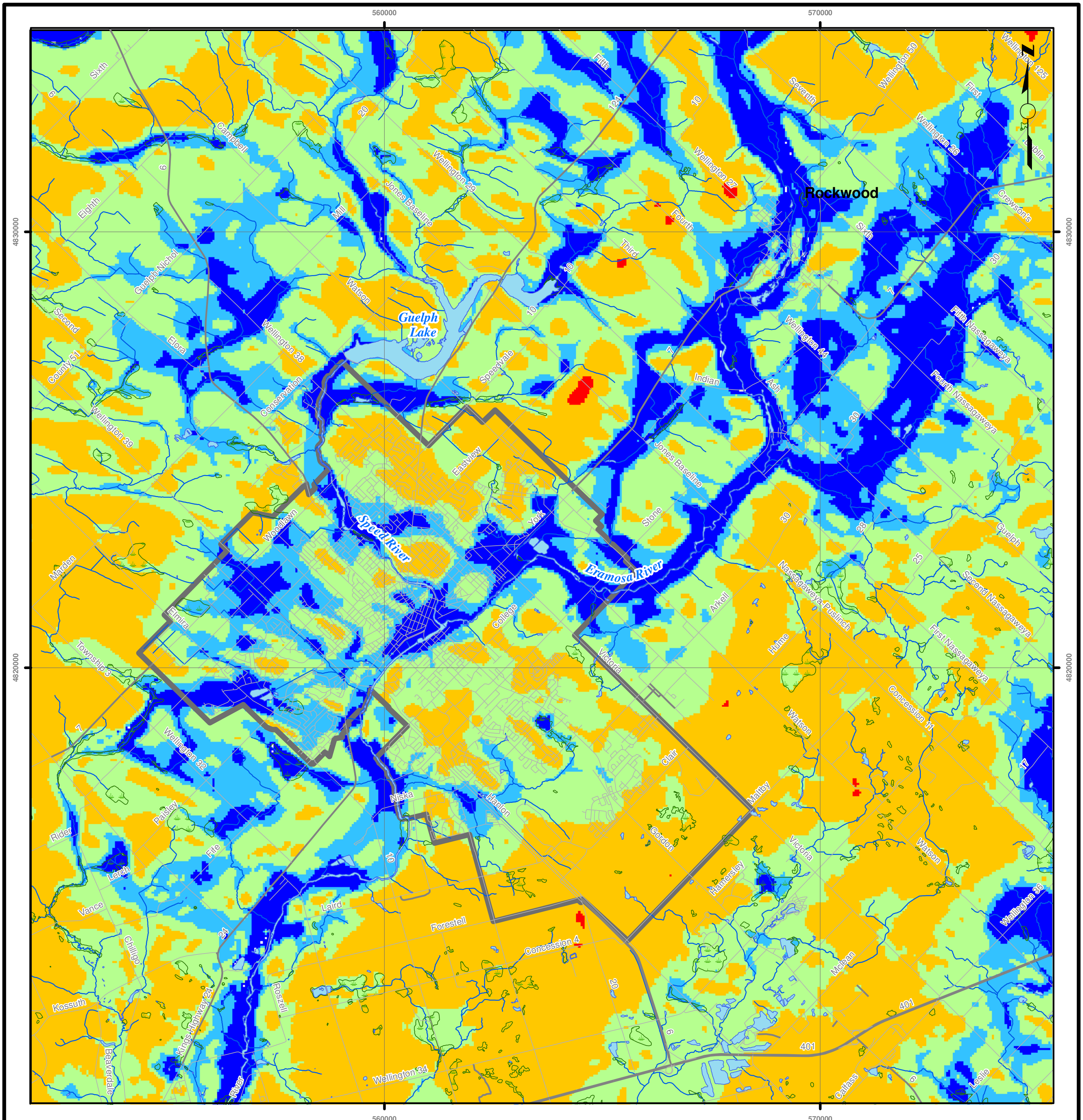
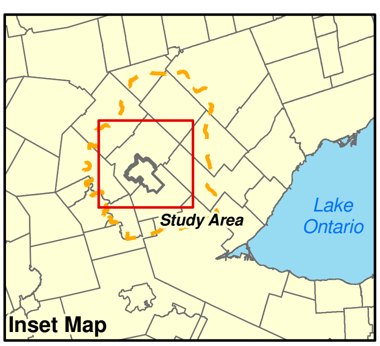
Figure 13.

Example SWAT Analysis





LEGEND

Roads (collector)		**Overburden Thickness (m)**	
Expressway / Highway		0 - 5	
Rivers / Streams		5 - 10	
Wetland		10 - 20	
Open Water		20 - 50	
City of Guelph Boundary		> 50	

Scale 1:120,000

0 2.5 5 Kilometres

REFERENCES:
Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 10-Mar-10; Created By: CC

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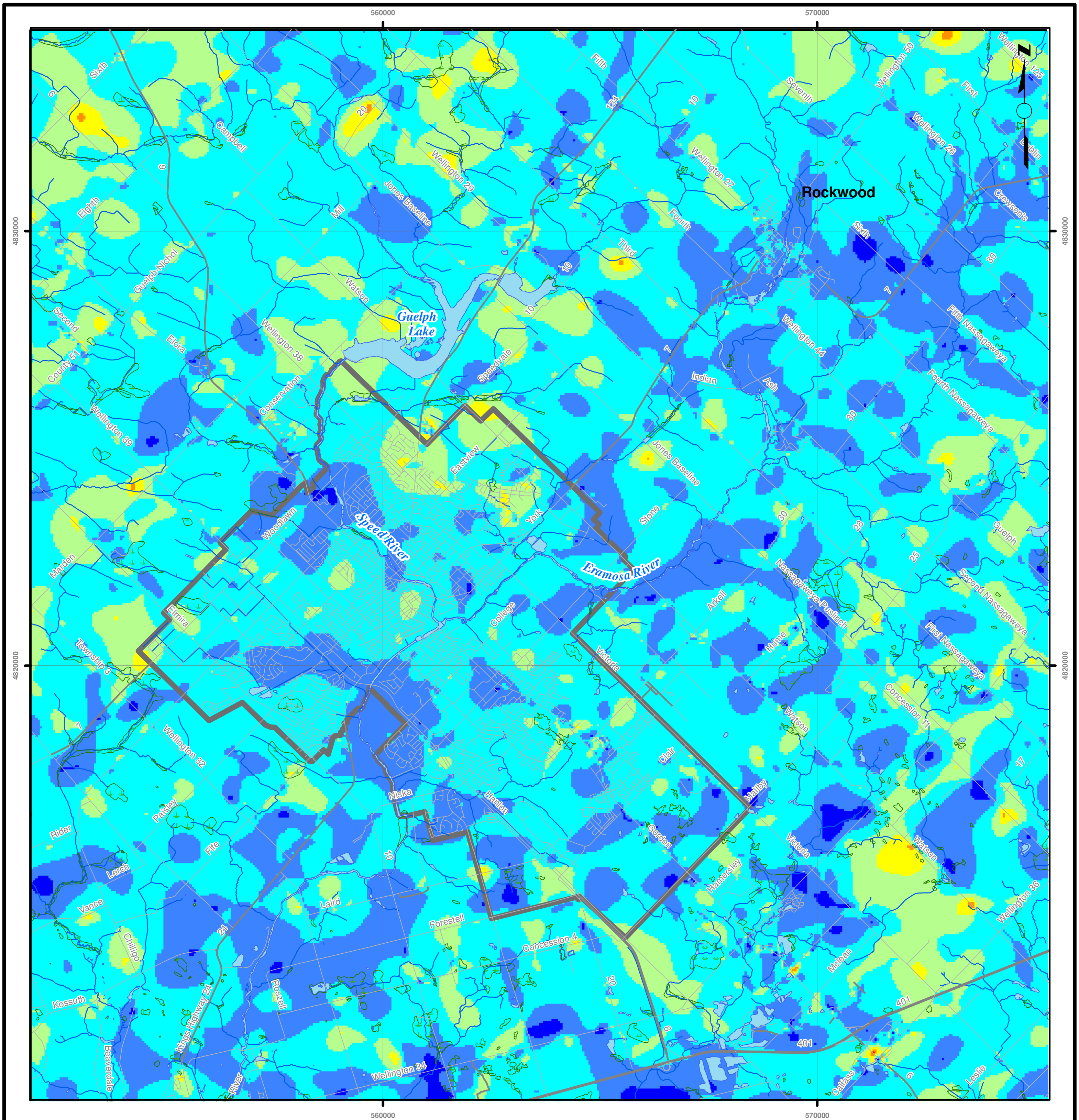
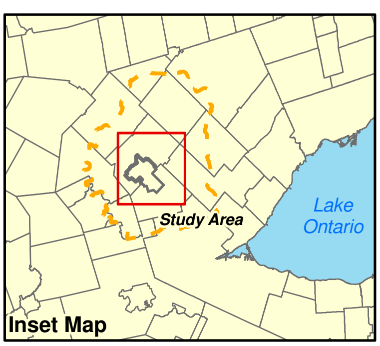
Figure 14.

Overburden Thickness





LEGEND

- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary

Effective K (-α)

- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8

Scale 1:120,000

0 2.5 5

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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Projection: UTM Zone 17N, NAD 83

Map Version: 1; Map Date: 10-Mar-10; Created By: CC

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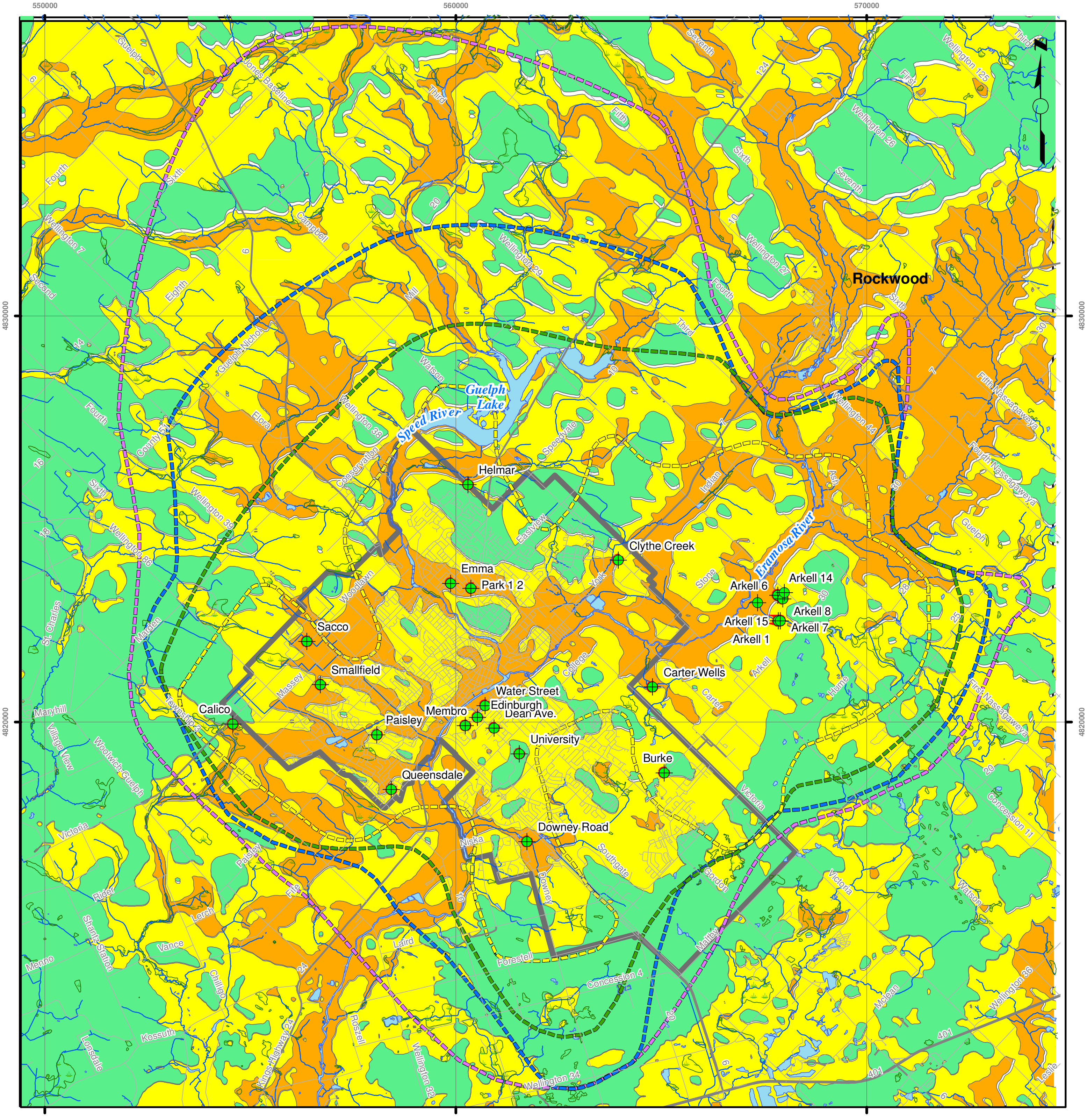
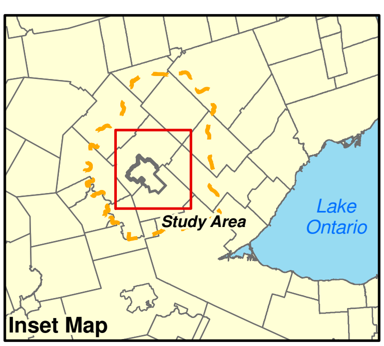
Figure 15.

Effective K Map





LEGEND

- Water Supply Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary

Modified GwISI

- <30 (High)
- 30-80 (Medium)
- >80 (Low)

WHPAs

- 100m (WHPA-A)
- 2yr (WHPA-B)
- 5yr (WHPA-C)
- 10yr (WHPA-C1)
- 25yr (WHPA-D)

Scale 1:130,000

0 2.5 5 Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 2; Map Date: 4-Mar-10; Created By: CC

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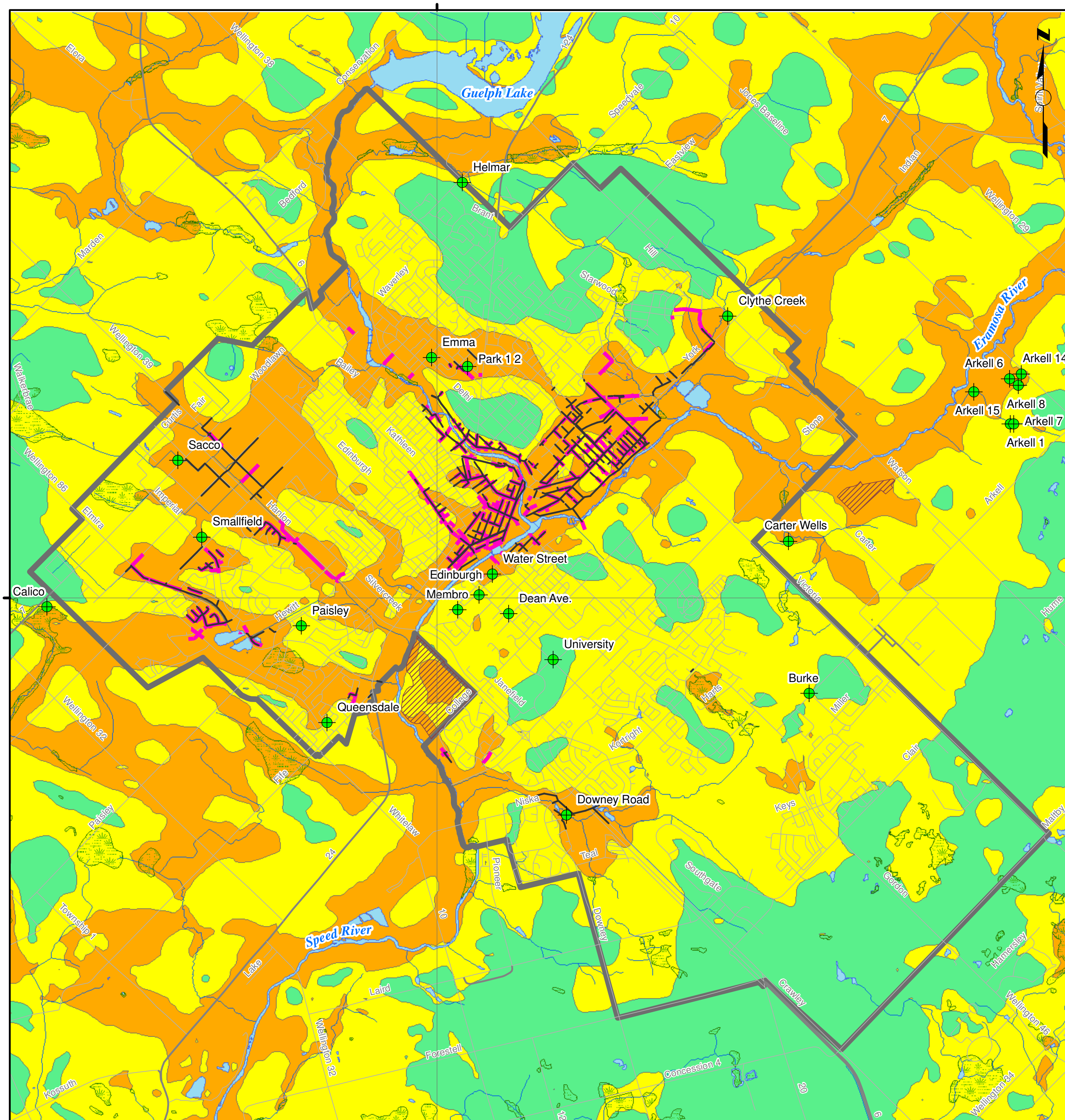
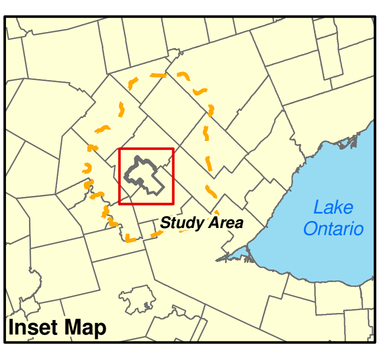
Figure 16.
Groundwater Vulnerability Map (Modified GwISI)





LEGEND

- Water Supply Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water

Preferential Pathways

- Sanitary Sewers Near Bedrock
- Storm Sewers near Bedrock

GwISI Index

- <30 (High)
- 30-80 (Medium)
- >80 (Low)

- City of Guelph Boundary
- Pits and Quarries

Scale 1:75,000

0 2.5 5
Kilometres

REFERENCES:
Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 10-Mar-10; Created By: CC

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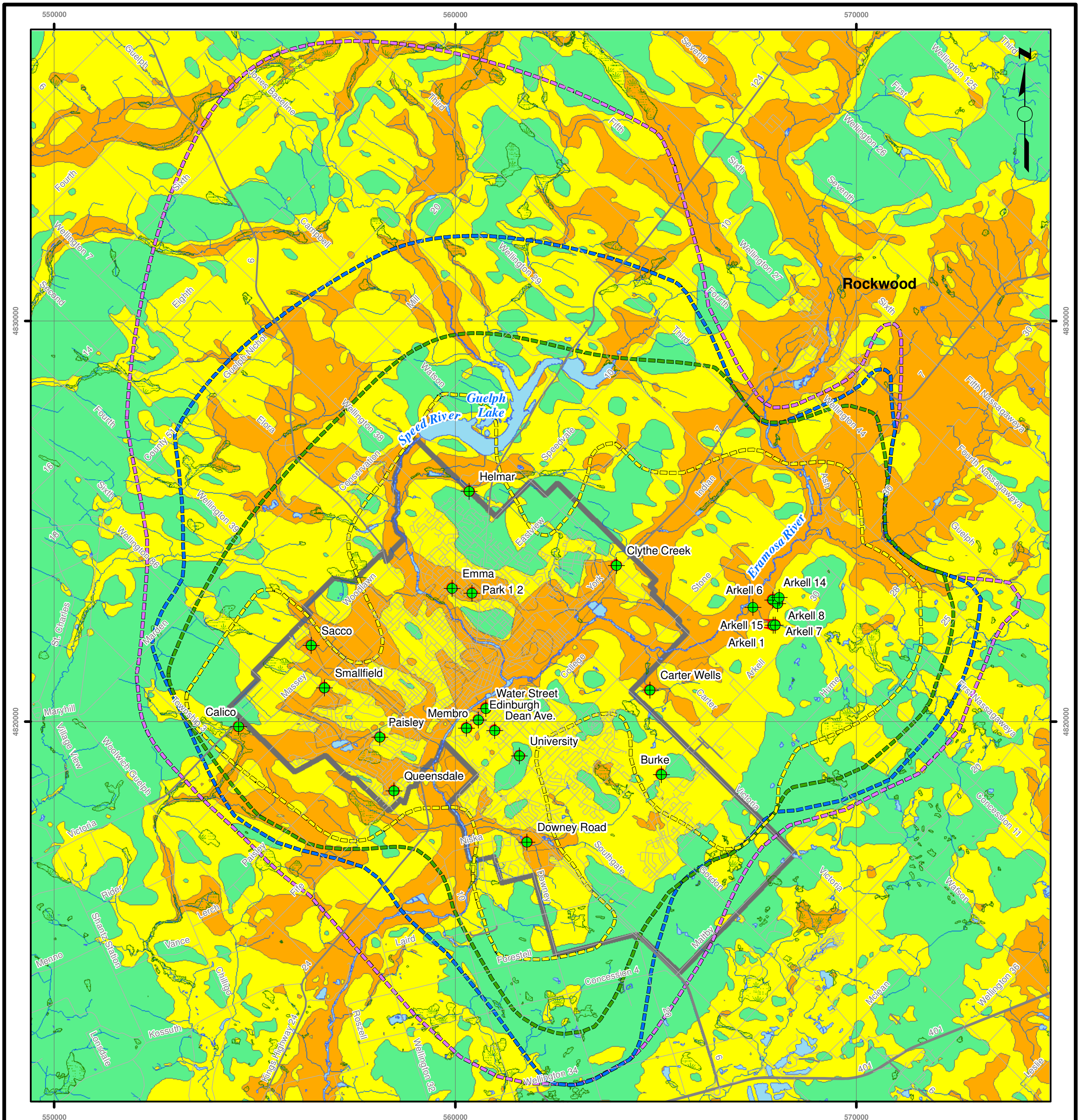
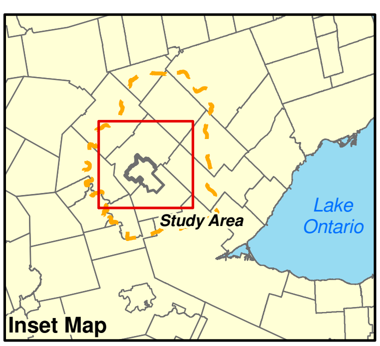
Figure 17.

Transport Pathways





LEGEND

- Water Supply Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary

GwISI

- <30 (High)
- 30-80 (Medium)
- >80 (Low)

WHPAs

- 100m (WHPA-A)
- 2yr (WHPA-B)
- 5yr (WHPA-C)
- 10yr (WHPA-C1)
- 25yr (WHPA-D)

Scale 1:130,000

0 2.5 5

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 2; Map Date: 4-Mar-10; Created By: CC

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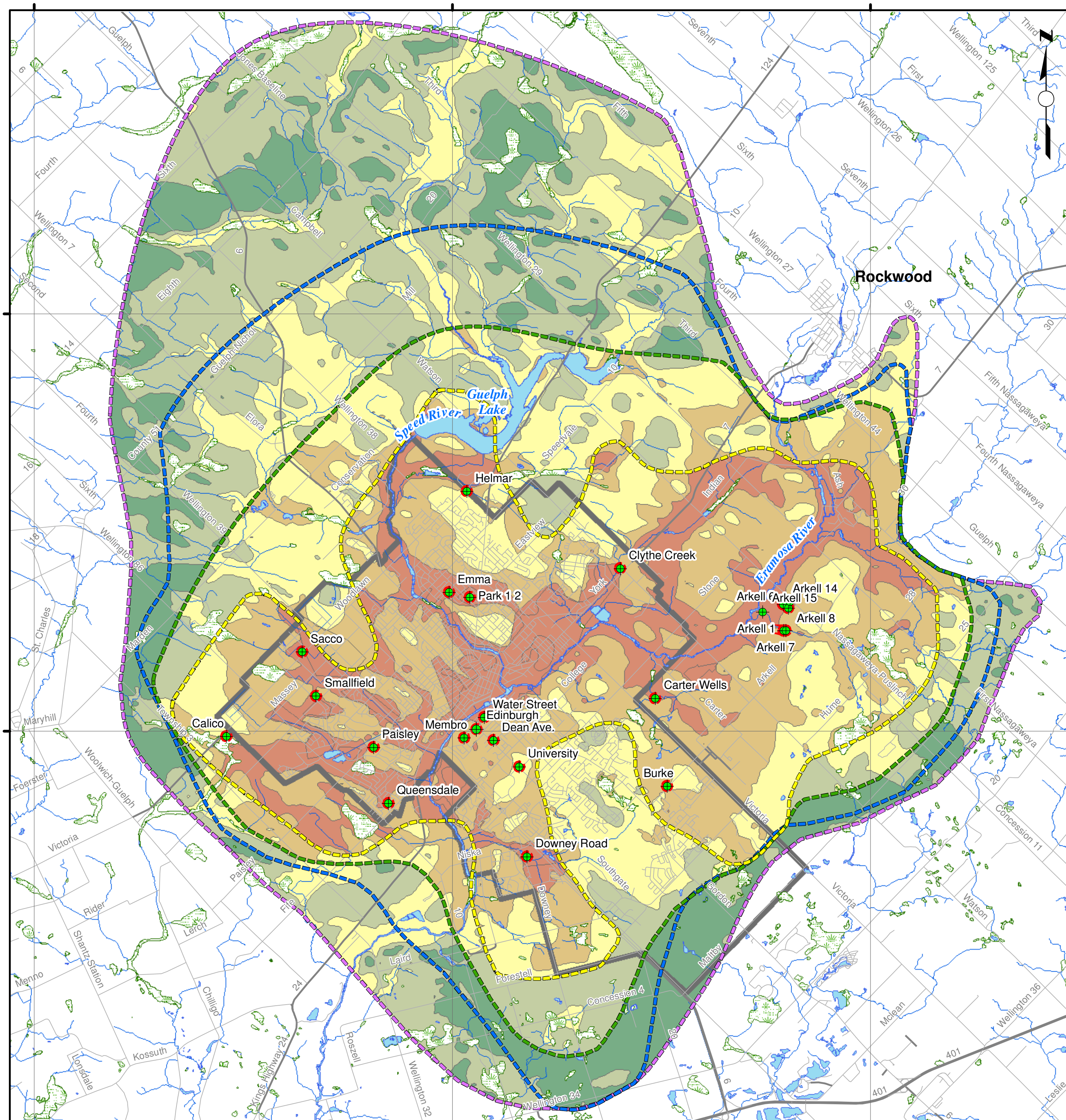
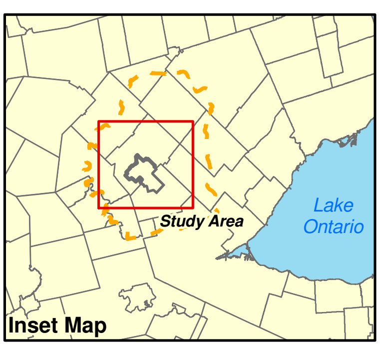
Figure 18.
Revised Groundwater Vulnerability Map





LEGEND

- Water Supply Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary

WHPAs	Vulnerability Score
100m (WHPA-A)	2
2yr (WHPA-B)	4
5yr (WHPA-C)	6
10yr (WHPA-C1)	8
25yr (WHPA-D)	10

Scale 1:130,000

0 2.5 5

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 3; Map Date: 10-Mar-10; Created By: CC

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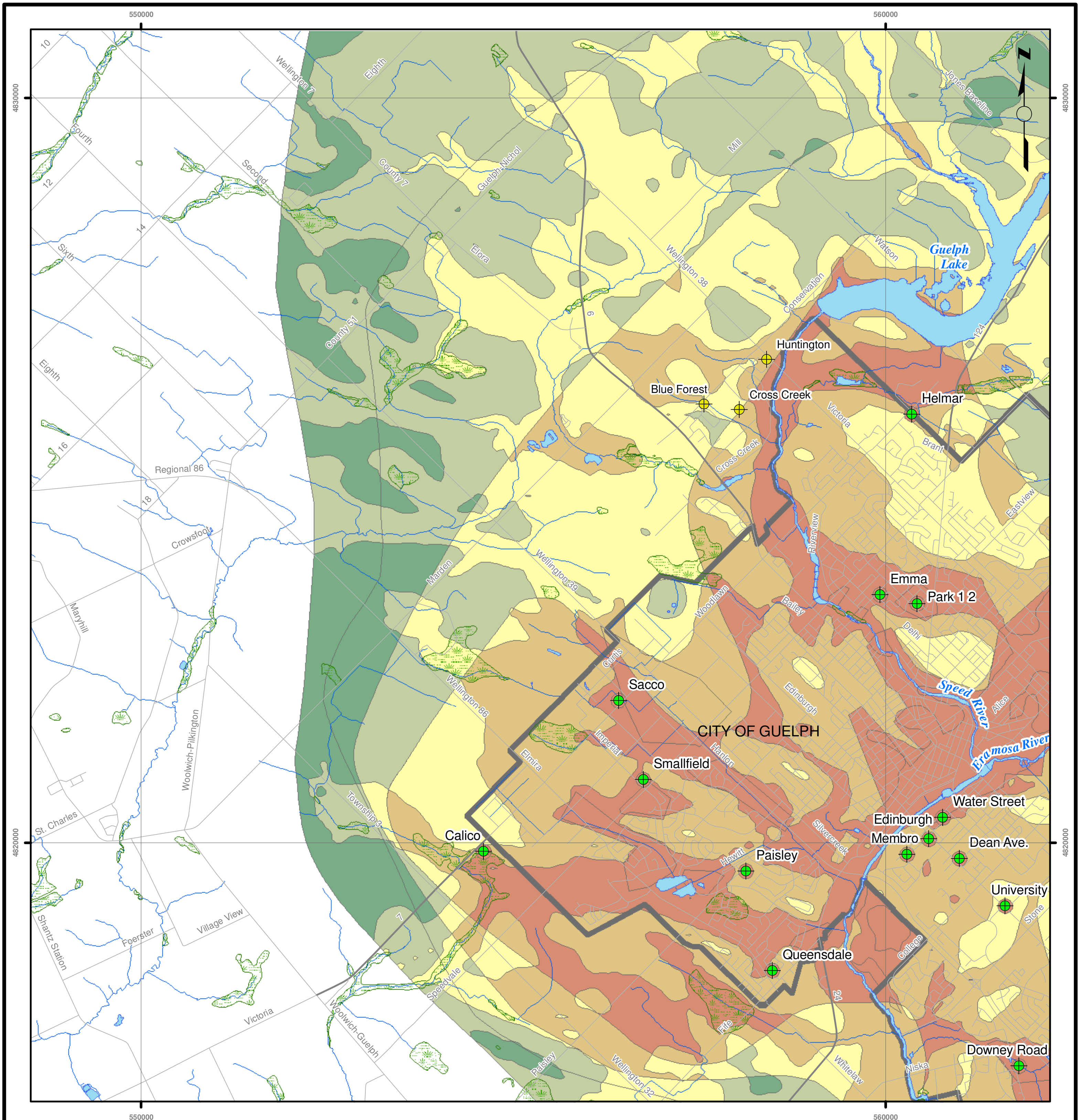
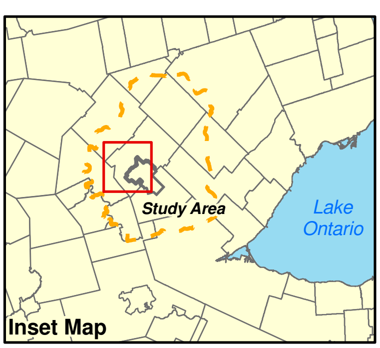
Figure 19.

Groundwater Vulnerability Scoring





LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary

Vulnerability Score

- 2
- 4
- 6
- 8
- 10

Scale 1:70,000

0 1.25 2.5 Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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Projection: UTM Zone 17N, NAD 83
Map Version: 2; Map Date: 10-Mar-10; Created By: CC

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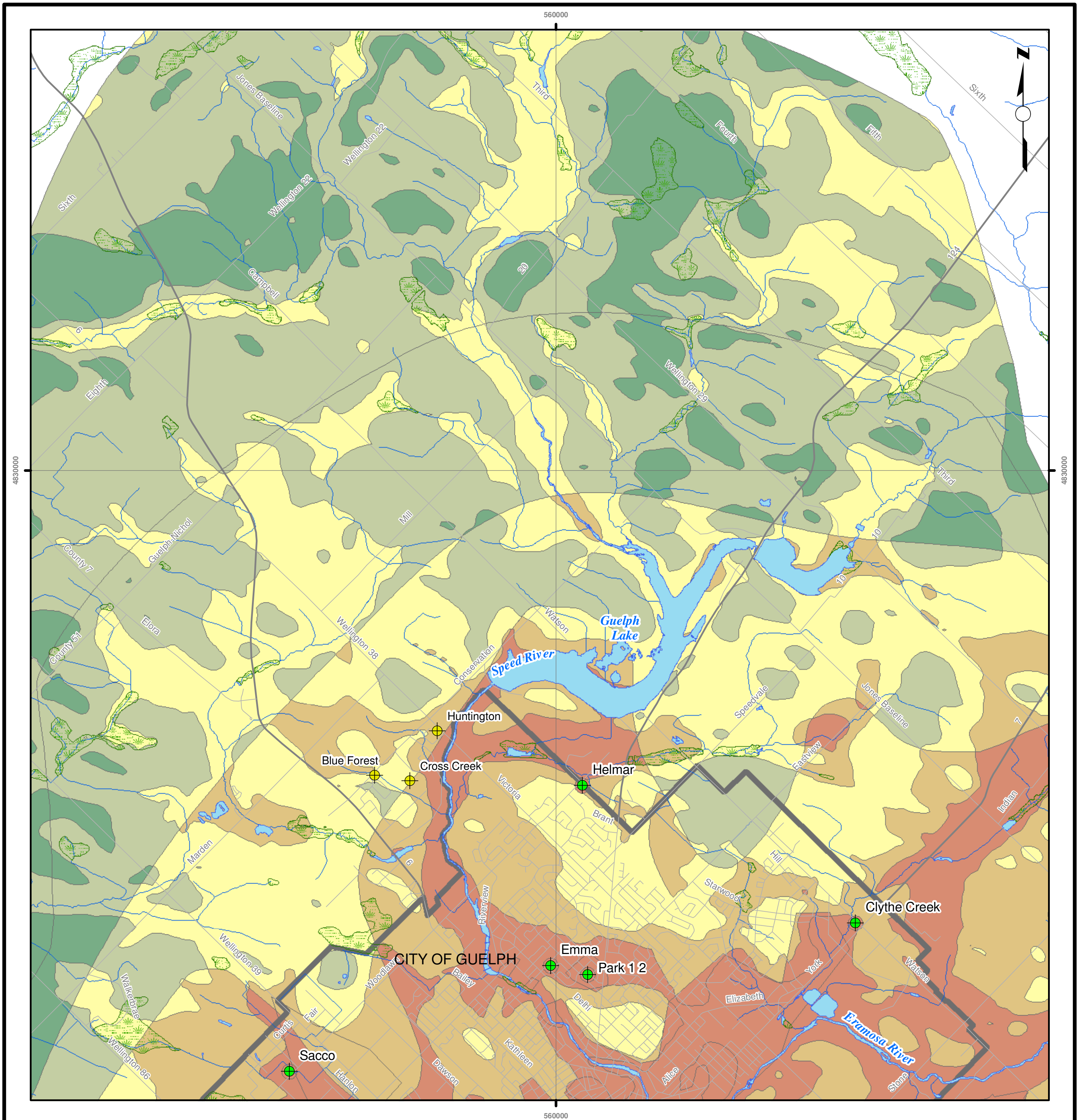
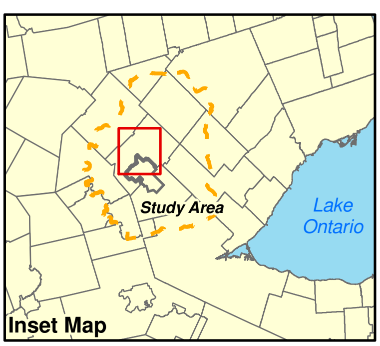
Figure 20.
Groundwater Vulnerability Scoring Northwest Quadrant

Fig20_GroundwaterVulnerabilityScoring_NW.mxd

Project: 2006005_GuelphSourceProtection





LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary

Vulnerability Score

- 2
- 4
- 6
- 8
- 10

Scale 1:70,000

0 1.25 2.5

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83

Map Version: 2; Map Date: 10-Mar-10; Created By: CC

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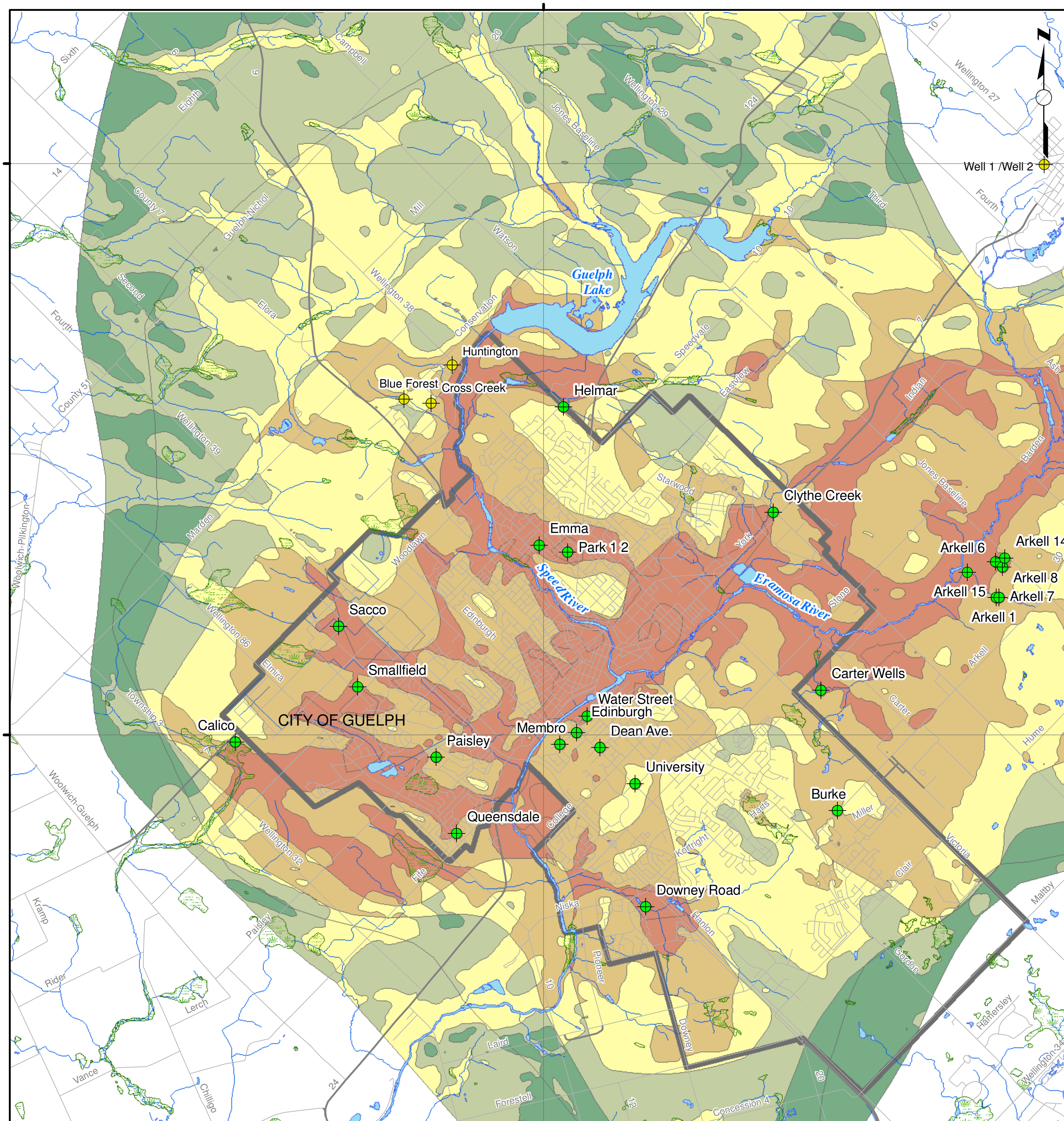
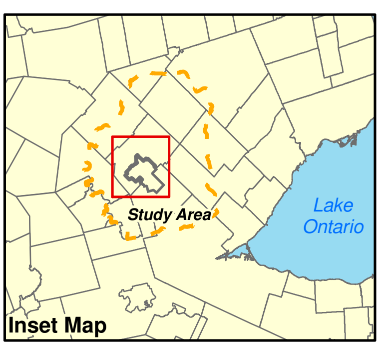
Figure 21.

Groundwater Vulnerability Scoring Northeast Quadrant





LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary

Vulnerability Score

- 2
- 4
- 6
- 8
- 10

Scale 1:95,000

0 1.25 2.5 Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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Projection: UTM Zone 17N, NAD 83
Map Version: 2; Map Date: 10-Mar-10; Created By: CC

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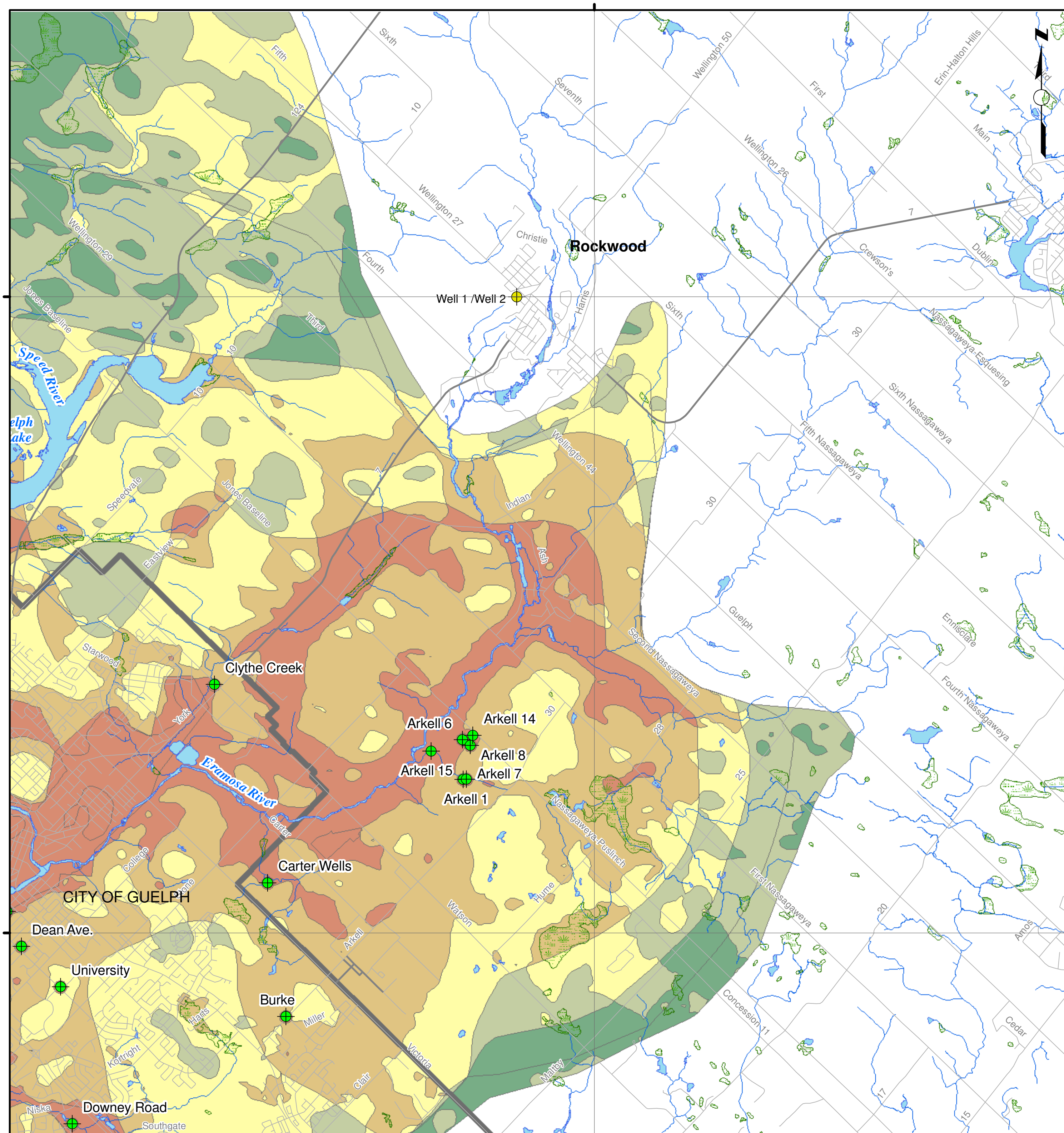
Figure 22.

Groundwater Vulnerability Scoring Southwest Quadrant

Fig22_GroundwaterVulnerabilityScoring_SW.mxd

Project: 2006005_GuelphSourceProtection

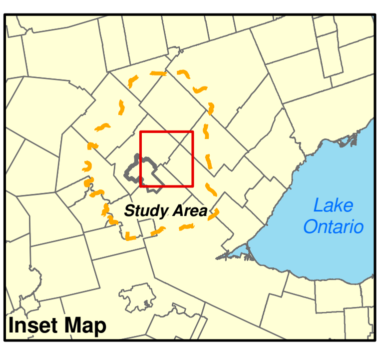


LEGEND

- Water Supply Wells
- Other Municipal Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary

Vulnerability Score

- 2
- 4
- 6
- 8
- 10



Scale 1:85,000

0 1.25 2.5

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 2; Map Date: 10-Mar-10; Created By: CC

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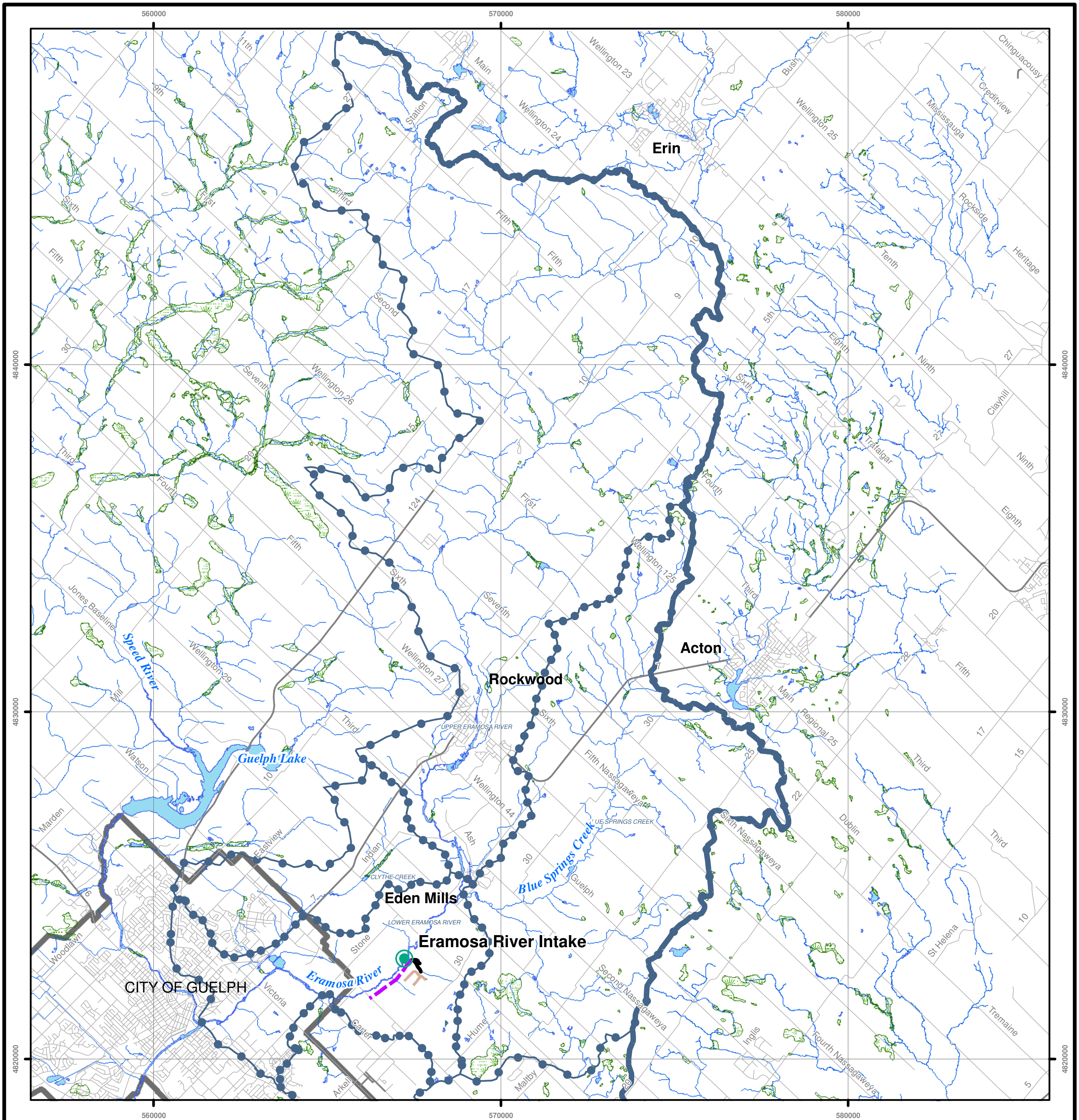
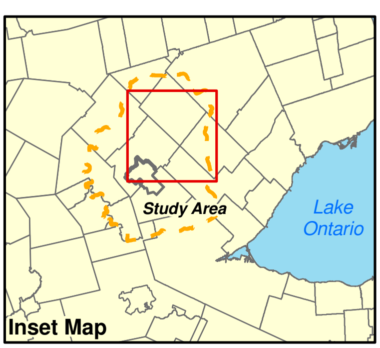
Figure 23.
Groundwater Vulnerability Scoring Southeast Quadrant





LEGEND

- Eramosa River Intake
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Aquaduct
- Arkell Recharge Pit and Trench
- Glen Collector
- Wetland
- Open Water
- Subwatershed Boundaries
- GRCA Watershed Boundary
- City of Guelph Boundary

Scale 1:150,000

0 2.5 5

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83

Map Version: 1; Map Date: 10-Mar-10; Created By: CC

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Figure 24.

Location of Eramosa Intake

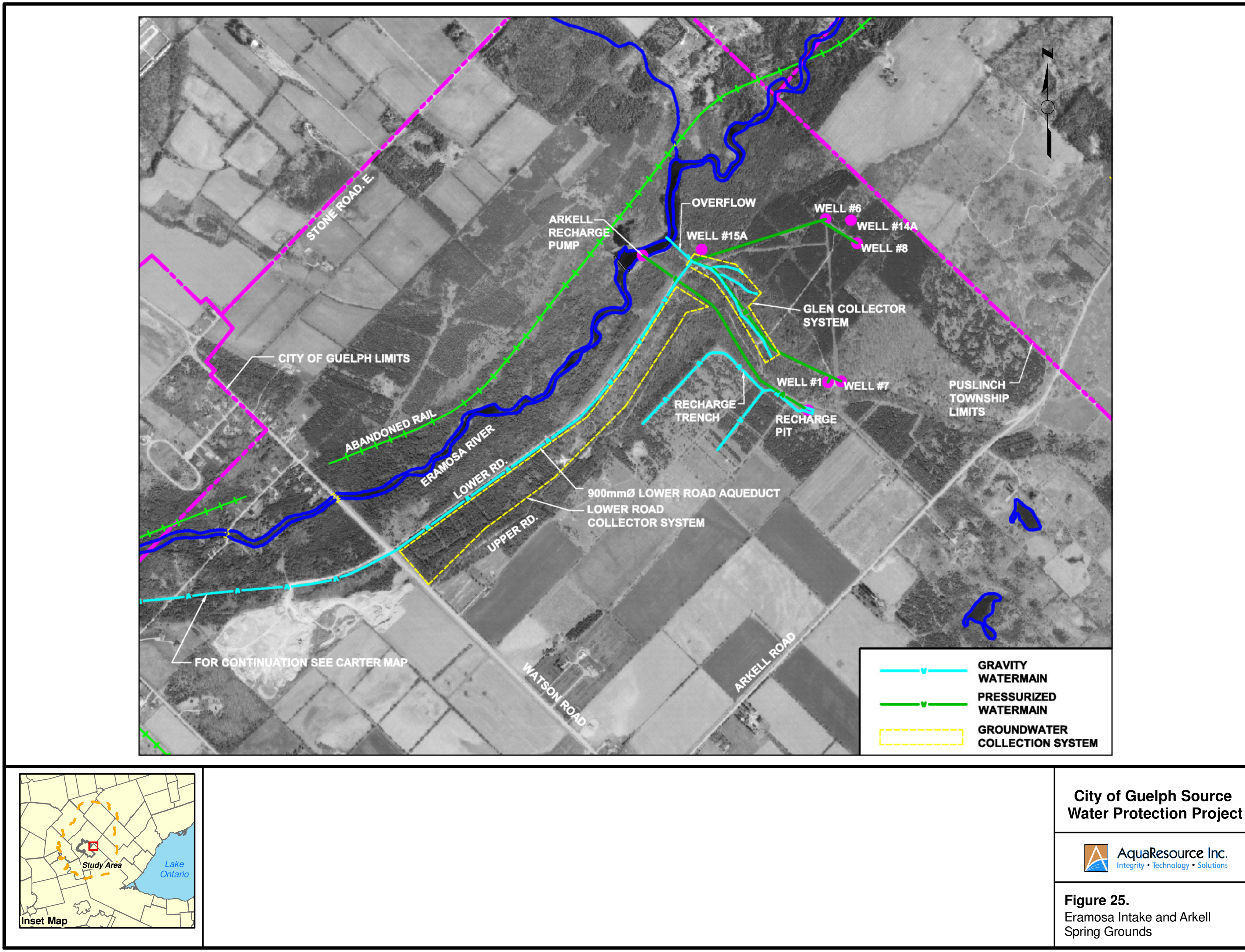

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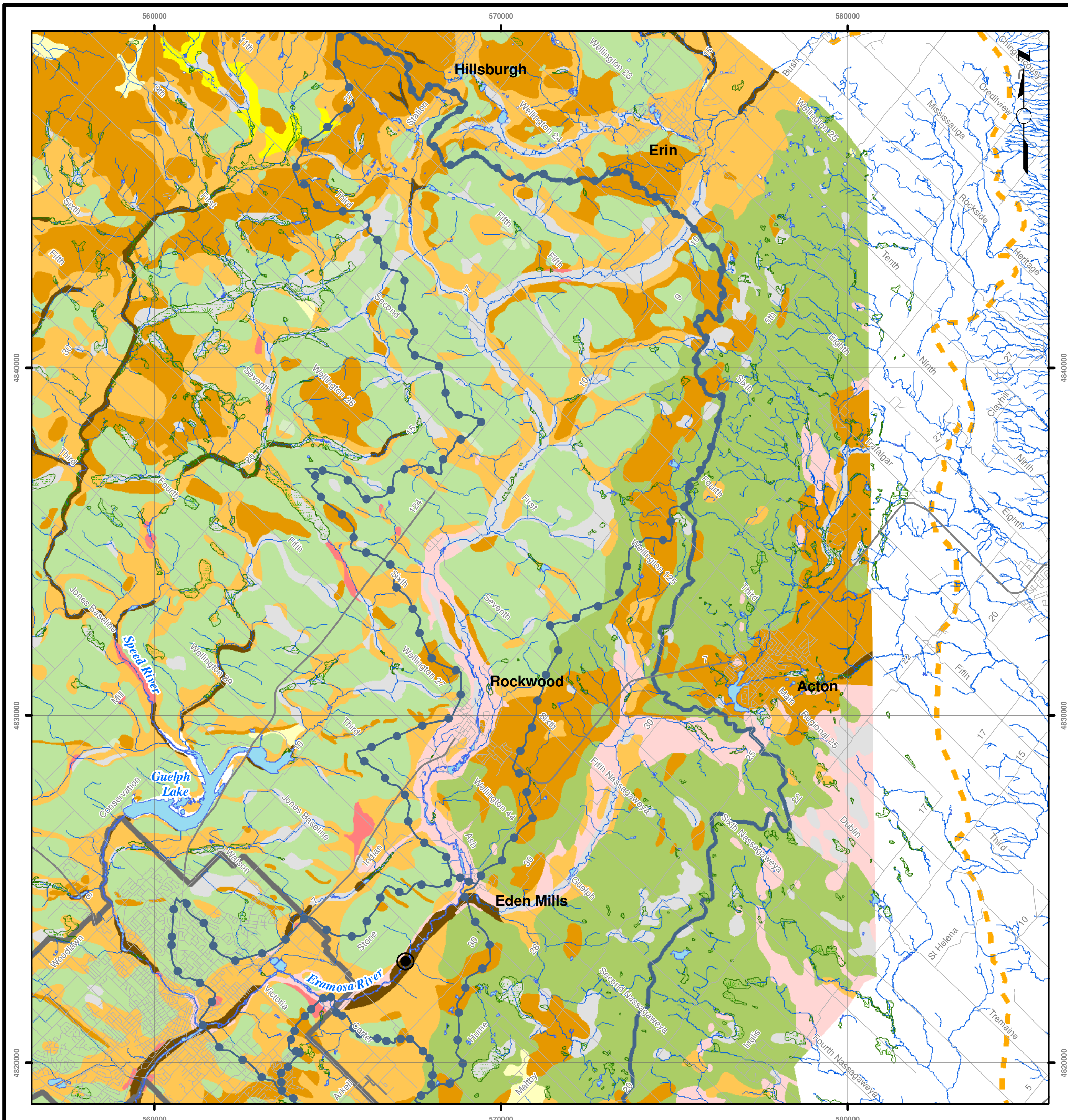
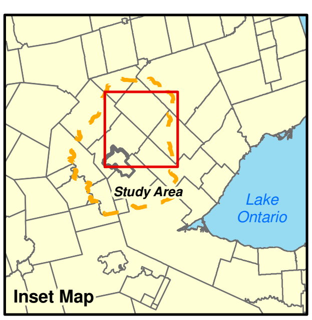
Figure 25.
Eramosa Intake and Arkell Spring Grounds

Fig25_Eramosa_ArkellIntake_DB.mxd

Project: 2006005_GuelphSourceProtection





LEGEND

- Eramosa River Intake
- Roads (collector)
- Expressway or Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Tier 3 Study Area Boundary
- Subwatershed Boundaries
- GRCA Watershed Boundary

Quaternary Geology

- Water
- Organic Deposits
- Man-made Deposits
- Amabel & Lockport Fm.
- Guelph Formation
- Maryhill Till
- Port Stanley Till
- Wentworth Till
- Glaciofluvial Ice-Contact Deposits
- Glaciofluvial Outwash Deposits
- Glaciolacustrine Deposits, Shallow Water
- Glaciolacustrine Deposits, Deep Water
- Modern Fluvial Deposits

Scale 1:150,000

0 2.5 5

Kilometres

REFERENCES:
Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 10-Mar-10; Created By: CC

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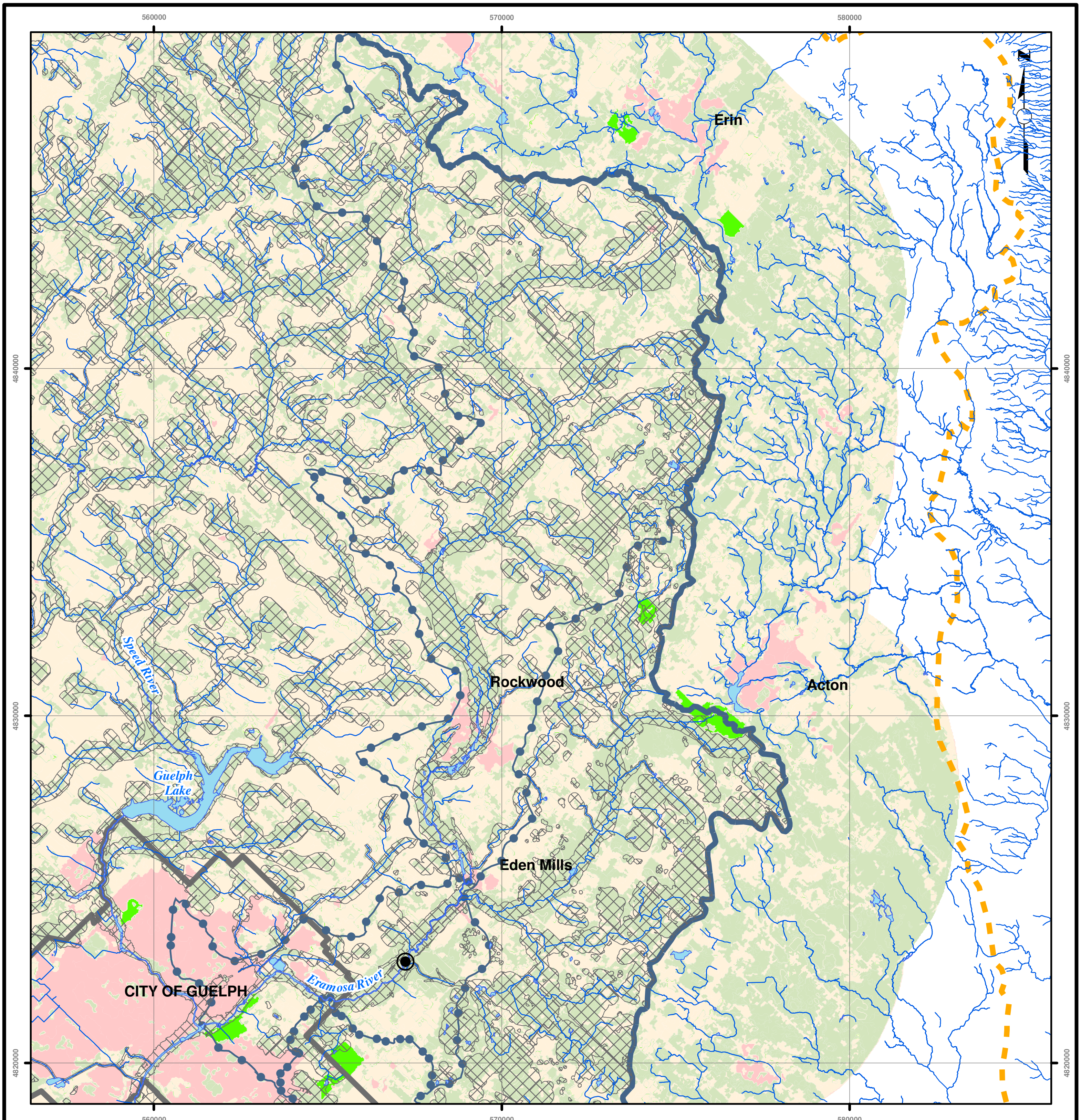
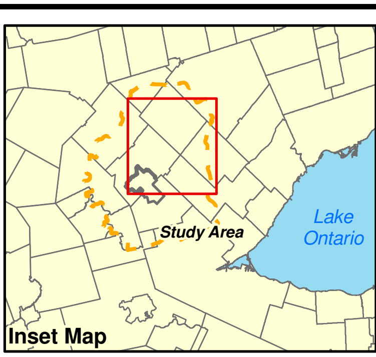
Figure 26.

Surficial Geology





LEGEND

- Eramosa River Intake
- Rivers / Streams
- Open Water
- City of Guelph Boundary
- Subwatershed Boundaries
- GRCA Watershed Boundary
- Regulated Areas

Landcover

- Built Up
- Agricultural Areas
- Natural Areas
- Golf Courses

Scale 1:150,000

0 2.5 5 Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 10-Mar-10; Created By: CC

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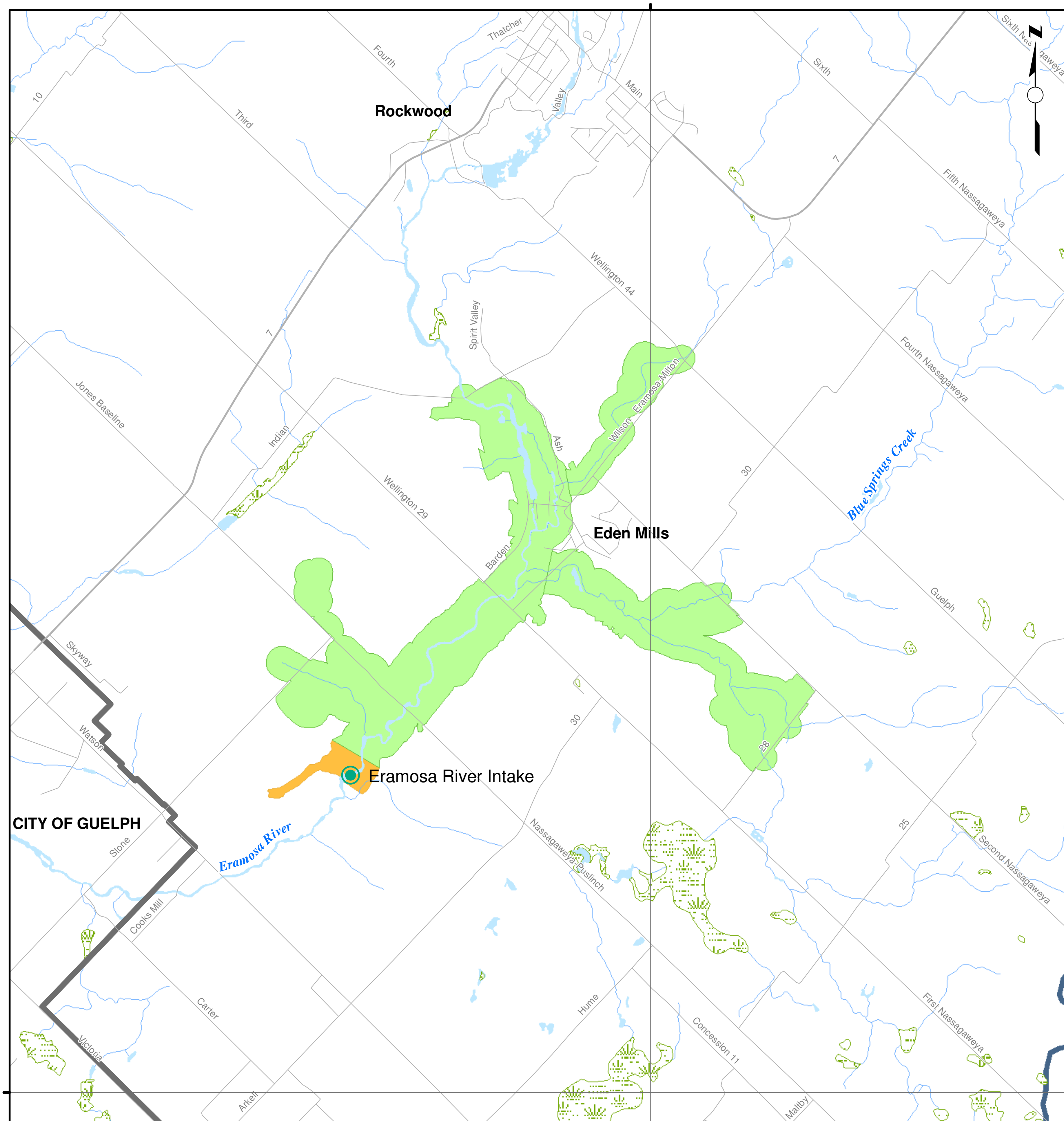
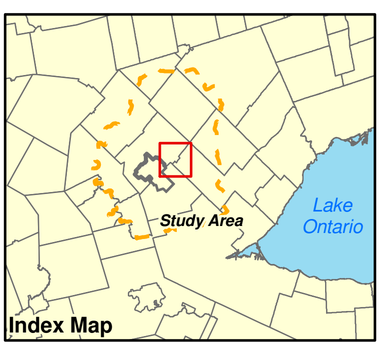
Figure 27.

Landcover





LEGEND

- Eramosa River Intake
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- GRCA Watershed Boundary
- Intake Protection Zone 1
- Intake Protection Zone 2

Scale 1:50,000

0 0.2 0.4 0.8 1.2 1.6 2

Kilometres

REFERENCES:
Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 10-Mar-10; Created By: CC

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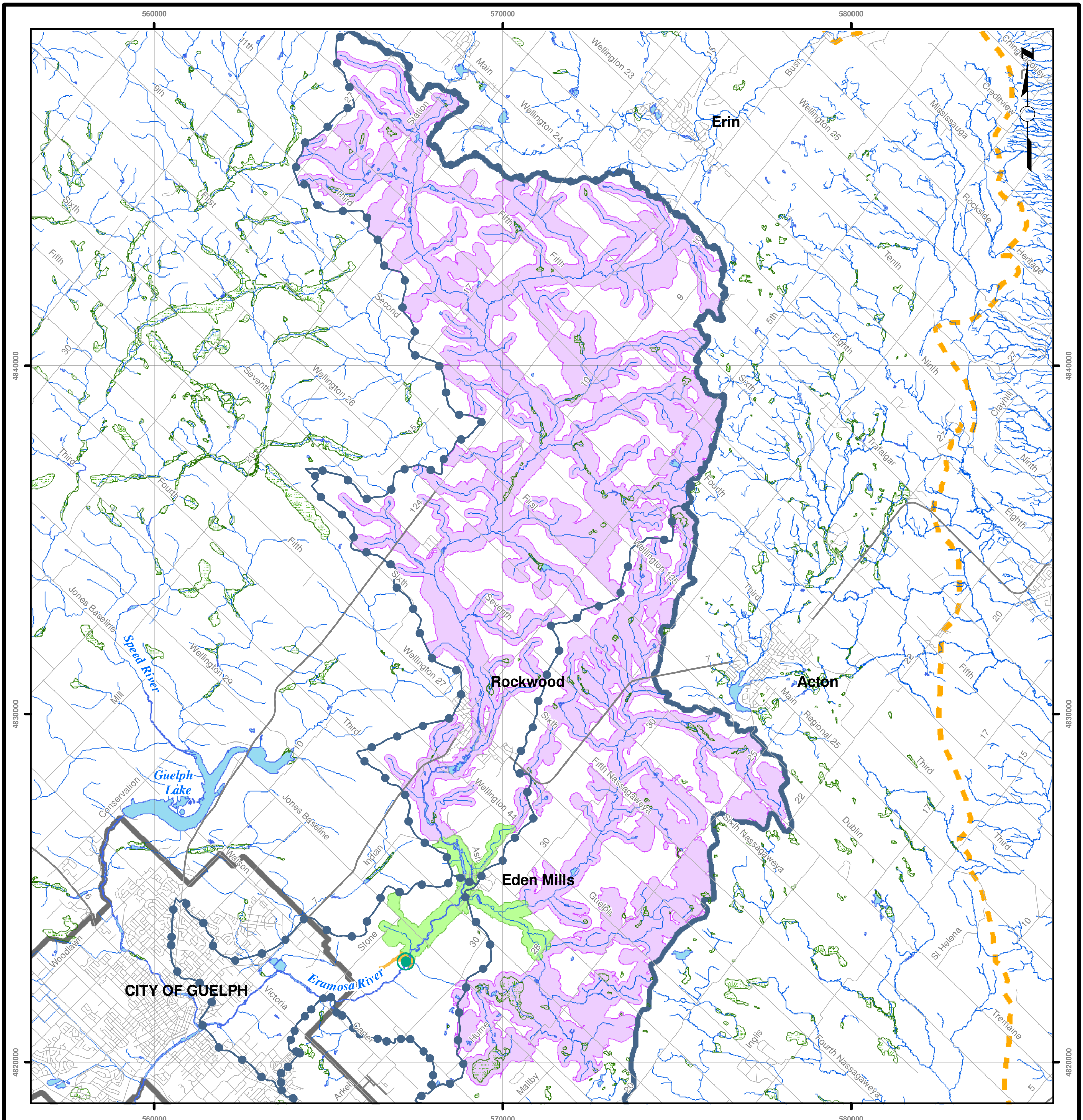
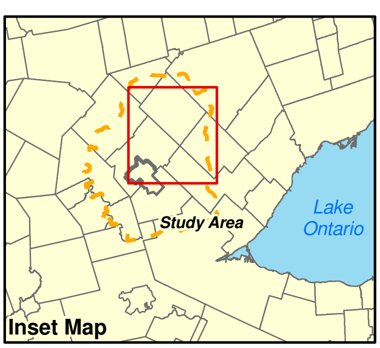
Figure 28.

IPZ-1 and IPZ-2





LEGEND

- Eramosa River Intake
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Subwatershed Boundaries
- GRCA Watershed Boundary
- Tier 3 Study Area Boundary
- Intake Protection Zone 1
- Intake Protection Zone 2
- Intake Protection Zone 3

Scale 1:150,000

0 2.5 5 Kilometres

REFERENCES:
Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 10-Mar-10; Created By: CC

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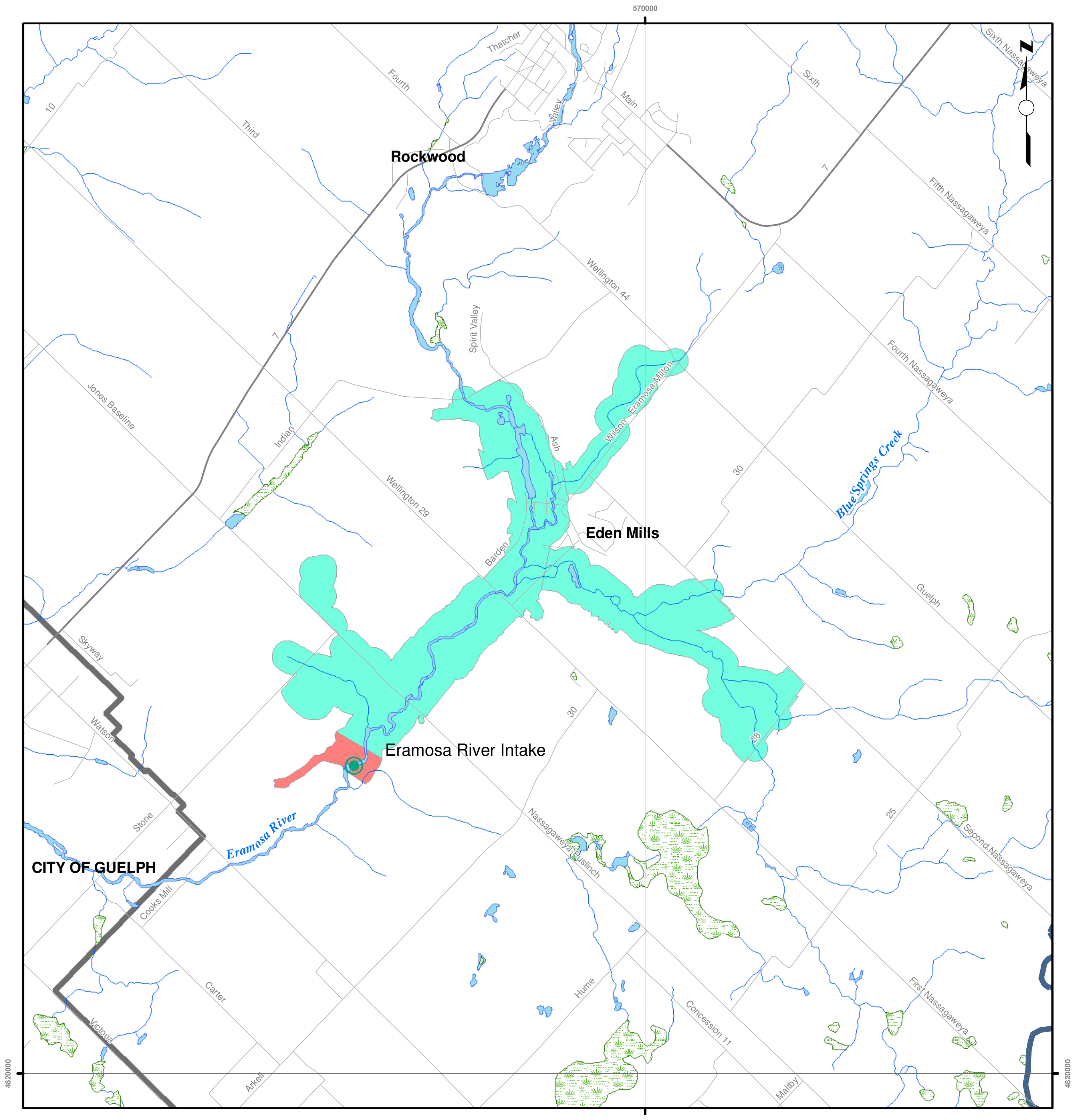
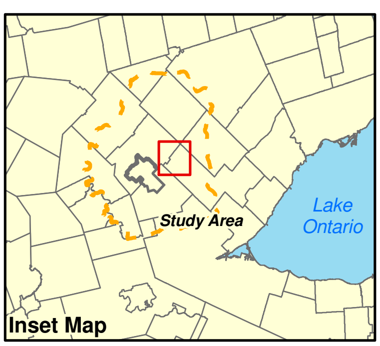
Figure 29.

All Intake Protection Zones





LEGEND

- Eramosa River Intake
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- GRCA Watershed Boundary

Vulnerability Score

- Vulnerability Score 10
- Vulnerability Score 7

Scale 1:50,000

0 1.25 2.5

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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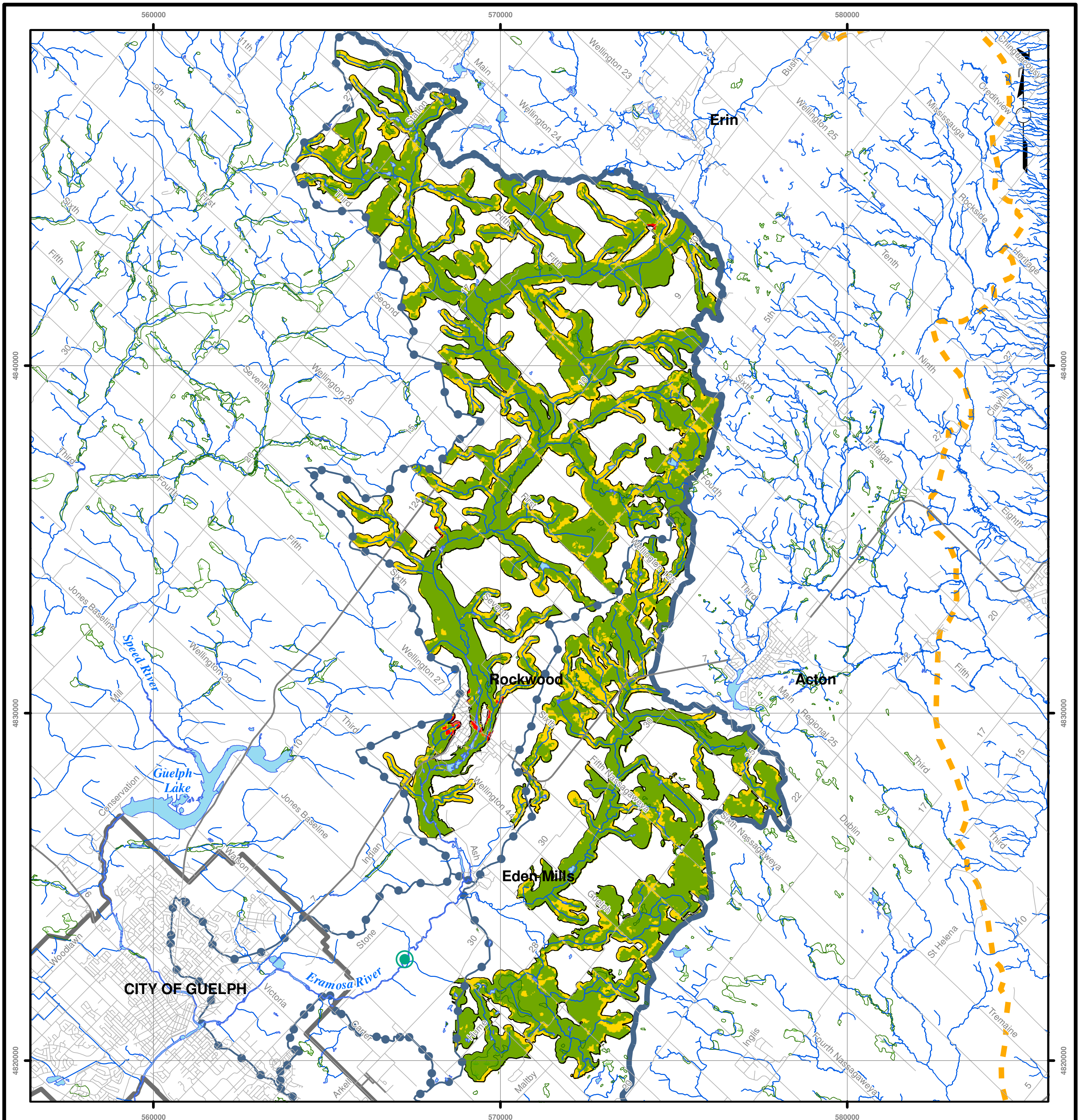
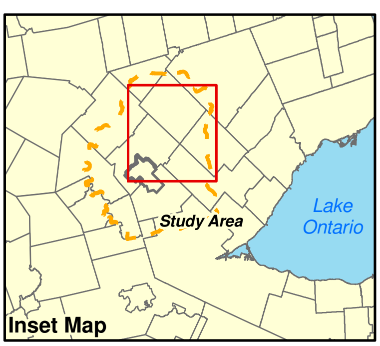
Figure 30.

IPZ-1 and IPZ-2 Vulnerability Scoring





LEGEND

- Eramosa River Intake
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Subwatershed Boundaries
- GRCA Watershed Boundary
- Tier 3 Study Area Boundary

Vulnerability Score

- Vulnerability Score 1
- Vulnerability Score 3
- Vulnerability Score 5

Scale 1:150,000

0 2.5 5

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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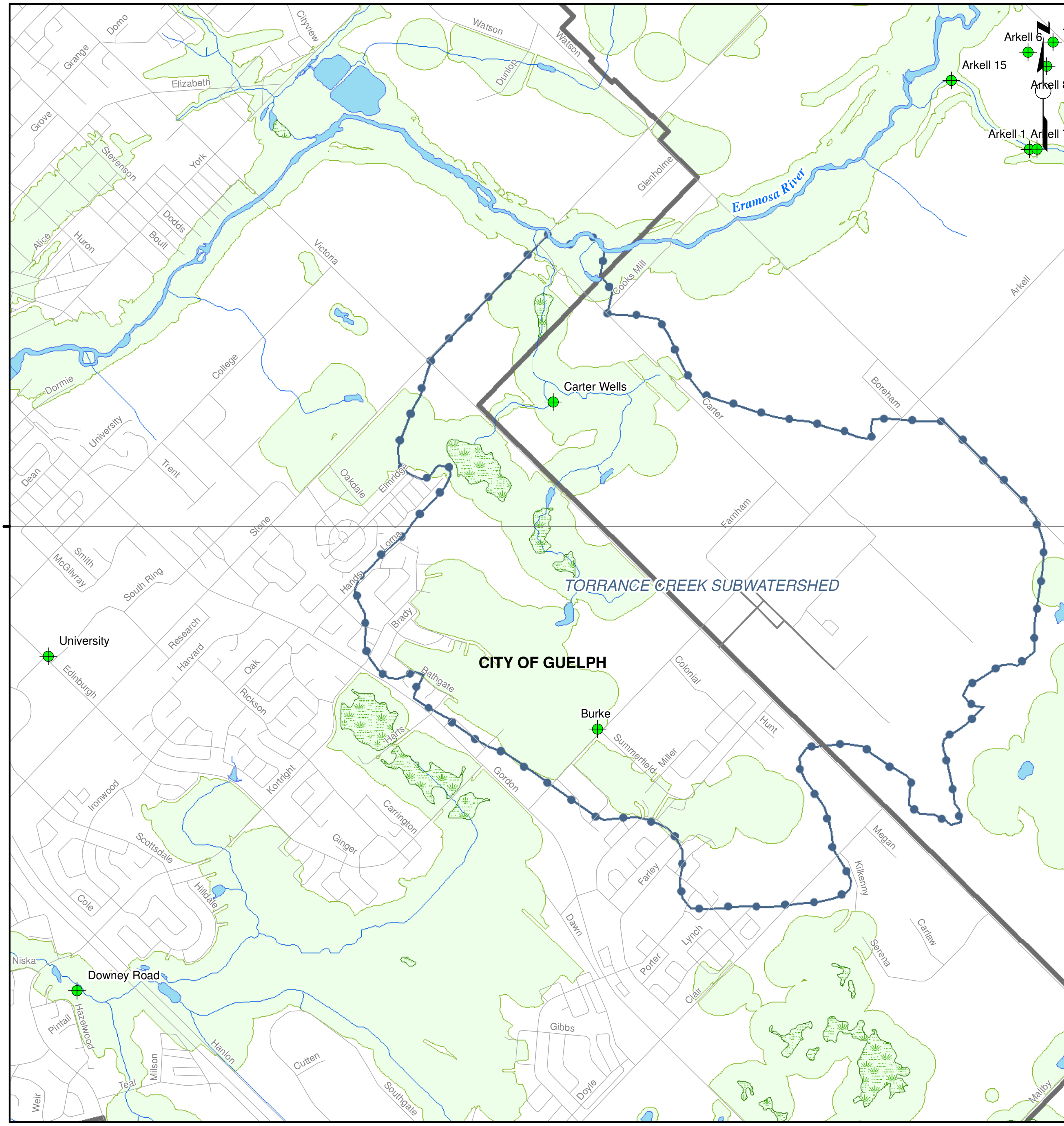
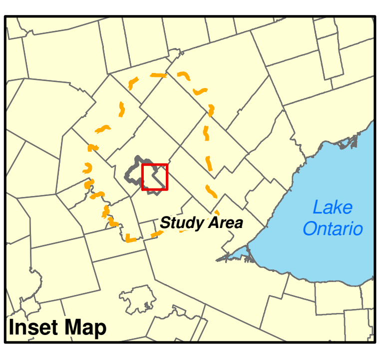
Figure 31.

IPZ 3 Vulnerability Scoring

Fig31_IPZ3_VulnerabilityScoring.mxd

Project: 2006005_GuelphSourceProtection





LEGEND

- Water Supply Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Wetland
- Open Water
- City of Guelph Boundary
- Torrance Creek Subwatershed Boundary
- Regulated Areas

Scale 1:35,000

0 1.25 2.5

Kilometres

REFERENCES:
Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

Projection: UTM Zone 17N, NAD 83
Map Version: 1; Map Date: 10-Mar-10; Created By: CC

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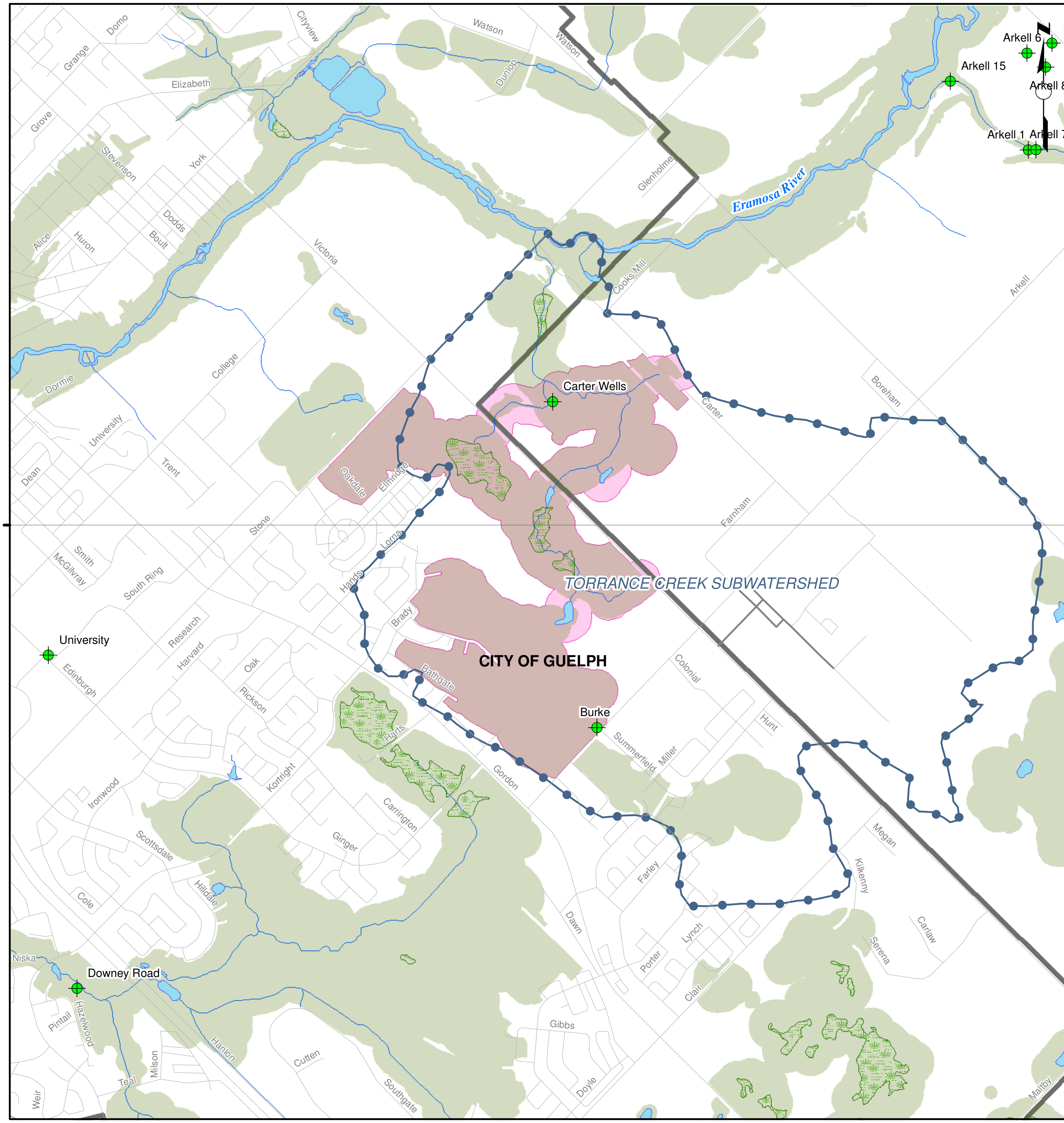
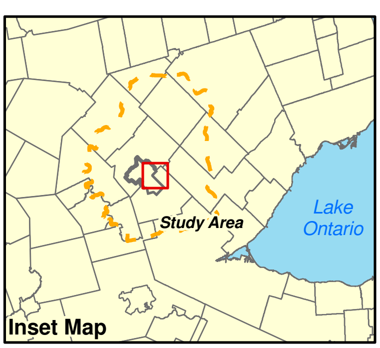
Figure 32.
Location of Carter Well and Torrance Creek





LEGEND

- Water Supply Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Rivers / Streams
- Wetland
- Open Water
- Torrance Creek Subwatershed Boundary
- City of Guelph Boundary
- Regulated Areas
- WHPA E

Scale 1:35,000

0 1.25 2.5

Kilometres

REFERENCES:

Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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Projection: UTM Zone 17N, NAD 83

Map Version: 1; Map Date: 10-Mar-10; Created By: CC

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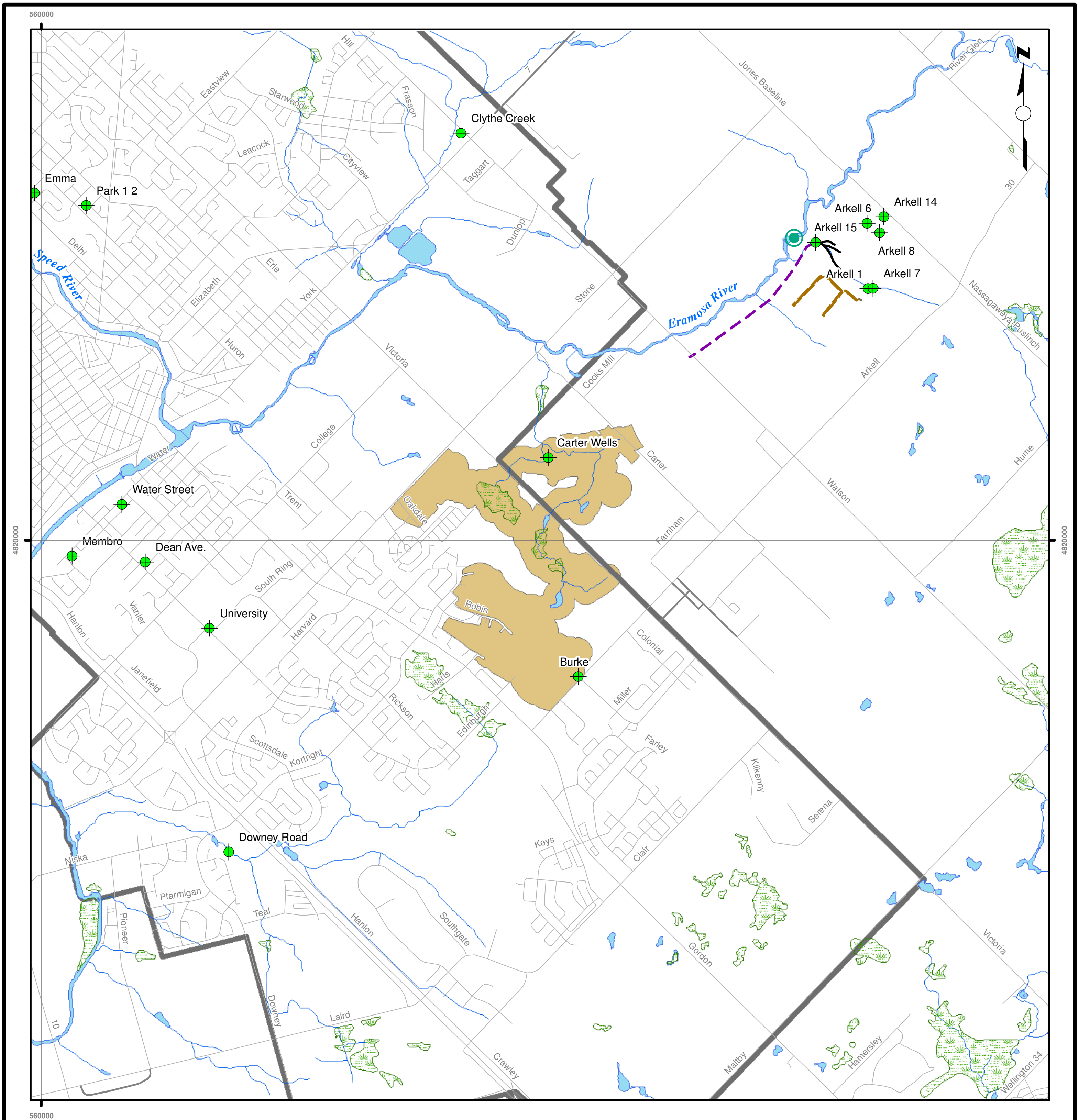
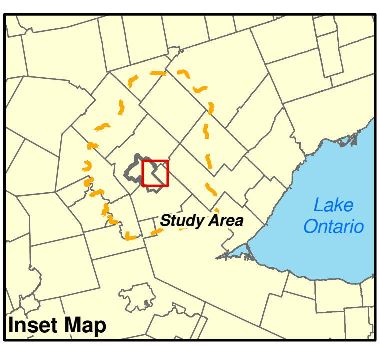
Figure 33.

Carter Well – WHPA E





LEGEND

- Eramosa River Intake
- Water Supply Wells
- Roads (collector)
- Expressway / Highway
- Rivers / Streams
- Aquaduct
- Glen Collector
- Arkell Recharge Pit and Trench
- Wetland
- Open Water
- City of Guelph Boundary
- Vulnerability Score 8

Scale 1:50,000

0 1.25 2.5

Kilometres

REFERENCES:
Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008

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Figure 34.

Carter Well – WHPA E Scoring