Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

CENTRE WELLINGTON SCOPED TIER THREE WATER BUDGET ASSESSMENT
PHYSICAL CHARACTERIZATION REPORT

Report Prepared for:
GRAND RIVER CONSERVATION AUTHORITY

Prepared by:
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EXECUTIVE SUMMARY

This physical characterization report was developed from the review of dozens of historic reports and datasets from a variety of data sources in the Township of Centre Wellington, and surrounding area. This document summarizes the current understanding of the physical characterization of the Centre Wellington Study Area.

A Tier Two Water Budget and Local Area Risk Assessment was completed for the Grand River Watershed in 2009. Six subwatersheds that contain municipal water supply systems were flagged at having an elevated potential for hydrologic stress from a groundwater or surface water perspective. This included the Irvine Creek Groundwater Assessment Area, which contains the towns of Fergus and Elora. Consequently, this Scoped Tier Three Assessment was initiated to evaluate the long term sustainability of the quantity of the water supply system. The Scoped Tier Three Assessment will assess the current and future stresses on municipal drinking water sources under current and future conditions. The assessment will include the development of a water budget tool (groundwater flow model) that will be applied to evaluate how water levels in municipal wells will change under various current and future conditions such as changes in land use development, current and future increases in municipal water takings, as well as long term drought conditions. The water budget tool will be used to help the Township evaluate the long term sustainability of their bedrock aquifers.

The Study Area for the Scoped Tier Three Assessment encompasses the Township of Centre Wellington and portions of neighbouring townships of Woolwich, East Garafraxa, Mapleton, Guelph/Eramosa, Wellington North and Towns of Grand Valley and Erin.

Physical Setting

Across the Study Area, ground surface topography gently slopes from a high of approximately 500 m above sea level (asl) in the north and northeast to a low of 325 m asl along the Grand River valley, east of Elmira. Steep vertical cliff faces exist in the Elora Gorge where the Grand River eroded through the overburden and bedrock in the Elora area. The Grand River runs in a southwesterly direction through the centre of the Study Area, and its main tributaries include Irvine, Carroll and Swan Creek. The Conestogo and Speed rivers, and their respective tributaries are other notable watercourses in the Study Area.

Coldwater streams in the Study Area include portions of the Grand River, and Swan, Lutteral and Canagagigue creeks and their tributaries. Reaches of streams that host coldwater fish species such as brook trout and brown trout are reliant on groundwater discharge, which is the flow of groundwater into a river or stream. The temperature of groundwater remains fairly constant (approximately 13^{O}C) and this flow of cool water moderates the stream temperature in hot summer months, and prevents the stream (and fish) from freezing in the winter. Provincially Significant Wetlands (PSWs) of interest to this

study include the Speed-Lutteral-Swan Creek Wetland Complex, Living Springs Wetland Complex, North Cumnock Wetland Complex, Ritch Tract Swamp, Alma Wetland Complex, Inverhaugh Valley Wetland Complex, and North Woolwich Swamp.

Overburden (soils that rest on top of bedrock) in the Study Area was laid down thousands of years ago as glaciers advanced and retreated through the Study Area. Most of the overburden in the area is fine-grained (i.e., silt and clay) with some sand-rich areas at surface in the south, and the northeast (associated with the Orangeville Moraine). For this report, the overburden model layering from a recent study of the area, conducted by the Ontario Geological Survey (Burt and Dodge 2016) was adopted.

The thickness of overburden in the Study Area overlying bedrock reaches a maximum of 100 m to the west and northwest of Alma, to zero thickness where bedrock lies at surface along the Elora Gorge and in other river valleys. Bedrock geology beneath the Study Area consists primarily of dolostone bedrock was derived with the support of the Ontario Geological Survey (F. Brunton).

The bedrock surface in the Study Area slopes from north to south and in many areas, valleys were eroded into the top of the bedrock surface and subsequently infilled with overburden. One bedrock valley of interest runs from the northeast to southwest from the southern limits of Belwood Reservoir to the southern reaches of Elora. Some portions of the bedrock valley are infilled with sands, although the majority of the valley is interpreted to be infilled with finer-grained silts and clays. Other buried bedrock valleys include a valley that lies north of Fergus and Elora and trends along the same direction as the modern day Grand River, and another valley that trends in a north-south direction in the western portion of the study area, west of Arthur to west of Alma.

Hydrogeologic Setting and Groundwater Flow

The overburden and bedrock within the Study Area were subdivided into layers of aquifers and aquitards. Aquifers are layers of permeable rock, sand or gravel from which groundwater can be extracted. Aquitards, in contrast are layers of impermeable rock (e.g., shale), silt or clay that restrict the flow of water from one area to another. Within the Study Area, four main overburden aquifers were characterized (i.e., Grand River Outwash Aquifer; Orangeville, Elmira, and Upper Waterloo Moraine Sands and Equivalents Aquifer; Pre-Catfish Creek Outwash Aquifer; Pre-Canning Aquifer) as well as four bedrock aquifers (e.g., upper fractured bedrock; Guelph, Goat Island, and Gasport Formations). All of the municipal water supply wells in Fergus and Elora draw water from the fractured bedrock of the Guelph, Goat Island and Gasport Formations.

Regionally, groundwater flow in the overburden follows ground surface topography and declines from a high of approximately 480 m asl in the north, to a low of approximately 325 m asl in the south along the Grand River. Locally, groundwater discharges into rivers and streams, notably the Grand River, Irvine Creek, Swan Creek and others. Groundwater flow in the Guelph, Goat Island and Gasport Formations, flow from the north at elevations of approximately 475 m asl, to lower elevations in the south at approximately 310 m asl. Bedrock water levels are depressed locally in the vicinity of the municipal water supply due to municipal pumping.

Centre Wellington Water Supply System and Water Demand

Centre Wellington relies solely on groundwater to meet their municipal water demand. Three municipal wells are located in Elora (Wells E1, E3 and E4), and six in Fergus (Wells F1, F2, F4, F5, F6, and F7) and all wells are completed in bedrock aquifers. Four additional municipal water supply wells lie within the Study Area and supply the towns of Arthur (three wells) and Marsville (one well). Water takers that pump more than 50 m^3/d (50,000 L/d) for non-agricultural purposes need to apply for a Permit to Take Water from the Ontario Ministry of Environment and Climate Change. As part of the permitting process, permit applicants need to show the ministry that their water taking will not negatively impact the environment or other water users. In some cases hydrogeological studies and field work are undertaken to assess whether unacceptable impacts may occur, and how to mitigate any impacts that may occur (MOECC 2016b).

The 2016 average municipal taking amount is 5,422 m^3/day for the Centre Wellington wells and 993 m^3/day for the Arthur and Marsville wells. Since 2012, the municipal water demand in Centre Wellington has increased slowly from approximately 4,800 to 5,422 m^3/day, which is below the permitted rates for the wells.

There are 14 non-municipal permits to take water within the Study Area that draw water from the groundwater system (9 permits) and surface water system (5 permits). The total permitted rates for the nine groundwater takings is approximately 19,233 m^3/day; however, the actual reported water takings are much lower with a total estimated consumptive water taking of only 5,756 m^3/day. (*Consumptive water takings are water takings were the water is removed from an aquifer or river and not returned to the same aquifer or river*). Other water takings were also considered in the study including agricultural and domestic water takings, which do not require permits from the Ministry. The Middlebrook Well was also noted as another potential water taker within the Study Area, although it does not currently have an active permit to take water.

Groundwater Testing and Monitoring

The municipal wells in Fergus and Elora were the focus of several water supply studies and pumping tests over the years. The results of those studies were reviewed and assembled as part of this project. In general, the wells produced values that were consistent with typical dolostone aquifers of this area with transmissivity values that range from 52 to 395 m^2/day in Fergus, and 38 to 158 m^2/day in Elora. The transmissivity of the aquifer at the Middlebrook Well was estimated to have a similar value that ranged from 100 to 205 m^2/day. Transmissivity is a term that describes the ability of an aquifer of a given thickness to transmit water.

Water quality data collected from the Centre Wellington municipal wells and tested for microbiological parameters, organics and inorganics was also reviewed to help identify if there were contributions from shallow overburden or deeper bedrock aquifers. Water quality in the Elora municipal wells is generally of good quality and below the aesthetic and maximum allowable concentrations as defined by the Ontario Drinking Water Standards, although elevated sulphate (bedrock sources) and chloride (anthropogenic sources) concentrations were detected. The water quality in the Fergus wells is also good with treatment in place at one well for a historical concentration of trichloroethylene (TCE), and at another well for elevated concentrations of naturally occurring iron that are above aesthetic objectives. The water quality is also noted to have elevated sulphate, hardness, magnesium, and other parameters that are typical of carbonate bedrock aquifers.

Centre Wellington staff monitor the water levels in both the municipal pumping wells and in nine municipal monitoring wells. Water levels generally decrease during the summer months and during periods of peak demand, and increase in the spring/fall due to the decreased demand and enhanced precipitation (groundwater recharge).

Water levels are also being monitored by Highland Pines Campground, near Belwood Lake, and Nestle Waters Canada. Highland Pines operates an extensive monitoring network of bedrock wells with decreasing water levels in the summer months during peak demands, and increasing water levels in spring and fall during decreased demand and enhanced groundwater recharge. Nestle monitors water levels in the Middlebrook Well and other wells in the area.

Summary

This report outlines the current understanding of the hydrology, hydrogeology, and water demands within the Study Area. It was based on review of data from a wide variety of sources. As new information, studies or information become available during subsequent stages of the project, it is expected that the characterization will evolve and become part of a continuous improvement process.

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1 INTRODUCTION

This report documents the characterization of the physical setting for the Centre Wellington Scoped Tier Three Water Budget Assessment. The characterization represents the assembly and analysis of data and knowledge from multiple sources and will provide the basis for constructing a groundwater water budget tool for Centre Wellington area.

This report is organized into the following sections:

Section 1: Introduction: comprises an overview of the tiered water budget assessment process, a review of the goals and scope of this project, an overview of relevant background reports and a description of the study team members.

Section 2: Physical Setting: describes previous water resources studies conducted in the Study Area, and the physical features of the Study Area such as topography, surface water systems, and geologic and hydrogeologic conditions.

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

Section 4: Groundwater Level Monitoring: describes the municipal and non-municipal groundwater monitoring that has occurred or is ongoing in the Study Area.

Section 5: Summary and Conclusions: summarizes the key outcomes of the report.

1.1 Scoped Tier Three Assessment

The Province of Ontario introduced the *Clean Water Act* (Bill 43) to ensure that all residents have access to safe drinking water. Under the *Clean Water Act*, Source Protection Authorities are required to conduct technical studies to identify existing and potential water quality and quantity threats to municipal drinking water. The *Clean Water Act* requires that each Source Protection Committee prepare an Assessment Report for their Source Protection Area in accordance with Ontario Regulation 287/07 (General Regulation; MOE 2006) and the *Technical Rules: Assessment Report, Clean Water Act, 2006* (MOECC 2015). A requirement of the Assessment Report is the development of water budgets that assess the threats to water quantity sources under a tiered framework. Tier One Water Budget and Tier Two Water Budget and Subwatershed Stress Assessments (Tier Two Assessment) within this framework evaluate the subwatershed's hydrological stresses, while the Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) examines the threats to water quantity sources and evaluates the ability of the sources to meet a community's current and future drinking water needs.

This Scoped Tier Three Assessment is a technical study that will assess the current and future stresses on municipal drinking water sources under a variety of scenarios, including changes in groundwater recharge due to land use development, current and future increased municipal and non-municipal water takings, as well as climate change. The assessment will evaluate the safe additional available drawdown at each municipal well in the Centre Wellington water supply system, and it will develop and apply water budget tools to evaluate how water levels will change within the municipal wells under various current and future scenarios.

Tier Three Assessments that have taken place across the province evaluated the ability of existing municipal wells or intakes to sustain current and future water demands when faced with increased municipal water demand, reductions in recharge due to land use development, and climatic variability. This study is termed a "Scoped Tier Three Assessment" as many of the Risk Assessment Scenarios evaluated in other Tier Three Assessments cannot be evaluated at this time. Specifically, the future land development conditions in the Centre Wellington area are uncertain as the Township's Growth Management Strategy only goes to 2031 and is not yet complete. Second, it is known that additional groundwater wells will likely be required to meet the future demands, but as the Township has not yet initiated a Long Term Water Supply Master Plan or Class Environmental Assessments for new water supplies, it does not have any wells that meet the definition of a "Planned System." (A Planned System is defined as 1) an approved well under the Environmental Assessment Act, 2) a well identified as the preferred solution under the Environmental Assessment Act, or 3) a well that would serve a reserve under the Indian Act). As such, the future scenarios defined by the Technical Rules would not lead to meaningful results for the Township and should not be run at this time.

This Scoped Tier Three Assessment will develop and apply water budget tools that will support the Township in safe-guarding their long term municipal water supplies. Scenarios will be designed (in cooperation with Township staff) and run to help identify the potential change in water levels in municipal wells due to: a) additional hypothetical future water supply wells (to be determined following input from the Water Supply Master Plan study expected to start in summer 2017); b) climatic variability (and climate change); and c) reductions in recharge due to future changes in land use development.

1.1.1 Water Budgets in the Grand River Conservation Authority and Centre Wellington Area

A Tier Two Assessment was completed for the Grand River Watershed in 2009 (AquaResource 2009a, 2009b). The study identified subwatersheds and groundwater assessment areas that contain municipal water supply systems that had an elevated (moderate or significant) potential for hydrologic stress from a surface water or groundwater perspective. Within the Grand River Watershed, the Tier Two Assessment identified the following groundwater assessment areas as having a moderate or significant potential for hydrologic stress with an estimated percent water demand that is equal to or exceeding 10% when considering future (e.g., 25-year) water demands:

- Irvine Creek
- Canagagigue Creek
- Upper Speed
- Central Grand
- Mill Creek
- Big Creek

The percent water demand calculated for the Irvine Creek Groundwater Assessment Area was 5% under current conditions (low potential for hydrologic stress), but 10% under future water demands in the drought scenario (moderate potential for hydrologic stress). Following the Tier Two Assessment, the Grand River Conservation Authority (GRCA) updated the water taking data for the Irvine Creek Groundwater Assessment Area (Shifflett 2015) and the results of that analysis showed a reduction in the percent water demand for future water demands from 10% to 9.3%, which reduced the potential hydrologic stress level from moderate to low. However, when uncertainty was taken into account, the percent water demand exceeded the 10% threshold for the increased Future Demand scenario (10.4%) and the Future Demand scenario with reduced recharge (12.6%; Shifflett 2015). The Tier Two Assessment results identified that the potential for hydrologic stress in this area is linked to growth within Centre Wellington; however, the growth targets from Wellington County had not been incorporated into the Township's Official Plan, so the associated stress level was uncertain. When a water taker applied for a new permit in the area in close proximity to the municipal wells, a Tier Three Assessment for the groundwater supply sources in the Irvine Creek Groundwater Assessment Area (i.e., Fergus and Elora) was initiated to examine the long-term sustainability of these municipal water supply sources.

1.2 Project Goals and Objectives

The objective of this Tier Three Assessment is to evaluate the long-term sustainability of the municipal water supply systems in the Township of Centre Wellington from a quantity perspective, and to identify potential water quantity threats to the water sources. The impact of increased municipal water demand, changes in land use development and climatic change will be evaluated using quantitative water budget tools. Impacts will be evaluated by reviewing the simulated changes in water levels in the municipal wells, groundwater discharge to coldwater streams and water table decline under Provincially Significant Wetlands (PSWs). The understanding gained through this evaluation will help the Township manage a reliable water supply system for current and future generations.

One of the steps in the Tier Three Assessment process is to estimate existing and future municipal water demands. This includes estimating Existing (current), Committed, and Planned demands. These terms have established definitions under the *Clean Water Act,* and generally, refer to the amount of water required to meet the projected growth of a municipality as identified in a Master Plan or Environmental Assessment. As the Planned Demand for the Township has not yet been assessed through the municipal planning process, the full requirements of a Tier Three Assessment under the Clean Water Act cannot be completed. As such, the objective of this project is to develop the tools and information to support water management decisions, and apply those tools to complete the Tier Three Assessment; however, the incorporation of results into the Grand River Source Protection Plan may be delayed.

To meet these overall study goals, a comprehensive review and refinement of the local hydrogeologic characterization was undertaken for the Centre Wellington Study Area (Figure 1) with a focus on the Fergus and Elora areas. This report describes the characterization and conceptual model components of the Tier Three Assessment, which form the basis for the development of the groundwater flow model. A separate report will document the development and calibration of the Tier Three Assessment groundwater flow model, and the subsequent Risk Assessment portions of the project.

The objectives of the physical characterization portion of the study were to review all available data and characterize the physical setting in the regional and local well field areas; estimate the consumptive groundwater demands in the area; develop conceptual hydrostratigraphic layers that represent the regional and local three-dimensional hydrostratigraphy; and analyze available groundwater monitoring data across the Study Area.

This document outlines the current conceptualization of the hydrogeology of the area. This conceptualization will evolve and be updated as part of a continuous improvement process when new geologic, hydrogeologic, or hydrologic data are collected.

1.3 Study Team

The Tier Three Assessment was completed by Matrix Solutions Inc. (Matrix) and was directed by a technical team composed of representatives from the GRCA (part of the Lake Erie Source Protection Region), Township of Centre Wellington, Wellington Source Water Protection (partnership of County of Wellington municipalities to implement the Clean Water Act) and the Ministry of the Environment and Climate Change (MOECC).

All documents produced in the Tier Three Assessment are reviewed by a Provincial Peer Review Team consisting of the following individuals: Dr. Hugh Whiteley, P.Eng. (University of Guelph), Dr. David Rudolph, P.Eng. (University of Waterloo) and Dr. Rob Schincariol, P.Geo. (University of Western Ontario).

2 PHYSICAL SETTING

2.1 Study Area

The Study Area (Figure 1) encompasses the Township of Centre Wellington, which contains the communities of Fergus and Elora, and portions of the neighbouring townships of Woolwich (Region of Waterloo), East Garafraxa and Town of Grand Valley (Dufferin County), and the townships of Mapleton, Guelph/Eramosa, Wellington North, and Town of Erin within Wellington County. The City of Guelph lies south of the Study Area. The Study Area was delineated at a large enough extent so that the boundaries will not influence predictions during the future numerical modelling stages of the project. The Study Area needs to be large enough to fully encapsulate the area where drawdown associated with future municipal pumping will occur, as delineated in the future Risk Assessment phase of the study. The Study Area boundaries were guided by surface water features and interpreted groundwater flow in the overburden and bedrock, discussed in Section 2.6 of this report.

Centre Wellington is completely reliant on groundwater to meet their municipal water demand. Three municipal water supply wells are located in Elora (Wells E1, E3, E4), and six municipal wells are located in Fergus (Wells F1, F2, F4, F5, F6, and F7). All of the water supply wells are completed in bedrock and were constructed between 1935 and 2002. Packers were installed in Wells E3, F2, and F7.

Land use within the Study Area is predominantly agricultural with urban areas and natural heritage features, such as wetlands and forests, scattered throughout (Figure 2). Agricultural land use where till plains are mapped at surface have reduced evapotranspiration compared to forested lands; where tile-drainage exists on the fields, infiltration is increased and overland runoff reduced compared to undrained fields; recharge to groundwater will be reduced if the increase in amount of infiltrated water diverted to rapid subsurface discharge to the stream from the drained field exceeds the increase in the amount of infiltration on the drained field.

2.2 Previous Water Resources Studies in the Centre Wellington Area

A large number of regional- and local-scale water resource studies have been carried out within the Study Area. Table 1 summarizes, in chronological order, some of the hydrologic, geologic, and hydrogeologic studies completed in the Study Area that were referenced during the background review and development of the conceptual model. These studies will also provide important information (e.g., aquifer parameters) during later stages in this Tier Three Assessment. Appendix A includes additional references reviewed.

TABLE 1 Water Resources and Geology Studies Completed in the Study Area

Project	Author	Description
Three-Dimensional Modelling of Surficial Deposits in the Orangeville-Fergus Area of Southern Ontario	Ontario Geological Survey (OGS; Burt and Dodge 2016)	This report summarizes the field work, data, and analysis used to build a three-dimensional model of surficial deposits in the Centre Wellington area between the Region of Waterloo in the west and the Town of Orangeville in the east. The digital data from the study is also available.
Revised Water Demand and Tier 2 Water Quantity Stress Assessment, Irvine River Groundwater Assessment Area	Grand River Conservation Authority (Shifflet 2015)	This memo details the revisions to the water taking data for the Irvine River Groundwater Assessment Area, the reassessment of percent water demand for current and future conditions and the reassessment of the hydrologic stress level.
Grand River Source Protection Area Approved Assessment	Lake Erie Source Protection Committee (LESPC 2015)	This report outlines the results of the Source Protection studies undertaken to date including the Watershed Characterization, and a summary of the Tier One and Tier Two Water Budget, Subwatershed Stress Assessments, and the Water Quality Threats and Issues of the Source Protection Area.
Municipal Wells F1, F6 and E3, Investigation of Chloride in Drinking Water	Golder Associates Ltd. (Golder 2015a)	This report summarizes the investigation of chloride trends relative to pumping trends in Wells F1, F6, and E3 and seeks to clarify whether chloride should be an issue under the Clean Water Act.
Well Field Capacity Assessment	Golder Associates Ltd. (Golder 2013)	This report describes a well field capacity assessment and groundwater monitoring plan for Elora and Fergus in accordance with Permit To Take Water (PTTW) conditions. The study involved the installation and testing of multi-level monitoring wells, execution and analysis of three aquifer tests, and refinement and application of a MODFLOW groundwater model previously applied in the Study Area.
Preliminary Well Field Capacity Assessment and Proposed Testing Program	Golder Associates Ltd. (Golder 2010a)	This report describes the background review of previous well testing and preliminary shutdown/pumping testing results in Fergus and Elora. Preliminary testing was conducted to inform the development of a more comprehensive testing program.

Project	Author	Description
Source Protection Vulnerability, Issues and Threats Assessment	Golder Associates Ltd. (Golder 2010b)	This report describes a vulnerability, issues, and threats assessment for the municipal water supply systems in Fergus and Elora. Work included delineation of wellhead protection areas (WHPAs), identification of water supply system issues, threats to water quality and data gaps/uncertainties.
Integrated Water Budget Report, Grand River Watershed	AquaResource Inc. (AquaResource 2009a)	This document summarizes the development and refinement of the water budget framework for the Grand River Watershed based on the integration of GAWSER and FEFLOW numerical models. This included an estimate of water demand across the watershed.
Tier 2 Water Quantity Stress Assessment	AquaResource Inc. (AquaResource 2009b)	This study estimates the potential stress of subwatersheds and Groundwater Assessment Areas in the Grand River Watershed where the Percent Water Demand (ratio of estimated water demands to available surface and groundwater supply) exceeds certain prescribed thresholds under current and future conditions.
Revisions to the Early Silurian Stratigraphy of the Niagara Escarpment	OGS (Brunton 2008; 2009)	This study describes a revised stratigraphy of bedrock aquifers and aquitards in the Niagara Escarpment area of southern Ontario.
County of Wellington Groundwater Protection Study	Golder Associates Ltd. (Golder 2006)	This report describes the assimilation of hydrogeological data/mapping from individual townships, into a Wellington County dataset. The study involved assessing water use, identifying potential contaminant sources, delineating WHPAs, and developing a groundwater management and protection strategy.
Middlebrook Water Source – Elora – Long Term Source Sustainability	Gartner Lee Ltd. (Gartner Lee 2005)	This report details the results of a 30-day pumping test of the Middlebrook Well in compliance of a PTTW.
Fergus Municipal Well F2, Well Integrity Testing and Pumping Test Data Assessment	Blackport Hydrogeology Inc. (Blackport 2005)	This report presents a summary of a pumping test and well integrity testing at Fergus Well F2.
Fergus Well 1, Additional GUDI Assessment	Blackport Hydrogeology Inc. (Blackport 2003)	This report summarizes additional GUDI hydrogeological evaluation of Fergus Well F1.
Hydrogeological Investigation, Elora Test Well 4B	Anderson GeoLogic Ltd. (AGL 2002a)	This report documents the hydrogeological study on Test Well TW4B which became Elora municipal Well E4.
Groundwater Management and Protection Strategies, Groundwater Management Study	Blackport Hydrogeology Inc. (Blackport 2002a)	This report characterizes the water resources of the Township of Centre Wellington, evaluates groundwater quantity and quality, and develops recommendations for the management and protection of groundwater supplies.
Wells F1 and F2 GUDI Assessment	Blackport Hydrogeology Inc. (Blackport 2002b)	This report summarizes a Groundwater Under Direct Influence of surface water (GUDI) hydrogeological assessment of Fergus Wells F1 and F2.
Water Resources Characterization, Groundwater Management Study, Township of Centre Wellington	Blackport Hydrogeology Inc. and WHI (Blackport and WHI 2002)	This report built on earlier characterization work to protect groundwater resources and recommends groundwater management and protection strategies. MODFLOW groundwater flow model application is discussed.
Hydrogeological Investigation, Fergus Test Well 7B	Anderson GeoLogic Ltd. (AGL 2002b)	This report documents the hydrogeological study on Test Well 7B which became Fergus municipal Well F7.
Hydrogeological Investigation, Proposed Middlebrook Water Company Facility	Naylor Engineering Associates Ltd. (Naylor 2001)	The report summarizes a hydrogeological investigation of the Middlebrook Well consisting of aquifer well tests and assessment of well interference.

Project	Author	Description
Municipal Well 3 Water Supply Investigation	Terraqua Investigations Ltd. (Terraqua 1992a)	This report summarizes a groundwater yield investigation at the proposed site for Elora municipal Well 3 which involved drilling, well construction, and testing.
Water Supply Investigation, Fergus Municipal Well 2	Terraqua Investigations Ltd. (Terraqua 1992b)	This report summarizes the hydrogeological investigation of Fergus Well F2, which included a pumping test and inventory and impact assessment on private wells.
Supplemental Water Supply Investigation, Fergus Municipal Well 6	Terraqua Investigations Ltd. (Terraqua 1992c)	This report describes a 72-hour performance test of Fergus Well F6 to determine drawdown and possible well interference in support of a PTTW application.
Investigation of TCE Contamination	Terraqua Investigations Ltd. (Terraqua 1991)	The study assessed the hydrogeology in Fergus, investigated the source of trichloroethylene (TCE) found in F1 and private wells, and assessed possible mitigation measures.
Fergus Groundwater Investigation, Well No. 6	International Water Supply Ltd. (IWS 1989)	This report documents the construction and assessment of Fergus Well F6.

2.3 Ground Surface Topography and Drainage

Within the Study Area, ground surface topography slopes from the north, with a high of approximately 500 metres above sea level (m asl); toward the south elevations decline to 325 m asl along the base of the Grand River valley (Figure 3). Steep changes in ground surface topography occur along the 20 m high vertical cliff faces of the Elora Gorge where the Grand River eroded through bedrock in the Elora area.

Local topographic lows are present where rivers and streams eroded the ground surface; these include the topographic lows along Swan and Cox creeks south and east of Elora (Figure 3). Local topographic highs coincide with the Orangeville Moraine, which is present in the northeastern limits of the Study Area in the Township of East Garafraxa (Burt and Dodge 2016), and the Elmira Moraine, present in the northern portion of the Township of Woolwich (Bajc and Shirota 2007). Surface water flow in the Study Area follows ground surface topography, with the primary drainage features flowing to the south and main tributaries flowing from the west and east.

The following sections provide additional details on the surface water features including the watercourses, water bodies, thermal regimes, and wetlands.

2.3.1 Rivers and Creeks

The primary watercourse in the Study Area is the Grand River, which runs southwest through the centre of the Study Area (Figure 4). The Grand River enters the Study Area in the northeast, in the Township of East Garafraxa and flows southwest into the Township of Centre Wellington where it enters Belwood Reservoir. From Belwood Reservoir, the Grand River flows on bedrock, through the centre of Fergus and the south side of Elora where it enters the Elora Gorge. As the Grand River continues southward, it transitions to flowing on modern alluvium deposits and leaves the Study Area just south of West Montrose, within the Region of Waterloo.

The main tributaries to the Grand River within the Study Area include Irvine Creek, Carroll Creek and Swan Creek (Figure 4). Irvine Creek originates in the northern part of the Township of Centre Wellington, flows southward where it passes through Salem and enters the Grand River on the west side of Elora. Carroll Creek originates near Alma and flows southward, then eastward and eventually joins the Grand River south of Elora. Swan Creek enters the Grand River from the east, downstream of the confluence with Carroll Creek. Cox Creek and Canagagigue Creek both originate in the southern part of the Study Area, from the east and west, respectively but do not converge with the Grand River until further downstream. Various other minor tributaries feed into the Grand River from the east and west, along its path through the Study Area.

Other notable watercourses in the Study Area include the Conestogo River and its tributaries (e.g., Mitchell's Creek, Farleys Creek, and Brandy Creek) to the west and northwest, and the Speed River and its tributaries to the east and southeast (e.g., Lutteral and Marden creeks; Figure 4).

2.3.1.1 Streamflow Characteristics

Two stream gauges were used to characterize the hydrologic response of the area immediately surrounding Fergus/Elora; Irvine Creek near Salem (02GA005) and Speed River at Armstrong Mills (02GA040). The stream gauges on the main Grand River (i.e., West Montrose gauge, which has a drainage area of 1,170 km^2) were not included as their hydrologic response is predominantly influenced by the Upper Grand watershed (e.g., County of Dufferin) and is not reflective of the Study Area. A third stream gauge, Eramosa at Watson Road, while located outside of the Study Area, was included for comparative purposes. Table 2 lists the details of the two Water Survey of Canada gauges, including a summary of the major surficial geology types found upstream of each gauge.

TABLE 2 Stream Gauges and Summary of Surficial Geology in the Drainage Areas

Gauge Name	Gauge ID	Drainage Area (km^2)	Period of Analysis	Surficial Geology Composition (% Area)			
				Sands and Gravels	Till	Silts and Organics	Bedrock
Irvine Creek near Salem	02GA005	195	2007-2014	15%	78%	6%	<1%
Speed River near Armstrong Mills	02GA040	174	2002-2016	61%	33%	6%	<1%
Eramosa Above Watson Road	02GA012	230	2002-2016	55%*	27%	11%	7%

* includes Wentworth Till, a stony sandy till.

While the drainage areas for the Irvine Creek and Speed River stream gauges are comparable, the composition of the surficial geology differs significantly. Surficial geology in the Irvine Creek catchment is predominantly till at surface (~80%), with minor sands and gravels (~15%), whereas the Speed River near Armstrong Mills is predominantly (~60%) sand and gravel deposits associated with the Orangeville Moraine. As a result, the Irvine Creek catchment was expected to display a flashier response to rainfall events, where the Armstrong Mills catchment was expected to have a larger baseflow component. The majority of the Study Area, especially surrounding Fergus and Elora is dominated by till plains (see Section 2.4.2 for details) and as such, the Irvine Creek near Salem gauge is considered representative of the hydrologic response of most ungauged watercourses in the Study Area. The Eramosa River catchment is geologically similar to the Speed River near Armstrong Mills; however, the drainage area for the Eramosa River contains a higher proportion of hummocky topography. Hummocky topography is characterized by an undulating topography that traps overland runoff and provides additional opportunity for water to infiltrate and recharge the groundwater flow system. As such, the hydrologic regime of the Eramosa River is baseflow dominated.

Streamflow characteristics were evaluated using graphical and statistical analysis of hydrograph data. A baseflow separation algorithm (BFLOW; Arnold et al. 1995, Arnold et al. 1999) was used to estimate the proportions of overland runoff and baseflow. Baseflow is composed of contributions from a variety of sources, including; regional and local groundwater flow systems; rapid subsurface runoff (also known as interflow); releases from wetland storage; or wastewater treatment plant discharges. Baseflow values presented herein are the aggregate of all of these sources. While the evaluated gauges may be minimally impacted by releases from wetland storage or wastewater treatment plan discharges, baseflow values include contributions from local and regional groundwater systems, as well as rapid subsurface flow. As a result, baseflow values will be higher than the groundwater recharge rates that sustain the regional and local groundwater flow systems. The period of analysis was limited to recent years where Water Survey of Canada operated and maintained the gauges.

Table 3 contains the average annual streamflow yield, baseflow yield (both expressed as mm/year), as well as the proportion of total flow that is considered to be baseflow. The Irvine Creek near Salem gauge produces approximately 100 mm/year more streamflow than Armstrong Mills. This difference is due to soil type, proportion of the area with tile drained agricultural fields, and ground surface topography that leads to higher overland runoff, especially in the cooler half of the year in the Irvine watershed. Another difference is the reduced proportion of wet areas with forest vegetation that reduces annual evapotranspiration on the Irvine. Of the 475 mm/year of streamflow generated by Irvine Creek, only 120 mm/year is estimated to be baseflow. Baseflow, also known as dry-weather flow, is, in southern Ontario, sustained from groundwater discharge with some minor contribution from releases from surface storage in wetlands. The Irvine Creek catchment's baseflow component is estimated to be 25% of total streamflow as compared to 41% on the Armstrong Mills catchment. This difference between streamflow patterns in the two watersheds is expected given the surficial geology present in each of the drainage areas and the enhanced groundwater recharge on the Orangeville Moraine area where ground surface topography is hummocky and runoff is reduced. In general, the high proportion of till in the Irvine Creek catchment lead to a runoff-driven system, while the high proportion of sand and gravel deposits upstream of the Armstrong Mills gauge results in a predominantly baseflow driven system for that catchment.

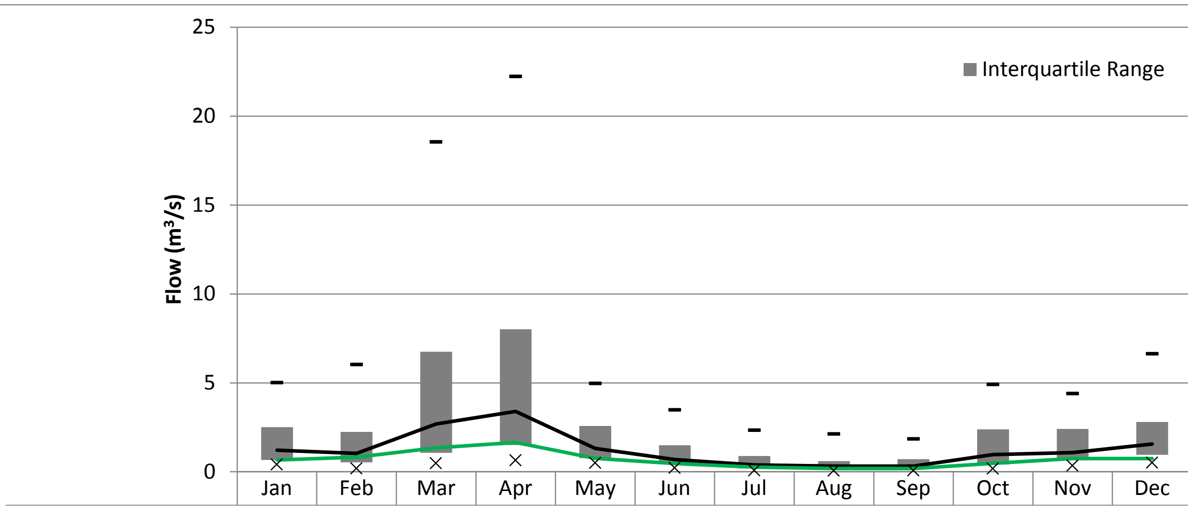
TABLE 3 Summary of Streamflow Characteristics

Gauge Name	Streamflow Yield (mm/year)	Baseflow Yield (mm/year)	Baseflow (% of Total Streamflow)
Irvine Creek near Salem	475	120	25%
Speed River near Armstrong Mills	398	163	41%
Eramosa River at Watson Road	354	199	56%

Charts 1, 2, and 3 display the 10th, 50th and 90th percentile daily flows, as well as the interquartile range (25th to 75th percentile) for each month of the period of record for the three stream gauges considered. The 10th percentile represents the flow that is exceeded 10% of the time (high flow) during a month, while the 90th

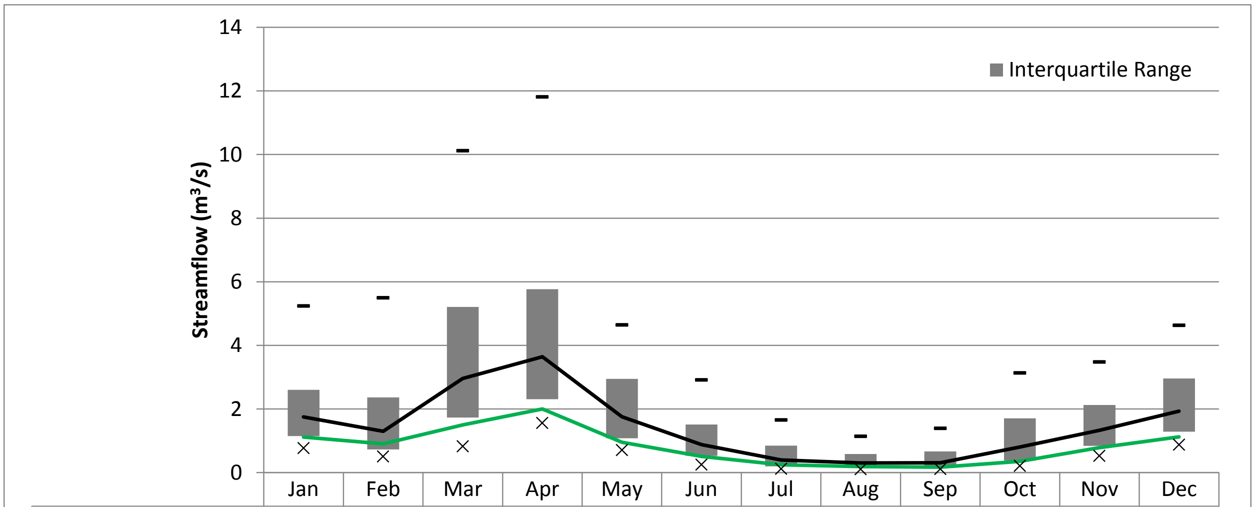
percentile represents the flow that is exceeded 90% of the time (low flow). These charts illustrate the observed streamflow variability within and between months, and the median monthly baseflow estimate.

All three gauges exhibit responses typical of southern Ontario watercourses. Streamflow peaks in the months of March and April are due to the spring freshet, and decline through early summer to a summer low, before increasing in the fall as soilwater storage levels increase, infiltrability decreases, and evapotranspiration rates reduce toward their mid-winter minimum. The key differences between the gauges illustrate the Irvine Creek catchment's runoff-dominated system, a subdued response watershed with mixed soils, and a baseflow driven system with extensive high-infiltrability soils. Despite the drainage areas for Irvine Creek and the Speed River being almost equal, the 10th percentile daily flows for the Irvine Creek in March and April are almost double that observed at the Armstrong Mills gauge. Eramosa at Watson Road, while having a drainage area that is 30% larger, has a similar 10th percentile flows for the month of April as Armstrong Mills. This is strong evidence that when compared to the Upper Speed River and Eramosa River, there is minimal infiltration occurring in the Irvine Creek during this time period, as water is converted to overland runoff. Baseflow for the Irvine Creek is lower than both Armstrong Mills and Eramosa River during the fall, winter, and spring periods. During the summer months, both Armstrong Mills and Irvine Creek produce significantly less baseflow than the Eramosa River, indicating that Armstrong Mills and Irvine Creek are systems that do not receive a reliable source of baseflow during dry periods.



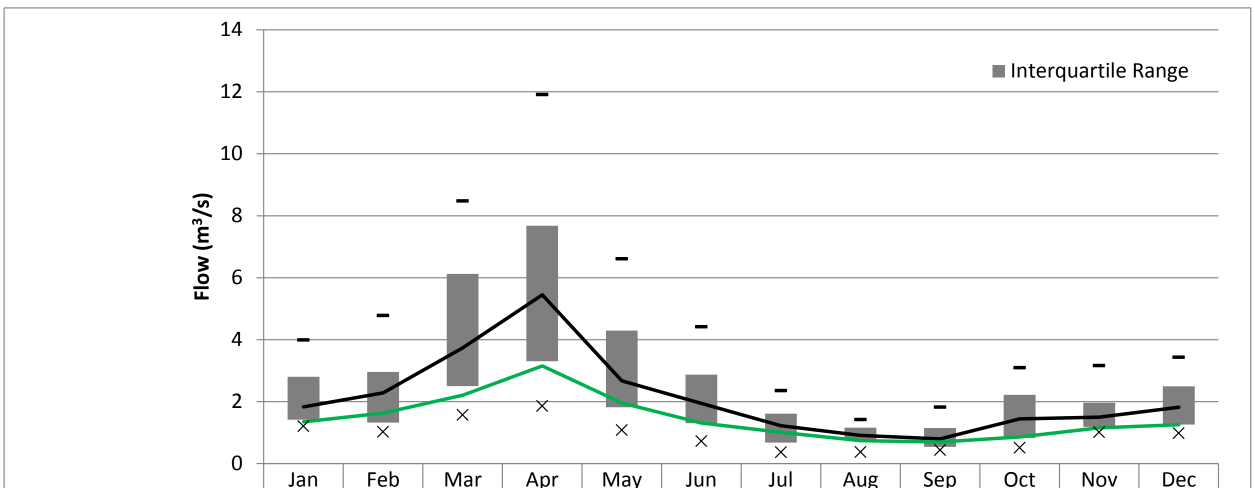
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10th Percentile	5.0	6.0	18.6	22.2	5.0	3.5	2.3	2.1	1.8	4.9	4.4	6.6
Median Streamflow	1.2	1.0	2.7	3.4	1.3	0.7	0.4	0.3	0.3	1.0	1.1	1.6
90th Percentile	0.4	0.2	0.5	0.6	0.5	0.2	0.1	0.1	0.1	0.2	0.3	0.5
Median Baseflow	0.7	0.8	1.3	1.6	0.8	0.5	0.3	0.2	0.2	0.5	0.7	0.7

CHART 1 Irvine Creek near Salem Flow Regime



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10th Percentile	5.2	5.5	10.1	11.8	4.6	2.9	1.7	1.1	1.4	3.1	3.5	4.6
Median Streamflow	1.8	1.3	3.0	3.6	1.8	0.9	0.4	0.3	0.3	0.8	1.3	1.9
90th Percentile	0.8	0.5	0.8	1.6	0.7	0.2	0.1	0.1	0.1	0.2	0.5	0.9
Median Baseflow	1.1	0.9	1.5	2.0	1.0	0.5	0.2	0.2	0.2	0.4	0.8	1.1

CHART 2 Speed River near Armstrong Mills Flow Regime



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Interquartile Range	1.4	1.6	3.6	4.4	2.5	1.6	0.9	0.4	0.6	1.4	0.8	1.2
25th percentile	1.4	1.3	2.5	3.3	1.8	1.3	0.7	0.7	0.5	0.8	1.2	1.3
10th Percentile	4.0	4.8	8.5	11.9	6.6	4.4	2.4	1.4	1.8	3.1	3.2	3.4
Median Streamflow	1.8	2.3	3.7	5.5	2.7	1.9	1.2	0.9	0.8	1.4	1.5	1.8
90th Percentile	1.2	1.0	1.6	1.9	1.1	0.7	0.4	0.4	0.4	0.5	1.0	1.0
Median Baseflow	1.3	1.6	2.2	3.2	2.0	1.3	1.0	0.7	0.7	0.9	1.2	1.3

CHART 3 Eramosa River at Watson Road Flow Regime

2.3.2 Thermal Regimes

The thermal regime of a river or stream can provide a general indication of the groundwater and surface water interaction. Groundwater discharge is important to the watercourses within the Study Area as the discharge areas may be critical for fisheries spawning and also in moderating the temperature and flow in creeks and streams. The rate of groundwater discharge into the creeks and rivers depends on the elevation of the water table in the area surrounding the creek (which varies seasonally), as well as the hydraulic conductivity of the streambed materials. The thermal regimes of the surface water features in the Study Area, as mapped by the Ministry of Natural Resources and Forestry (MNRF), is illustrated on Figure 4.

Cold water streams, which may support cold water fish communities (e.g., brook and brown trout) include the Grand River south of Belwood Reservoir to West Montrose, Swan Creek, Lutteral Creek, and portions of Canagagigue Creek and their tributaries in the southeastern portion of the Study Area. Brook and brown trout spawning locations are illustrated on Figure 4, and they generally occur in areas where transmissive geologic units, such as outwash deposits are mapped at surface. The mapping of cold water streams agrees with detailed water temperature mapping that shows cooler zones along the Grand River, north of West Montrose (Friends of the Grand River 2002). Cool water streams are prevalent just west of the Grand River, particularly in Carroll Creek, Irvine Creek, and smaller tributaries, as well as small tributaries along Belwood Reservoir. These cool water features coincide with areas where tills are mapped at ground surface (e.g., Tavistock Till).

2.3.3 Reservoirs and Lakes

The largest water bodies in the Study Area are Belwood Reservoir, Woolwich Reservoir, and Guelph Lake (Figure 4). All three reservoirs were formed through the construction of dams on their respective water courses, and they provide recreational fishing and boating opportunities to the public. Belwood Reservoir (approximately 6.7 km^2) is located along the Grand River upstream of Fergus, was formed in 1942 and is regulated by the Shand Dam. The Woolwich Reservoir (approximately 1 km^2) is located just north of Elmira on Canagagigue Creek and is regulated by the Woolwich Dam. Guelph Lake (approximately 3.6 km^2) was formed in 1974 through the construction of Guelph Dam and is located on the Speed River just upstream of the City of Guelph.

2.3.4 Provincially Significant Wetland Complexes

Wetlands are an integral part of groundwater flow systems. Wetlands are defined as any water body with water saturation in the rootzone, at, or above the soil surface, for some time during the year. There are two general types of hydrologic settings in which wetlands occur. Wetlands in isolated upland depressions with no outlet stream often have water levels that are perched or mounded above the regional water table. These wetlands provide recharge to the groundwater flow system but are otherwise not connected to the flow system. Wetland features that are perched or mounded above the water table, are common in the Study Area, but are not a focus of this investigation.

Wetlands also lie in depressions that intersect the regional water table. The water levels in these wetlands are expressions of the water table elevation at that location and the hydroperiod of these wetlands reflect the temporal variation in water table position. Depressions with low-elevation spill locations on their perimeter usually generate intermittent or perennial outflow in an outlet stream. Wetlands in these settings often have a complex spatial and temporal pattern of interaction with the groundwater flow system with recharge to, and discharge from, the water table aquifer being possible, although discharge predominates for any wetland that is the source of a perennial stream.

There are five types of wetlands: fens, bogs, swamps, marshes, and open-water marshes. Fens are peat-forming wetlands that receive nutrients from sources other than precipitation, such as drainage from surrounding soils and/or groundwater discharge. Bogs are peat-forming wetlands that receive all or most of their water from precipitation rather than runoff, groundwater discharge, or streams. Swamps are characterized by forest, shrub, or reed cover and may partially depend on nutrient-rich groundwater derived from mineral soils. Marshes are sites which intercept groundwater but are permanently or periodically inundated by nutrient rich surface water. While marshes may intercept the groundwater table, they typically recharge the underlying groundwater flow system. Open water marshes are deeper, normally perennial pools within wetlands, and shallow portions of lakes and rivers.

The classification of a wetland describes the interaction between the wetland and the underlying groundwater flow system. In general, fens and swamps occur at locations of net local or regional groundwater discharge, and bogs and marshes occur at locations of net local or regional groundwater recharge. For this reason, fens and swamps, particularly those that are designated by the MNRF as PSWs, are the focus of this study (Figure 4). PSWs are identified by the province as the most valuable wetlands, and they are classified using a standard science-based ranking system that assesses the wetland functions and societal values (MNR 2017).

The following PSWs were mapped in the Study Area and are illustrated on Figure 4: Speed-Lutteral-Swan Creek Wetland Complex, Living Springs Wetland Complex, North Cumnock Wetland Complex, Ritch Tract Swamp, Alma Wetland Complex, Inverhaugh Valley Wetland Complex, and North Woolwich Swamp. All of these PSWs are composed of both marsh and swamp wetland classes, and it is common to have several different types of wetlands within a wetland complex or PSWs. Other wetlands that exist in the Study Area, but are not classified as PSWs, include the Irvine Creek Wetland Complex, Salem South Wetland Complex, Central Carroll Creek Wetland Complex and Creek Bank Valley Wetland. These non-PSWs are also composed of both marsh and swamp wetland classes, except for Central Carroll Creek Wetland Complex, which is classified as a swamp.

The closest wetlands to the Centre Wellington municipal wells are located approximately 1.1 km southwest of Well E4 (Inverhaugh Valley Wetland Complex; marsh and swamp) and less than 1.0 km east and southwest of Well F5 (Speed-Lutteral-Swan Creek Wetland Complex; marsh and swamp). Wells F6 and F7 are located adjacent to the Irvine Creek Wetland Complex (marsh and swamp); however, this wetland is not a PSW.

The PSWs in the Study Area were characterized using existing wetland mapping in the Study Area. In subsequent stages of this project (i.e., the groundwater flow modelling or Risk Assessment phases), if groundwater discharge to a PSW is predicted to occur due to increases in municipal pumping but the impact of that reduction is not understood due to lack of wetland characterization data, field work may be undertaken to fill that data gap and determine the significance of the reduction in groundwater discharge on the function of the PSW.

2.4 Geologic Setting

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

2.4.1 Regional-Scale Bedrock Geology

Bedrock geology beneath the Study Area consists of dolostone and shale Paleozoic bedrock formations that overlie deeply buried Precambrian basement rocks (Figure 5; Armstrong and Dodge, 2007). The Paleozoic bedrock formations dip regionally to the southwest (Johnson et al. 1992) and in some areas with bedrock valleys, the bedrock is buried beneath thicker Quaternary- aged overburden sediments. Paleozoic bedrock outcrops are found in the Fergus and Elora area along the banks of the Grand River valley, notably the Elora Gorge, where 20 m high vertical faces of rock are exposed. Figure 5 also illustrates the location of bedrock outcrops along portions of Swan Creek, Cox Creek, Lutteral Creek, Marden Creek, and the Speed River where overburden was eroded.

Recent work on the Silurian geology of southwestern Ontario has led to changes in naming and understanding of the depositional environments of the Silurian sequence stratigraphic framework (Priebe, Neville and Brunton 2017; 2014; Brunton et al 2013; Brunton and Brintnell 2011; Brunton et al. 2012). The understanding of the bedrock units detailed in the following sections, including formation descriptions, are drawn from this recent work and other earlier studies (i.e., Brunton 2008, 2009) completed by staff at the Ontario Geological Survey (OGS). Table 4 lists the youngest formations listed at the top of the table and the oldest formations at the bottom.

TABLE 4 Paleozoic Geology beneath Study Area

Previous Conceptualization[1]		Revised Conceptualization		Lithology
Formation	Member	Formation	Members	
Salina Group (A to G Formations)				Interbedded dolostone, mudstone, and shale with lenses of evaporites
Guelph	Guelph	Guelph	Hanlon	Carbonate wackestone to mudstone
			Wellington	Medium to thickly bedded crinoidal grainstones and wackestones and reefal complexes
	Eramosa	Eramosa	Stone Road	Cream coloured coarsely crystalline dolostone
			Reformatory Quarry	Light brown to cream, thinly to thickly bedded, coarsely crystalline dolostone
			Vinemount	Dark grey to black, thin bedded, finely crystalline dolostone with shaley beds
		Goat Island	Ancaster	Medium to ash grey, chert-rich, finely crystalline dolostone

Previous Conceptualization[1]		Revised Conceptualization		Lithology
Formation	Member	Formation	Members	
Amabel (unsubdivided)			Niagara Falls	Finely crystalline, cross-laminated crinoidal grainstone (stromatoporoid dominated). Occasional reefal facies in basal succession, where present)
		Gasport	Gothic Hill	Cross-bedded crinoidal grainstone-packstone (tabulate coral dominated) with sequences of reef mound and coquina lithofacies. (Reefing-upward cycles)
		Lions Head		Finely-crystalline dolostones
		Irondequoit		Grey to pinkish-grey medium-bedded crinoidal dolostone
Reynales		Rockway		Greenish-grey argillaceous dolostone
		Merritton		Pinkish-brown argillaceous dolostone
Cabot Head		Cabot Head		Greenish-grey and red silty shale

[1] Johnson et al 1992

As illustrated on Figure 5, the Salina Group and Guelph Formation are mapped to subcrop within the Study Area. An updated plan view bedrock map consistent with the interpretation outlined in Table 4 and below has not been produced by the OGS, and as such, the subcrop boundaries are subject to interpretation and may not be exactly as illustrated.

2.4.1.1 Cabot Head Formation

The thickness of the Cabot Head Formation on a regional basis ranges from 10 to 40 m and is described as grey-green non-calcareous silty shale with thin interbeds of sandstone and limestone (Johnson et al. 1992). This unit represents the base of the stratigraphic units assessed in this study.

2.4.1.2 Lions Head, Merritton, Rockway, and Irondequoit Formations

The Lions Head, Merritton, Rockway, and Irondequoit Formations are thin (< 5 m) carbonate bedrock formations that are interpreted to be spatially continuous across the Study Area. The Lions Head Formation is a finely crystalline dolostone interpreted to be deposited in a deep water environment (Johnson et al 1992). The unit is discontinuous and where present, has a maximum thickness of 3 m within the Study Area.

The Merritton Formation consists of a bioturbated argillaceous dolostone with a fine crystalline matrix and dark shaley partings. This formation was previously mapped in other areas as the Fossil Hill Formation. This unit is present throughout the Study Area with an estimated thickness of less than 2 m.

The Rockway Formation is a thin unit (unit varies from 1 to 2 m in the Study Area), and is mapped as a fine crystalline argillaceous dolostone to limestone with shaley partings (Brunton 2008).

The Irondequoit Formation is another thin unit (less than 5 m in the area) consisting of thickly to medium-bedded crinoidal dolomitic limestone (Brunton 2008).

2.4.1.3 Gasport Formation

The Gasport Formation is a cross-bedded crinoidal grainstone-packstone (dolostone) with reef mounds (Brunton 2008). The thickness of this formation varies widely across southern Ontario with thicknesses of only a few metres in the Fergus and Elora areas to over 60 m in the Guelph area. The thickness of the unit is dependent on the presence of interpreted reef mound complexes and the depth of water present when the reef mounds were formed (Brunton 2008). The reef mounds, crinoidal grainstones and coquina beds, are interpreted to have zones of increased primary and secondary porosity (i.e., numerous vugs, cavities, and fractures). This unit was previously mapped and referred to as the Amabel Formation in previous studies in the Study Area (e.g., Golder 2013; Gartner Lee 2005; Blackport and WHI 2002; Blackport 2002a, 2002b; Terraqua 1991).

2.4.1.4 Goat Island Formation

The Goat Island Formation is interpreted to be present across the Study Area and consists of two members: the Ancaster Member (upper) and Niagara Falls Member (lower; Brunton 2008). The Ancaster Member is a finely crystalline dolostone and its thickness varies depending on the thickness of the underlying Gasport Formation (Brunton 2008). The Niagara Falls Member is a finely crystalline dolostone (crinoidal grainstone) with small reef mounds.

2.4.1.5 Eramosa Formation

The Eramosa Formation consists of three members: the Vinemount Member (lower), Reformatory Quarry Member (middle), and the upper Stone Road Member (Brunton 2008).

The Vinemount Member is approximately 10 m in thickness on average in the Guelph area, but pinches out in the eastern portion of the Study Area. The Vinemount is composed of thinly bedded, fine crystalline dolostone with shaley beds that give off a distinctive petroliferous odour when broken (Brunton 2008). This unit contains mud-rich and microbial mat-bearing lithofacies is dark grey to black in colour, and was commonly mapped in previous studies of the area as the Eramosa Member of the Guelph Formation (Johnson et al. 1992).

The Reformatory Quarry Member is a fairly thin (approximately 5 m) dolostone unit with a seismite marker bed traced from Niagara to the Bruce Peninsula (Brunton 2008). The Reformatory Quarry Member is present in the eastern part of the Study Area but pinches out before reaching Fergus.

The Stone Road Member is a cream coloured coarsely crystalline unit that is thin (< 5 m) or absent in cores within the Study Area and is difficult to distinguish from the overlying Guelph Formation.

2.4.1.6 Guelph Formation

The Guelph Formation consists of medium to thickly bedded crinoidal grainstones and wackestones (dolostone) with lesser reefal complexes (Brunton 2008). The upper portion of the Guelph Formation is characterized as being finer-grained and laid down in a lagoonal environment, whereas the lower facies of the Guelph Formation is interpreted to be a reefal facies.

2.4.1.7 Salina Group

The Salina Group consists of interbedded shale, mudstone, dolostone, and evaporites (including gypsum and salt; Johnston et al, 1992). The formation is the uppermost bedrock unit in the western portion of the Study Area, and is not present in the central and eastern portions of the Study Area.

2.4.2 Karst Features within the Study Area

Karst is a distinctive type of topography or terrain, formed primarily by the dissolution (chemical erosion) of carbonate rocks such as limestone or dolostone due to the movement of acidic groundwater or surface water over thousands to millions of years (Brunton 2009). Groundwater can enlarge the openings in subsurface fractures, especially along pre-existing faults or fractures and bedding planes, creating an extensive subsurface drainage system. Over time, the fractures increase in size and groundwater flow through these conduits increases. Karst landscapes include a wide range of closed-surface depressions, well-developed underground drainage system and few streams or rivers.

Karstification of bedrock leads to large fracture apertures, groundwater pathways that are fairly continuous within the bedrock aquifers. The fractures dominate the groundwater flow, but the storage of water lies in the lower-permeability rock (matrix). Understanding karstification is important in areas where groundwater is the primary source of drinking water, because contaminants associated with agricultural activities (i.e., nitrates, bacteria from livestock waste, pesticides, etc.), can flow rapidly through karstic bedrock.

Karst tends to be most pronounced on the uppermost bedrock surface where bedrock is, or was exposed. Paleokarst refers to karst that forms on bedrock surfaces that were exposed in the past, but these surfaces were subsequently buried by sediments deposited on top, or by changes in groundwater flow conditions (Worthington 2011).

Within the Study Area, sinkholes and other surficial expressions of karstic terrain have not been mapped; however, small caverns and caves and well eroded joints or fractures are visible along the banks of the Grand River, and southeast of the Study Area along the Eramosa River valley where bedrock outcrops at surface (Kunert et al 1998; Kunert and Coniglio 2002). In these areas, water flowing over the dolostone bedrock slowly dissolves the carbonate rock enhancing existing fractures and the interconnected vuggy portions of the bedrock. The upper surface of the Guelph Formation is interpreted to be a paleokarst horizon and within the Study Area, the upper surface of the Guelph was eroded by several river valleys (see Section 2.4.3 for details).

2.4.3 Bedrock Topography

A major unconformity separates the bedrock from overlying overburden deposits. This unconformity represents the period between the deposition of the Paleozoic bedrock (Section 2.4.1) and the deposition of overlying Quaternary-aged sediment (Section 2.4.4) approximately 200 million years later. During this period, the bedrock surface was exposed and extensively eroded by repeated glacial advance and retreat cycles (Armstrong and Carter 2010; Johnson et al., 1992). The bedrock topographic surface reflects the erosion and drainage patterns that were established during that time period.

Figure 6 illustrates the bedrock topographic surface within the Study Area. This surface was created using all available borehole data across the Study Area. This includes high quality overburden core holes drilled by the OGS (Burt and Dodge 2016), and high quality bedrock corehole and borehole data outlined in Section 2.4.2. Lower quality data used to define the define the top of bedrock surface also included the domestic well picks from the Orangeville- Fergus mapping project (Burt and Dodge 2016) and MOECC Water Well Information System (WWIS) data (received from the MOECC in February 2017) outside the extent of the OGS mapping domain. Deep overburden wells that were found to "push down" the bedrock surface were also used to define the bedrock surface. Control points were added in areas where bedrock is mapped to outcrop at surface (OGS 2010) and along interpreted thalwegs of buried bedrock valleys defined by Burt and Dodge (2016), Greenhouse and Karrow (1994), Lee (1975) and other valleys interpreted by Matrix as part of this project.

Following assembly of the data, the top of bedrock points were qualitatively and quantitatively analyzed to ensure spatial consistency, which identified and reconciled outliers whereby adjacent boreholes, or boreholes at the same location had different top of bedrock elevations. Second, the data was reviewed to ensure there was appropriate representation of buried channels, given data quality and distribution, and that overburden push-down points were consistent with the nearby top of bedrock picks. Over 91% of the original data points were retained and used in the development of the dataset (i.e., 19,700 points were retained out of a total of approximately 21,200 points in the original dataset).

The final completed bedrock surface illustrated on Figure 6 was interpolated using the natural neighbour algorithm to produce a surface with 10 m cell sizes. The top of bedrock surface was then constrained to ground surface using a high quality (2 m) digital elevation model (DEM) of the Study Area.

Bedrock topography within the Study Area slopes from north to south and ranges from approximately 450 m asl north of Belwood Reservoir at the north end of the Study Area to 310 m asl along the Grand River in the southern reaches of the Study Area (Figure 6). The most significant buried bedrock valley is termed the Elora Bedrock Valley. The eastward origin of the valley starts on the west side of Belwood Reservoir, continues southwest where it crosses below the Grand River at the Elora Gorge, and continues trending southwest to the Grand River on the south side of Elora (Figure 7). This valley geometry and infill have been studied by many researchers including Jensen (1975), Lee (1975), Hilton (1978) and Greenhouse and Karrow (1994). The valley is interpreted to be approximately 15 km long and incised approximately 15 to 60 m into the bedrock surface, with the base of the valley varying from U shaped to V shaped along the length (Greenhouse and Karrow 1994). The interpreted depth and continuity of the valley are based on borehole logs that intersect the valley and the valley slopes and geophysical surveys that were run across the valley (Burt and Dodge 2016; Greenhouse and Karrow 1994). The infill of the valley varies along the length of the valley and is discussed in greater detail in Section 2.4.6.

A buried bedrock valley is also present north of Fergus and Elora, and trends along the same direction as the modern day Grand River. The depth and infill of this valley is not well understood due to the lack of higher quality data in the area; however, it is interpreted to be incised approximately 20 m into the surrounding bedrock surface (Figure 6).

Another bedrock depression that trends in a north-south direction, in the western portion of the Study Area was also noted (Figure 6). This broad bedrock depression runs from an area west of Arthur in the north, to an area west of Alma in the south, and loosely coincides with the location of the Salina Group subcrop boundary (see Section 2.4.4 and Figure 8 for details). The location and depth of this feature is coincident with the top of bedrock surface developed by the Ontario Geological Survey (Gao et al 2006).

2.4.4 Regional Quaternary Geology

Within the Study Area, overburden units deposited during the Quaternary period (2 million years before present (ybp) to 10,000 ybp) detail a record of repeated ice advance and retreat of ice lobes that originated from the Huron-Georgian Bay and the Erie-Ontario lake basins (Bajc and Dodge, 2011). Evidence of till units as old as Early Wisconsinan are interpreted to exist in the southeastern portions of the Study Area; however, the majority of the overburden sediments present are Late Wisconsinan-aged fine- grained tills and more recent outwash deposits. Figure 8 illustrates the surficial geology mapped within the Study Area (OGS 2010), and Table 5 lists the overburden deposits (from youngest to oldest) as mapped by Karrow (1968), Cowan (1976) and Burt and Dodge (2016).

TABLE 5 Summary of Overburden Deposits in the Study Area

Geologic Unit/ OGS Name	Lithology	Comments
Grand River Outwash Aquifer (AFA2)	Dirty sand and gravel	DEM defines the ground surface and top of this unit.
Port Bruce Stade Aquitard – Tavistock and Port Stanley Tills (ATB1)	Sandy, silty to clayey till	
Orangeville, Elmira, and Upper Waterloo Moraine Sands and Equivalents Aquifer (AFB1)	Fine to coarse sand and gravel	Unit is thickest in the northeast (Orangeville Moraine) and southwest (Elmira Moraine).
Maryhill Till and Glaciolacustrine Sediments (Aquitard; ATB3)	Silty to clayey till, silt, clay	
Catfish Creek Drift Aquitard (ATC1, AFC2, and ATC2)	Stoney, silty to sandy till	Catfish Creek Outwash (AFC2) has very limited distribution in the Study Area; as such, ATC1 and ATC2 grouped together.
Pre-Catfish Creek Outwash Aquifer (AFD1)	Sand and gravel	Unit infills some buried bedrock valleys and is present in the western portions of the Study Area associated with the Elmira Moraine.
Canning Drift Aquitard (ATE1)	Silty to clayey till, silt, clay	
Pre-Canning Aquifer (AFF1)	Sand and gravel	Unit is thickest in the southwestern portions of the Study Area near Elmira.
Pre-Canning Aquitard (ATG1)	Stony, silty to sandy till	Present in central and western portion of the Study Area.

Identification and correlation of till sheets and their associated stratigraphic order provide the basis for the reconstruction of the glacial history of the Study Area. Studies used both physical and chemical data from field and laboratory observations to identify and relate stratigraphic units from one location to another. The glacial history, including depositional environments, sedimentary characteristics, and stratigraphic framework of overburden sediments in the Study Area, is summarized in the following sections. In general, till (diamict) in the Study Area is predominately fine-grained (silty/clayey) and often represents aquitard units. Coarser-grained sand and gravel, deposited in glacial outwash material form discontinuous upper overburden aquifers. A summary of the Quaternary glacial history and sedimentary deposits of the Study Area is presented in Burt and Dodge (2016) and is summarized in the following subsections with the oldest sediments described first. In the naming convention used by the OGS (Burt and Dodge 2016; Bajc and Shirota 2007), the first two letters identify if the unit is interpreted as an aquitard (AT) or an aquifer (AF), and the latter two characters correspond to the sequence of the units, with A (and 1) as the youngest sequence and F (and 3) as the oldest.

2.4.4.1 Pre-Canning Aquitard (ATG1)

The Pre-Canning aquitard unit within the Study Area consists of one or two older subglacial tills that overlie bedrock or the contact zone aquifer across much of the Study Area. The aquitard is composed of several distinctly different tills, but it is not clear if the tills represent multiple ice advances or oscillations in the ice margin followed by a regional ice advance. The unit is thicker in the western portions of the Study Area and thins to the east, with some thicker accumulations occurring in the base of the buried bedrock valleys. There are no surface exposures of this unit within the Study Area, but high quality core describe the unit as a stony to very stony, sandy silt till, characterized by a distinctive yellowish brown colour with rare beds of dirty sand and/or gravel (Burt and Dodge 2016).

2.4.4.2 Pre-Canning Aquifer (AFF1)

The Pre-Canning aquifer within the central and eastern portions of the Study Area is largely absent except for sand and gravel deposits that form small, isolated aquifers that reach thicknesses of up to 7 m in the northeast portion of the Study Area. These sands were interpreted to be laid down as subaquatic fans in this area (Burt and Dodge 2016).

In the western portion of the Study Area, thick glaciofluvial sand and gravels form a Pre-Canning aquifer that is up to 25 m thick in the Elmira area and northwestern portion of the Study Area (Bajc and Shirota 2007; Bajc et al. 2014).

2.4.4.3 Canning Drift (ATE1)

The Canning Drift Aquitard within the Study Area consists of a stone-poor, fine-textured diamicton and glaciolacustrine sediments that exist sporadically and discontinuously across the Study Area. The aquitard is largely absent in the area surrounding Elora, Fergus, and areas to the southeast, but is present in the north and northeast where it reaches thickness of up to 15 m. This unit is thickest in the northwest where it reaches over 30 m in thickness. The two units (i.e., Pre-Canning aquitard coarse-textured till and Canning aquitard fine-textured till and glaciolacustrine deposits) were readily distinguished in overburden core within the Study Area; however, the aquitard is more difficult to interpret using lithologic descriptions in water well records (Burt and Dodge 2016). As such, the aquitard may be more continuous than it was interpreted, or the unit may also have been deposited and subsequently eroded during subsequent ice advances, as was the case in the nearby Region of Waterloo area (Bajc and Shirota 2007).

2.4.4.4 Pre-Catfish Creek Outwash (AFD1)

The Pre-Catfish Creek Outwash aquifer within the Study Area consists of a discontinuous, thin (i.e., generally less than 10 m) silt and fine-grained sand. The aquifer was interpreted to be laid down in a glaciolacustrine environment during the break-up and retreat of the ice lobe that deposited the Canning Till (ATE1). The aquifer is interpreted to infill a portion of the Elora buried bedrock valley where its thickness reaches 50 m, but borehole and geophysical surveys suggest the aquifer is laterally discontinuous along the buried bedrock valley (Greenhouse and Karrow 1994; Lee 1975).

2.4.4.5 Catfish Creek Drift (ATC1, AFC2, and ATC2)

The Catfish Creek Drift within the Study Area includes tills and stratified sediments that form a regional aquitard across southwestern Ontario (Bajc et al. 2015). Within the Study Area, the Catfish Creek Drift is thickest in the west and central regions (typically up to 20 m) and is fairly continuous except where eroded by rivers and streams, including the Grand River. The deposit thickens in the Region of Waterloo area, especially in bedrock topographic depressions and valleys and thins, becomes more sporadic and discontinuous in an eastward and southeastward direction across the Study Area. The nature of the Catfish Creek Drift is variable across the Study Area; the till is silty and more stone-poor in the northern, western, and central portions of the Study Area than areas in the eastern portion of the Study Area. The most recognizable deposits of Catfish Creek Till are over consolidated, stony to stony sandy silt till and described as “concrete-like” till or “hardpan” on water well records.

2.4.4.6 Maryhill Till and Associated Glaciolacustrine Sediments (ATB3)

The Maryhill Till Equivalent aquitard is a fine-grained clay rich till that consists of typically, stone-poor, silt- to clay-rich diamicton, occasional beds of silt and sandy silt diamicton, and glaciolacustrine silt and clay (Burt and Dodge 2016). Within the Study Area, this unit is discontinuous but rests on top of the Catfish Creek Till (Drift) in many areas. Where present, this unit is 0 to 7 m thick on average, but thickens to approximately 30 m on the Orangeville Moraine in the northeast.

2.4.4.7 Orangeville, Elmira, and Waterloo Moraine Sediments and Equivalents Aquifer (AFB1)

The Orangeville and Elmira Moraine Sediments/ Upper Waterloo Moraine Sands and Equivalents aquifer consist of sands and gravels deposited when ice-walled lakes formed during the initial breakup of ice that deposited the Catfish Creek Till. The Orangeville Moraine lies to the northeast of the Study Area (northeast of Belwood Reservoir) and the Elmira Moraine lies in the southwestern limits of the Study Area in the Region of Waterloo. The coarse-grained sediments associated with each of these moraines were deposited in the same period and they overlie the fine-textured tills and silt- and clay-rich glaciolacustrine aquitard deposits (ATB3) and the main Catfish Creek Till aquitard (ACT1; Burt and Dodge 2016).

The nature of these sediments varies across the Study Area. Northeast of the Study Area along the core of the Orangeville Moraine, this unit consists of laterally extensive beds of small boulders, cobbles and gravels that are overlain by cross-bedded gravels and cobble gravels, and interfingered with, and overlain by, trough cross-bedded gravel, gravelly sand and sand (Burt and Dodge 2016). The nature and structure (i.e., bedding) of these sediments indicates they were deposited in a very high-energy glaciofluvial environment, such as an ice-proximal setting. Away from the core of the moraines where we have thicknesses of up to 60 m, the unit thins to less than 5 m and consists of lower energy depositional conditions and is characterized by beds of rippled, fine-grained sand and silty sand with interbeds of coarser-grained sand typical of conditions present further away from the ice margin. This unit is thin (< 2 m) or absent in the Elora and Fergus areas and the southeastern portion of the Study Area.

2.4.4.8 Port Bruce Stade Aquitard (ATB1)

The Port Bruce Stade aquitards (i.e., Port Stanley and Tavistock tills) are the uppermost surficial aquitards across most of Study Area and are composed of subglacial tills and associated fine-textured glaciolacustrine sediments. These aquitards partially confine the margins of the Orangeville and Elmira Moraine aquifers (AFB1), and in many portions of the Study Area, these tills overlie the Maryhill Till Equivalent (ATB3) and the main Catfish Creek Till aquitards (ATC1; Burt and Dodge 2016).

The Tavistock Till is mapped at surface in the areas north and west of Fergus and Elora (Figure 8) where reaches thickness up to 30 m southeast of Arthur. It is a subglacial till that was laid down beneath the Georgian Bay ice lobe and is typically stone-poor with a silt to clayey silt matrix.

The Port Stanley Till is mapped at surface beneath Fergus and Elora and areas south and east toward the City of Guelph (Figure 8).The Port Stanley Till is a subglacial till described as a stony, silty sandy till and is coarser-grained than Tavistock Till. In these areas the Port Stanley Till averages 10 m in thickness but ranges from 0 m where eroded by rivers and stream, to 25 m thick southeast of Fergus.

2.4.4.9 Grand River Outwash Aquifer (AFA2)

The Grand River Outwash Aquifer is a thin and discontinuous aquifer that is located at surface in some portions of the Study Area, including the northern portions Fergus and north and northeast of Fergus toward Belwood Reservoir. The aquifer was laid down when ice retreated from the area for the last time, depositing outwash sands and gravels. Some thicker deposits (> 10 m) are being exploited for aggregate, both above and below the water table in areas to the northeast near the Orangeville Moraine (Burt and Dodge 2016).

2.4.5 Overburden Thickness

Figure 9 illustrates the interpreted overburden thickness beneath the Study Area. Overburden thickness is highly variable and reaches a maximum of 100 m west and northwest of Alma where the bedrock topographic surface is depressed (Figure 9) to less than a metre along the Elora Gorge and other river valleys where the overburden was eroded.

Overburden thickens in areas where ancestral drainage patterns eroded the bedrock surface creating valleys in the bedrock that were subsequently infilled with fine- and coarse-grained sediment. These valleys are present in the vicinity of Fergus and Elora and are carved up to 30 m into the surrounding bedrock area. The extent the valley was interpreted by Burt and Dodge (2016) to be steep walled with a flat bottom and this geometry was applied through the use of additional control points in the development of their top of bedrock surface. However, in this study, control points were added to enhance the extent of the valley, and honour the data that is present wherever possible (Figure 7). Interpreted bedrock valley thalwegs of Lee (1975) and Greenhouse and Karrow (1994) were referenced and used to develop the bedrock surface beneath Fergus and Elora (Figure 7).

2.5 Hydrostratigraphic Setting

Hydrostratigraphic units are developed by lumping or splitting stratigraphic units based on their hydrogeologic properties. The delineation of hydrostratigraphic units is completed using our knowledge of the regional and local understanding of the spatial distribution of stratigraphic units where higher quality data is available, and carrying this interpretation outwards using lower quality data stored in borehole logs.

Table 6 lists the hydrostratigraphic units identified within the Study Area. Aquifer units listed are defined solely on the basis of the estimated ability of the unit to yield water and do not consider water quality or vulnerability to surficial sources of contamination. Sections 2.5.1 and 2.5.2 outline the development of these hydrostratigraphic units.

TABLE 6 Summary of Hydrostratigraphic Units in the Study Area

Layer Type	Hydrostratigraphic Unit Type	Interpreted Hydrostratigraphic Unit	Primary Materials
Overburden	Aquifer	Grand River Outwash Aquifer	Sand and gravel
	Aquitard	Port Bruce Stade Aquitard – Tavistock and Port Stanley Tills	Sandy, silty to clayey till
	Aquifer	Orangeville, Elmira, and Upper Waterloo Moraine Sands and Equivalents Aquifer	Fine to coarse sand and gravel
	Aquitard	Maryhill Till and Associated Glaciolacustrine Sediments Catfish Creek Drift (Aquitard)	Silty to clayey till, silt, clay; Stoney, silty to sandy till
	Aquifer	Pre-Catfish Creek Outwash Aquifer	Sand and gravel
	Aquitard	Canning Drift Aquitard	Silty to clayey till, silt, clay
	Aquifer	Pre-Canning Aquifer	Sand and gravel
	Aquitard	Pre-Canning Aquitard	Stony, silty to sandy till
Bedrock	Aquifer	Contact Zone	Fractured bedrock
	Aquifer/ Aquitard	Salina Group	Interbedded dolostone, mudstone and shale with lenses of evaporites
	Aquifer/ Aquitard	Guelph Formation Eramosa Formation – Stone Road Member	Carbonate wackestone to mudstone (upper) and crinoidal grainstones and wackestones and reefal complexes (lower)
	Aquifer	Eramosa Formation – Reformatory Quarry	Coarsely crystalline dolostone
	Aquitard	Eramosa Formation – Vinemount	Finely crystalline dolostone with shaley beds
	Aquifer	Goat Island Formation	Finely crystalline dolostone and

Layer Type	Hydrostratigraphic Unit Type	Interpreted Hydrostratigraphic Unit	Primary Materials
			cross-laminated crinoidal grainstone
	Aquifer	Gasport Formation	Crinoidal grainstone-packstone with reef mounds and coquina lithofacies
	Aquitard	Lions Head, Irondequoit, Rockway, Merritton	Fine-crystalline mud-rich dolostone
	Aquitard	Cabot Head Formation	Silty shale

2.5.1 Bedrock Hydrostratigraphy

The structure of the bedrock surfaces across the Study Area presented in this report has capitalized on the background data review and interpretations put forth by OGS researchers (i.e., Brunton et al 2013; Brintnell 2012; Brunton and Brintnell 2011; Brunton 2008). Frank Brunton of the OGS has studied the Silurian bedrock units in the Guelph and surrounding area for over 8 years, and he provided the study team with his interpretations of the tops and bottoms of the bedrock units (referred to as bedrock "picks") within the Study Area in May 2017. Mr. Brunton also attended a peer review meeting and provided comment on the conceptual model. Matrix reviewed the geologic picks provided by Mr. Brunton, especially those made at the high quality wells within Fergus and Elora, and used his pick elevations alongside geophysical data to extend interpretations to nearby boreholes in the Fergus and Elora area to create continuous bedrock surfaces across the Study Area. Additional details are noted in the following sections.

High quality geologic data reviewed within (and surrounding) the Study Area included lithologic and geophysical data collected and interpreted by staff at the OGS in DDH5-09, DDH6-09, DDH8-09, DDH9-09, and DDH-10A (Figure 5). Core holes DDH6-09 and DDH10A-09 are not illustrated on Figure 5 as they lie outside the Study Area. Data and information from these logs were used by the OGS to extend the high quality interpretations across the Study Area.

The lithologic and geophysical (gamma and conductivity) data collected from six core holes in the Centre Wellington area were reviewed by the OGS (Mr. Brunton) and Matrix staff. These wells include MW1-12, MW2-11, MW3-11, MW4-12, MW5-11, and MW6-12 (Golder 2013; Figure 5); picks were made by Mr. Brunton at wells where continuous core was available (i.e., wells MW2-11, MW3-11, and MW5-11) and the interpretations were extended to the adjacent Wells E1, F5, and MW4-12 by Matrix using the downhole geophysical signatures (i.e., gamma logs) and stratigraphic elevations. A downhole geophysical probe was lowered into the monitoring wells to record the natural gamma levels in bedrock down the borehole. The probe measures the gamma radiation emitted by the bedrock formations, which primarily correlate with the isotopes of potassium found in clays. As such, spikes in the amplitude of the gamma signal were used to help identify subtle changes in the bedrock.

Geophysical data (i.e., gamma, conductivity, etc.) and flow profiling collected in Wells E1, F5, MW08-T3-02 and MW08-T3-04 (alongside detailed lithologic data) and the Middlebrook Well also were reviewed in detail and the Mr. Brunton provided hydrostratigraphic picks at these wells (Golder 2011, 2015b; Lotowater 2016a, 2016b, 2015a, 2015b; Figure 5). Mr. Brunton's interpreted elevations at the top of each bedrock unit changed since the drilling and initial interpretations undertaken in the Guelph Tier Three Assessment. The interpreted elevations outlined in Table 7 represent the current understanding of the elevations of the Silurian bedrock units in this area. An OGS geoscience report summarizing the interpretations in southern Ontario is currently being drafted and expected to be published in late 2017.

Lastly, Mr. Brunton interpreted the elevations at the tops of each bedrock unit at three oil and gas wells and a high quality OGS well in the Study Area. In addition, Matrix used the bedrock interpretations contained within the Oil, Gas and Salt Resource Library and the interpretations provided by Mr. Brunton to develop the bedrock layers (Section 2.5.1.1). Oil and gas wells located outside the Study Area (beyond the extents of Figure 5) were also used to constrain the top and bottom of the Salina Group in areas west of Centre Wellington.

2.5.1.1 Bedrock Conceptual Model Layer Development

Once all of the interpretations at the tops of the hydrostratigraphic units were saved to a database, the points were used to generate the top and bottom of hydrostratigraphic units across the Study Area. The surfaces were created by interpolating the elevations at the hydrostratigraphic contacts using a natural neighbour interpolation scheme (50 m grid resolution). All surfaces were constrained so deeper bedrock layers do not rise above overlying layers or ground surface.

The bedrock picks at the high quality wells in the Study Area are summarized in Table 7, along with the elevation at the base of the borehole. As outlined on Table 7, Well E1 is interpreted to be open across over 60 m of Guelph Formation before continuing through the Goat Island Formation, and into the Gothic Hill Member of the Gasport Formation. The Vinemount Member represents a competent aquitard in the Guelph area, but is interpreted to be absent in the Elora area.

Within the Fergus area, Well F7 is an open hole bedrock well that was interpreted to extend through the Guelph and Goat Island formations, into the underlying Gasport Formation (Table 7). As with the Elora wells, the Vinemount and Reformatory Quarry Members of the Eramosa Formation were interpreted to be absent in the pumping and monitoring wells within the Fergus area.

The reef mounds present in the Cambridge and Guelph areas south of Centre Wellington do not extend into the Fergus and Elora area. Core data from two boreholes drilled east of Fergus and Elora at MW08-T3-05 and MW08-T3-02 (Figure 5) were re-interpreted by Mr. Brunton in recent months and the thickness of the Gasport Formation decreased from over 40 m at these wells in the original conceptualization, to 27 to 38 m, respectively.

TABLE 7 Summary of Interpreted Bedrock Elevations at Municipal Supply Wells, Higher Quality Wells

Well Name	Elevation at Top of Bedrock Formations or Members (m asl)									Borehole Bottom Elev (m asl)
	Guelph Fm	Eramosa Fm		Goat Island Fm		Gasport Fm	Lions Head Fm	IRM Fm	Cabot Head Fm	
		Reform Quarry Mbr	Vine-mount Mbr	Ancaster Mbr	Niagara Falls Mbr					
Picks made by F. Brunton within the Fergus-Elora area										
Well F7	398.9	absent	absent	322.3	300.5	299.1				280.8
MW2-11	392.3	absent	absent	331.8	305.9	278.4	263.4	262.1	258.4	255.4
MW3-11	398.3	absent	absent	345.6	325.3	303.7	290.1	289.1	285.9	283.5
MW5-11	403.4	absent	absent	330.3	307.4	302.6	286.5	284.3	280.3	276.1
MW08-T3-04	394.7	absent	absent	352.0	308.3	283.8	absent	275.3	272.1	270.0
DDH5-09	377.4	absent	absent	311.6	253.4	250.8	242.0	240.0	235.0	232.0
Middlebrook Well	367.1	absent	absent	292.0						256.7
Picks made by Matrix Solutions Inc. within Fergus Elora by extending F. Brunton's interpretations to adjacent wells (< 400 m away from interpreted wells)										
E1	395.2	absent	absent	331.9	303.6	279.5				275.3
F5	402.2	absent	absent	347.1	322.2	303.8				296.8
MW4-12	397.4	absent	absent	319.1	301.1	295.7	276.4	273.8	272.0	268.1
Picks made by F. Brunton outside Fergus-Elora										
MW08-T3-02	358.5	345.4	absent	absent	337.3	321.9	absent	284.1	282.0	277.6
MW08-T3-05	409.3	397.3	absent	absent	394.7	355.5	absent	328.9	326.6	323.7
OGS-OFR5459	494.7	464.4	absent	460.4	430.2	427.1	413.6	410.8	406.6	`
Geco-T008389	395.1	366.9	absent	351.0	330.3	328.3	316.1	314.1	310.0	
Geco-N1-T008959	389.8	absent	absent	338.6	289.5					
Geco-WG-2-T001057	403.9	absent	absent	354.1	-	338.3				
MW08-T3-03	369.0	352.2	absent	345.3	339.5	332.4		306.0	303.8	
MW08-T3-06	absent	absent	absent	364.7	360.1	352.2		315.6	311.9	
MW08-T3-07		339.4	334.3	319.7	303.1	302.4		284.5	279.3	
MW08-T3-08		329.3	320.8	314.8	307.0	304.0		272.4	270.1	
MW08-T3-09		320.9	318.4	305.5		304.5		268.0	264.9	
MW08-T3-10		287.8	283.8	275.4	273.7	262.9		228.2	225.0	
OGS-DDH6-09	493.3			410.3	390.8	385.7	374.8	371.8	367.0	
OGS-DDH7-09	281.6			268.6	193.3	191.4		188.3	182.6	
OGS-DDH8-09	422.6	399.6	389.0	384.0	369.5	345.2	337.7		334.8	
OGS-DDH9-09		345.0	340.0	336.3	332.2	316.5		298.7	295.7	
IRM = Irondequoit, Rockway, and Merritton Formations										

The thickness of the Gasport Formation beneath Fergus and Elora was interpreted to range from 13 to 22 m in the municipal monitoring wells (Table 7). Eramosa Formation was only interpreted to be present in the eastern portions of the Study Area at and east of wells MW08-T3-02 and MW08-T3-05; the thickness of the Reformatory Quarry Member in these two wells was interpreted to be 3 and 8 m, respectively.

2.5.1.2 Summary of Bedrock Hydrostratigraphic Understanding

The municipal water supply aquifers in the Study Area are sourced from fractured bedrock including the Guelph, Goat Island, and Gasport Formation aquifers. Aquitards in the Study Area include the Vinemount Member and in places the Reformatory Quarry Member of the Eramosa Formation, as well as the Cabot Head Formation.

Within the Study Area, the lowermost unit characterized is the Cabot Head Formation. This silty shale unit is present across the Study Area and is an aquitard that represents the base of the upper carbonate bedrock units across the Study Area. Overlying the Cabot Head are the Lions Head, Irondequoit, Rockway, Merritton formations which are often considered poor aquifers that have similar hydrogeologic properties (Brunton 2008). As such, these four t formations were grouped together to create one hydrostratigraphic unit.

The Gasport Formation overlies the Lions Head, Irondequoit, Rockway, and Merritton formations, and represents a productive bedrock formation throughout the nearby Guelph area. Portions of the formation (i.e., coquina beds of the reef mounds) are interpreted to have zones of increased primary and secondary porosity (i.e., numerous vugs, cavities, and fractures) that in places can increase the transmissivity of the Gasport Formation.

The Goat Island Formation overlies the Gasport Formation and past studies (Brunton 2008) suggested that because the bedrock formation was finer-grained in nature, it was interpreted to have a lower hydraulic conductivity (or transmissivity) as compared to other formations (i.e., Gasport Formation). Recent studies that have built upon the previous work (Brunton et al 2013) suggest the formation exhibits a fining upward sequence whereby the lower member (Niagara Falls) is coarser grained than the upper (Ancaster).

The Eramosa Formation is thin throughout the Study Area (< 7 m) and where present east of Elora, the mud-rich and microbial mat-bearing Vinemount Member is interpreted to act as a competent aquitard. The Stone Road Member of the Eramosa Formation is absent or very thin (< 5 m) in this area and in previous studies (Brunton 2008), the unit was noted to have similar hydrogeologic properties to the lower portion of the Guelph Formation. As such, the Guelph Formation and Stone Road Member were grouped together to form one hydrostratigraphic unit.

The Guelph Formation is the uppermost unit in the central and eastern portion of the Study Area. Similar to the Goat Island Formation, the Guelph Formation is interpreted to exhibit fining upward sequence (Brunton et al 2013) whereby the upper portion is a mud-rich carbonate deposited in a lagoonal environment, while the lower portion is more reefal in nature. Therefore, from a qualitative perspective, one might expect the upper portion of the Guelph Formation to act as an aquitard (or weak aquifer), while the lower, reefal portion of the formation is likely to behave as a good aquifer. This trend is based on the grain-size and nature of the carbonate bedrock, and does not consider the degree of fracturing of the two members.

OGS staff published a document outlining the trends in packer testing results from across the Guelph, Fergus and Elora areas (Priebe et al 2017; Priebe et al 2014) and results of the analysis suggest that there are wide ranges of hydraulic conductivity values within bedrock units. A summary table illustrating the results of the packer tests by bedrock formation show wide variations in hydraulic conductivity values within bedrock formations. For example, the range of hydraulic conductivity values in the Gasport Formation range from 1×10^{-3} m/s to 6×10^{-7} m/s. However, the OGS suggested there may be a trend of increased hydraulic conductivity (or transmissivity) at the contact between the Ancaster and Niagara Falls members of the Goat Island Formation and at the contact between the Goat Island and Gasport Formations (Priebe et al 2017; Priebe et al 2014; Priebe and Brunton 2016).

The Salina Group is present in the western portions of the Study Area and it is composed of interbeds of dolostone and shale with evaporites (Armstrong and Carter 2010). The formation is considered an aquitard or poor aquifer.

2.5.2 Overburden Hydrostratigraphy

2.5.2.1 Hydrostratigraphic Layers

The OGS compiled subsurface geologic data from numerous data sources to create a hydrostratigraphic model of the overburden deposits in the Orangeville-Fergus area (Burt and Dodge 2016). Data sources included sediment exposures in aggregate pits, road cuts, river valleys, as well as stratigraphic descriptions from 43 continuously cored boreholes (drilled to the top of bedrock) and water-well records, seismic profiles, mapped surficial sediments, and a literature review of subsurface interpretations. The OGS compiled this data and created a hydrostratigraphic model that consisted of 17 hydrostratigraphic units (i.e., 16 overburden units and 1 bedrock unit). The OGS developed their hydrostratigraphic model layers by interpolating picks (interpreted elevation at the top of a given hydrostratigraphic unit) across the model domain for each of the model layers using a set of geologic data rules (Burt and Dodge 2016). This overburden hydrostratigraphic model developed by the OGS covers the central and eastern portion of the Study Area; Figures 5 and 8 illustrate the corehole locations drilled in the OGS overburden study (Burt and Dodge 2016), and these locations loosely define the westward limits of the Orangeville-Fergus hydrostratigraphic model layers (Burt and Dodge 2016). Where the OGS's hydrostratigraphic units were present within the Centre Wellington Study Area, the units were applied in this project.

The model layers were spot checked in various areas using higher quality lithologic data and found good agreement between the overburden layers and wells. As such, the layers were deemed suitable for use in this project.

Table 8 below summarizes the lithologic units present in the Orangeville-Fergus area, and those interpreted to be present and carried forward into the Centre Wellington Study Area (i.e., conceptual hydrostratigraphic unit on Table 6).

TABLE 8 Overburden Geologic and Hydrostratigraphic Units in the Study Area (Burt and Dodge 2016)

Hydrostrat. Unit Number	Hydrostrat. Unit	Geologic Unit	Lithology	Conceptual Hydrostratigraphic Unit
-	AFA1	Wentworth aquifer	Sand; silty sand; minor gravel	Not present in Study Area
	ATA2	Wentworth Till aquitard	Stony, sandy till to silty sandy till	
1	AFA2	Grand River Outwash Aquifer	Sand and gravel	AFA2
2	ATB1	Port Bruce Stade Aquitard – Tavistock and Port Stanley Tills	Sandy, silty to clayey till	ATB1
3	AFB1	Orangeville, Elmira, and Upper Waterloo Moraine Sands and Equivalents Aquifer	Sand; silt and sand rhythmites; localized gravel and cobbles	AFB1
4	ATB3	Maryhill Till and Associated Glaciolacustrine Sediments	Maryhill till, fine-textured glaciolacustrine sediments and equivalents	ATB3/ATC1/ATC2
-	AFB3	Lower Erie Phase aquifer	Sand; gravel; dirty sand and gravel; Rockwood buried valley fill	Excluded; Not hydrogeologically significant in Study Area
4	ATC1	Catfish Creek Drift (Aquitard)	Stony, sandy silt till; rare gravel; rare silt and sand	ATB3/ATC1/ATC2
-	AFC1	Catfish Creek aquifer	Sand; sand and gravel	Excluded; Not hydrogeologically significant in Study Area
4	ATC2	Lower Catfish Creek Till aquitard	Stony, sandy silt till; rare silt and sand	ATB3/ATC1/ATC2
5	AFD1	Pre-Catfish Creek Outwash Aquifer	Gravel; sand; silt	AFD1
6	ATE1	Canning Drift Aquitard	Clayey silt till; silt till; silt and clay	ATE1
7	AFF1	Pre-Canning Aquifer	Sand; gravel	AFF1
8	ATG1	Pre-Canning Aquitard	Stony to very stony, sandy silt till	ATG1

Table 8 notes that several of the units that are present in the OGS's Orangeville study area are not present with any substantial thickness in the Study Area, and consequently the number of hydrostratigraphic layer was reduced from 14 to 8. Specifically, the Wentworth Till and associated coarse-grained sediments are only present southeast of the Study, the Lower Erie Phase aquifer (AFB3) and the Catfish Creek aquifer (AFC1) are rare and isolated pockets of aquifer material that were not considered hydrostratigraphically significant (see Plate 2 of Burt and Dodge 2016 for isopachs of units). In contrast, the Maryhill Till (ATB3), the Catfish Creek Till (ATC1) and Lower Catfish Creek Till (ATC2) are present across much of the area, and as there is little to no intervening aquifer material, and as the three tills are assumed to have similar hydrostratigraphic properties, these three tills were merged together to form one hydrostratigraphic unit (Table 8).

Within the Region of Waterloo municipal boundary, Bajc and Shirota (2007) also created hydrostratigraphic layers that match the lithologic units and descriptions outlined in Table 8. As such, it was possible to extract the layers from the Region of Waterloo and seamlessly merge into the layers generated by Burt and Dodge (2016). This allowed us to capitalize on the hydrostratigraphic layers developed in these studies where present, and carry these interpretations to the remainder of the Study Area through the generation and interpretation of overburden cross-sections (Section 2.5.2.3).

2.5.2.2 Understanding of the Overburden Hydrostratigraphy

Overburden deposits in the Fergus and Elora areas are comprised largely of fine-grained tills, with localized areas that contain sand and gravel aquifer material. Thick and continuous sand and gravel aquifers (AFB1; Table 8) exist in the southwestern portion of the Study Area associated with the Elmira Moraine (Bajc and Shirota 2007) and in the northeastern portion of the Study Area associated with the Orangeville Moraine (Burt and Dodge 2016). In both areas, the sands and gravel aquifers are present at or just below the surface and several domestic water wells are completed within these upper sands. Areas where the Orangeville and Elmira moraine aquifers lie at surface act as significant groundwater recharge areas as they consist of coarse-grained sediment and contain hummocky topography that reduces runoff and enhances recharge to underlying aquifers.

Within the Fergus and Elora area, localized sand and gravel deposits are mapped to exist as discontinuous pockets of sand and gravel within the Elora Bedrock Valley that runs from Belwood Reservoir in the northwest to an area south of Elora in the southwest. These aquifers (AFB3 and AFC1) may be used for domestic water supply in some area; however, as the sands are discontinuous along the 15 km length of the valley, the infill sediments are unlikely to be a suitable water supply aquifer for Centre Wellington.

2.5.2.3 Overburden Cross-Section Interpretation

Ten cross-sections were generated and interpreted to extend the OGS hydrostratigraphic surfaces westward across the Study Area (Figure 10). Cross-sections varied from 7 to 25 km in length and were used to extend the hydrostratigraphic interpretations from the OGS westward to the remainder of the Study Area. The elevation at the top of each bedrock well noted in Table 7 were picked and the used to generate surfaces along the western side of the model domain using a natural neighbour algorithm at a 25 m spacing. The surfaces on the western portion of the model area were generated such there was a seamless transition between the OGS surfaces generated by Bajc and Shirota (2007) in the Region of Waterloo, and those generated by Burt and Dodge (2016) in the central and eastern portion of the Study Area.

2.5.3 Cross-Sectional Views of the Hydrostratigraphic Layers

Figure 10 illustrates the locations of three local-scale cross-sections that were generated in the central portion of the Centre Wellington Study Area. Figures 11 through 15 are cross-sections through the subsurface that illustrate the interpreted hydrostratigraphic units; two of the cross-sections are regional in scale (Figures 11 and 12), and three are local-scale cross-sections that illustrate the overburden and bedrock geology in the Fergus and Elora areas (Figures 13, 14, and 15).

All of the cross-sections illustrate the locations of high and low quality wells that lie within 400 m of the cross-section line. The well name, or MOECC water well record number are listed along the top of the cross-section, followed by the distance, or offset, between the water well location and the cross-section line. Water wells that are further from the cross-section line in places may show up as having the top of the borehole lie above or below ground surface because the hydrostratigraphic layers are displayed along the cross-section line, and the boreholes are overlain on the cross-sections. Similarly, screened intervals may appear in incorrect layers on the cross-section because the layers illustrated on the cross-section are representative of the surfaces encountered along that line, and the wells (and their interpreted geologic units) are projected onto that line. As such, there may be variability in the elevation of bedrock formations or overburden units along the section at individual boreholes. The overburden lithology reported in the well records is illustrated with different colours on the borehole with coarse-grained sediments coloured orange and yellow, and fine-grained sediments coloured blue and green.

2.5.3.1 Regional Scale Northwest to Southeast Cross-section

A 33 km long regional-scale cross-section was generated from the northwestern portion of the Study Area near Arthur to the southeastern portion of the Study Area near Guelph Lake (Figure 10) to illustrate the continuity of the overburden and bedrock layers created in this study (Figure 11).

Along this cross-section and across much of the Study Area, the overburden is dominated by stacks of fine-grained tills (coloured blue and green on section and on boreholes) with thin discontinuous units of sands and gravels (coloured yellow and orange on section and boreholes). Overburden exceeds thicknesses of 100 m on the left hand side of the section in the area to the north near Arthur, and pinches out completely along the Grand River and Swan Creek (Figure 11). Overburden consists primarily of fine grained tills (Tavistock, Port Stanley, Maryhill, Catfish Creek and Canning) with some thin and discontinuous aquifer units (Figure 11).

The topographic low in the bedrock present in the northwestern portion of the Study Area is also evident on the cross-section on the left hand side. The majority of the wells in this area are completed in confined overburden aquifers (Figure 11).

The elevations of the top and bottom of the bedrock units are illustrated on the cross-section. The Salina Group is present on the western reaches of the Study Area and is interpreted to dip to the southwest. The underlying bedrock units are fairly flat lying in this area with a similar dip to the southwest. The Guelph Formation is thickest in the northwest (approximately 60 m) and thins in a southeastward direction (approximately 40 m). The thicknesses of the Goat Island and Gasport Formation are fairly uniform along this cross-section with an increase in the top surface elevation of the Niagara Falls Member of the Goat Island Formation interpreted in the Elora area (Figure 11). Along this cross-section, the Eramosa Formation is thin (< 7 m), where present, on the eastern portion of the Study Area (Figure 11).

2.5.3.2 Regional Scale Southwest to Northeast Cross-section

A 40 km long regional-scale cross-section was generated from the northeastern portion of the Study Area in the Township of East Garafraxa to the southwest portion of the Study Area near Orangeville to the southeastern portion of the Study Area near Elmira (Figures 10 and 12). The cross-section was generated to illustrate the continuity of the overburden and bedrock layers created in this study throughout this area.

The nature of the overburden varies across this section. In the western portion of the cross-section (left hand side) there are sands and gravels mapped at surface (AFB1; Bajc and Shirota 2007) that reach thicknesses of up to 25 m. These thick sands are part of the Elmira Moraine and are underlain by layers of fine-grained tills and discontinuous layers of sands and gravels.

Overburden in the central portion of the cross-section is relatively thin (<15 m) and predominately consists of fine-grained tills (Port Stanley/ Tavistock, Maryhill, and Catfish Creek tills; Table 8). Thick sands (over 40 m) are present at surface on the eastern side of the cross-section, corresponding to Orangeville Moraine sediments (AFB1; Burt and Dodge 2016; Figure 12).

The topographic low in the bedrock in the middle of the cross-section corresponds to one of the buried bedrock valleys (Figure 11). The valley infill in this area is interpreted to consist of fine-grained tills in the lower portion of the valley (Canning Drift Aquitard; ATE1) and fine-grained sands (Pre Catfish Creek Aquifer; AFD1; Burt and Dodge 2016).

The elevations of the top and bottom of the bedrock units are illustrated on the cross-section. The Salina Group is present on the western reaches of the Study Area and is interpreted to dips to the southwest. The underlying bedrock formations also dip to the southwest in a similar manner to the Salina Group, following regional bedrock trends. The Guelph Formation is thickest in the west (40 m thick) and thins in an eastward direction where it pinches out on the eastern limits of the Study Area (Figure 5). The thicknesses of the Goat Island members differ along the section with a general thickening of the Ancaster Member to the west and thickening of the Niagara Falls Member to east (Figure 12). As illustrated on the cross-section, the Eramosa Formation members are interpreted to exist only the east side of the Study Area near the Orangeville Moraine, and along this cross-section through the Study Area, the Reformatory Quarry and Vinemount members are less than 15 m thick.

The Gasport Formation has a fairly uniform thickness across the area with a slight increase in thickness from less than 5 m up to 10 m beneath the Fergus and Elora area (Figure 11).

2.5.3.3 Elora Local Scale Cross-section

Cross-section C- C' runs through Elora from Salem in the north through the town and Wells E1 and E3 to the rural areas south of Elora (Figure 13). The overburden in the borehole logs that lie along this cross-section is primarily composed of fine-grained till corresponding to the Port Stanley Till at surface, and the Maryhill and Catfish Creek tills at depth (Table 8). There is also an area on the section east of Well E1 toward the Grand River that is interpreted as Canning Drift Aquitard (blue area overlying bedrock; Figure 13). The buried bedrock valley located south of well E3 is interpreted to contain a thick sequence of silty fine sands (Pre-Catfish Creek Aquifer; AFD1; Figure 13).

Wells E1 and E3 and their nearby monitoring wells are illustrated on the cross-section. The depth of the wells and the interpreted hydrostratigraphic units that the wells encounter are also illustrated. Well E1 is interpreted as an open hole well that extends into the Gasport Formation, whereas Well E3 is interpreted to terminate slightly shallower, in the Niagara Falls Member of the Goat Island Formation. The Guelph Formation is thick in this area (60 m) and further to the north (80 m), and is interpreted to thin to the south, especially where the buried bedrock valley incises into the Guelph Formation south of First Line. The thickness of the Goat Island Formation is fairly uniform across the area; however, there are differences in the thickness of the Ancaster and Niagara Falls Member along the cross-section (Figure 13). The Gasport Formation has a fairly uniform thickness of approximately 10 to 15 m across the cross-section. The Lions Head Formation and underlying Irondequoit, Rockway, and Merritton formations are fairly uniform in thickness across the area with the Lions Head decreasing from a thickness of 3 m beneath the Elora area, to zero metres south of the town (Figure 13).

2.5.3.4 Fergus Local-Scale Cross-section

Cross-section D- D’ runs from an area north of Fergus, through the town and Wells F1, F2, and F4 to the rural areas south of Fergus (Figure 14). Overburden in this area is primarily fine-grained (Port Stanley, Maryhill, and Catfish Creek tills; Table 8) with some areas of coarse-grained sediments, including part of the infill of the bedrock valley that is intercepted by Well F4. The buried bedrock valley is infilled by layers of coarse and fine-grained overburden; the upper portion of the valley contains fine-grained silty sands (Pre-Catfish Creek Aquifer; Table 8), and the lower portion is infilled with fine-grained Canning Drift Aquitard. As illustrated on the section, outside the buried bedrock valley there is little sand or gravel in the overburden in this area (Figure 14).

The thickness of the bedrock hydrostratigraphic units varies from north to south along the section with the Guelph Formation thinning slightly from 60 m in the north to less than 50 m in the south, with a notable erosion of the Guelph Formation in the central portion of the study along the buried bedrock valley.

2.5.3.5 Elora to Fergus Local Scale Cross-section

Cross-section E- E’ runs along the north side of the Grand River from the Middlebrook Drive area and the OGS high quality borehole DDH-5 in the west, to Fergus in the east (Figure 15). Overburden in this area is similar to cross-sections C-C’ and D-D’ with fine-grained (Port Stanley, Maryhill Catfish Creek) tills overlying bedrock across much of the area. Cross-section E-E’ intersects a buried bedrock valley west of highway 6 and the central portion of the cross-section, and in this area the valley is interpreted to be infilled with fine-grained material (Figure 15). The coarse-grained Grand River Outwash sediments are also evident on the eastern portion of the cross-section.

The cross-section includes Well E1 and several of the monitoring wells in the area. The bedrock formations in this area vary in thickness from west to east with a general thinning of the Goat Island Formation from a thickness of 50 m in the west to 25 m in the east. The remaining bedrock units have a fairly uniform thickness across the area. The Eramosa Formation is interpreted to be absent in this area (Figure 15).

2.6 Regional Groundwater Flow

Regional groundwater flow is primarily controlled by the ground surface topography, as well as the ability of the overburden and bedrock units to transmit water. Groundwater recharge, the portion of precipitation remaining after water is evapotranspired or transferred to streams via overland flow and interflow above the groundwater system. Groundwater recharge rates are influenced by the infiltrability of the ground surface; land use or vegetation; the depth, hydraulic conductivity and soil water storage characteristics of surficial overburden layers; and slope of the topography. Groundwater recharges the groundwater flow system in areas of high relief often where coarse-grained sediments are mapped at surface. Groundwater flows through the subsurface horizontally through aquifer units, and vertically through aquitards, until reaching groundwater discharge locations, such as rivers, streams, or pumping wells.

To evaluate groundwater flow directions across an area of interest, water level maps were generated for aquifers of interest. Static water levels reported in MOECC water well records and other higher quality datasets were interpolated across the Study Area to create maps of water level elevations for overburden and upper and lower bedrock (Figures 16, 17, and 18, respectively). The water levels in the MOECC water well database correspond to water levels measured and recorded by water well drillers after drilling a well. As such, these static water levels were collected over decades and may represent pre-pumping water level conditions that are not indicative of present day levels, which can be influenced by localized pumping (municipal or otherwise). In addition, the water levels for bedrock wells were interpreted to be representative of the hydrostratigraphic unit encountered at the base of the well; however, the vast majority of the wells in the Study Area are open hole bedrock wells that are open across several different bedrock formation. Despite the limitations, the data used to create the water level maps (Figures 16, 17, and 18) are the best available, and the maps are considered to be a reasonable representation of regional groundwater flow conditions at the scale illustrated on the figures.

2.6.1.1 Regional Groundwater Flow in the Overburden

The overburden groundwater level elevation maps were created by interpolating water level elevations contained within the following datasets within and surrounding the Study Area:

- private wells contained in the MOECC WWIS database interpreted to be completed within overburden units (approximately 1,085 wells)
- Provincial Groundwater Monitoring Network (PGMN) wells (4 overburden wells)
- control points added along some permanent surface water features interpreted to be an expression of the water table at that location
    - The water level elevation was assumed to be coincident with the DEM elevation along those rivers and streams (note: along the Elora Gorge, the elevation at the base of the gorge was not used as it is

assumed that the overburden water level along the gorge is expressed through seepage along the walls of the gorge).

An initial surface was interpolated across the Study Area (and beyond), and approximately 42 anomalous values (out of over 1,000 water level elevations) were flagged and removed as they were considered erroneous data points. The anomalous values were identified by mapping the change in water level elevation between the water well's observed water level elevation and the closest water level elevations observed in wells completed in the overburden. If the water level in a given well was dramatically different than those surrounding it, it was flagged for review, and supporting well data was reviewed such as the well depth, drill date, location or elevation reliability code. If the data was considered suspect or inconsistent with surrounding measurements, it was flagged as an erroneous data point and was excluded from the dataset. The water level elevations for all remaining wells completed in the overburden were interpolated at a 25 m grid cell spacing to create the water level elevation surface illustrated on Figure 16.

The overburden water level elevations follow ground surface topography and decline from a high of approximately 480 m asl in the north to a low of approximately 325 m asl in the south along the Grand River. On a local level, shallow groundwater flows toward and discharges into surface water features including portions of the Grand River, Swan Creek, and Belwood Reservoir. A muted groundwater flow divide exists in the west, south of Arthur where shallow groundwater flow is directed radially off the topographic high to the west toward Conestogo River and the southeast toward Fergus and Elora.

Figure 16 provides a regional level understanding of overburden groundwater flow within the Study Area. Water level elevations in the overburden vary on a seasonal basis and in response to pumping from permitted and non-permitted water takers in the area. As such, the water levels on Figure 16 are not intended to be an exact measure of water level elevations at a specific point within the Study Area. Also, the contour mapping of the water table elevation at any given location does not illustrate the vertical flow within an aquifer. In some areas, there may be significant vertical flow alongside the horizontal flow through the aquifer, which is not represented on the two-dimensional contour map.

2.6.1.2 Regional Groundwater Flow in the Contact Zone Aquifer and Upper Guelph Formation

A groundwater level elevation map for the contact zone aquifer and upper Guelph Formation was created by interpolating water level elevations contained within the following datasets in the Study Area:

- private wells contained in the MOECC WWIS database interpreted to be completed within bedrock units (4,225 wells)
- Centre Wellington monitoring wells (8 wells)
- other available monitoring wells in the area (2 wells)
- control points added along some permanent surface water features interpreted to be an expression of the water table at that location

    - The water level elevation was assumed to be coincident with the DEM elevation along those rivers and streams

The water level elevation surface (Figure 17) was created using wells that are interpreted to be completed within the contact aquifer and upper Guelph Formation bedrock units. An initial potentiometric surface was interpolated across the Study Area (and beyond), and 77 anomalous values (out of over 4,200 water level elevations) were flagged and inspected and removed from the dataset (see Section 2.6.1.1 for the process applied to remove erroneous data points). The bedrock surface was interpolated at a 25 m grid cell spacing to create the water level elevation surface illustrated on Figure 17.

The water levels on Figure 17 show a similar pattern to the overburden water levels with the highest water level elevations (480 m asl) in the north, and the lowest to the south along the Grand River (325 m asl). On a local level, water level elevations decline toward the Grand River and Belwood Reservoir. As with the overburden flow system, a groundwater divide exists in the west where deeper groundwater flow is interpreted to flow toward the Conestogo River in the west, and Fergus and Elora in the southeast (Figure 17).

Figure 17 provides a regional level understanding of groundwater flow in the contact aquifer and upper Guelph Formation within the Study Area. Water level elevations in the bedrock system vary seasonally and in response to pumping from permitted and non-permitted water takers in the area. As such, the water levels are not intended to be an exact measure of water level elevations at a specific point within the Study Area.

2.6.1.3 Regional Groundwater Flow in the Lower Guelph, Goat Island, and Gasport Formations

A groundwater level elevation map for the lower Guelph, Goat Island, and Gasport formations was created by interpolating water level elevations for all wells that were interpreted to have a borehole bottom elevation that ended anywhere in the base of the Guelph Formation (defined as the lower 7 m of Guelph Formation), the Goat Island or Gasport formations. The following data sources within the Study Area were used:

- private wells contained in the MOECC WWIS database interpreted to be completed within bedrock units (1,235 wells)
- Centre Wellington monitoring wells (7 wells)
- Centre Wellington municipal pumping wells (8 wells; pumped elevation applied)
- other available monitoring wells in the area (2 wells)
- control points added along some permanent surface water features interpreted to be an expression of the water table at that location
    - The water level elevation was assumed to be coincident with the DEM elevation along those rivers and streams.

The water level elevation surface (Figure 18) was created using wells that are interpreted to be completed within the lower Guelph, Goat Island, and Gasport formations. An initial potentiometric surface was interpolated across the Study Area (and beyond), and 33 anomalous values (out of over 1,200 water level elevations) were flagged and inspected and removed from the dataset (see Section 2.6.1.1 for the process applied to remove erroneous data points). The water level elevation surface illustrated on Figure 18 was interpolated using a 25 m grid cell spacing.

The regional bedrock water levels found within the lower Guelph, Goat Island and Gasport Formations (Figure 18) show a trend of high water level elevations (475 m asl) in the north, and low water level elevations in the south along the Grand River (310 m asl). Water level elevations decline locally in the vicinity of the municipal water supply wells in Fergus and Elora due to the influence of pumping. As evident in the overburden and upper bedrock flow systems, groundwater is interpreted to flow toward the Grand River and Belwood Reservoir (Figure 18). This water level elevation surface was only interpreted for the central and eastern portions of the Study Area as there were no groundwater wells in the western portions that were interpreted to be completed within these deeper bedrock units. In this western portion of the Study Area, wells are preferentially completed within the upper bedrock units, including the Guelph Formation and Salina Group, as the bedrock units dip toward the southwest.

As with the shallower water levels, those in Figure 18 will vary seasonally and in response to permitted and non-permitted pumping. As such, the water levels are not intended to be an exact measure of water level elevations at a specific point within the Study Area.

2.6.1.4 Vertical Head Difference

Figure 19 illustrates the vertical head difference across the Study Area between the overburden and the “shallow bedrock”, defined as the contact zone and upper Guelph Formation. This map was calculated as the difference in the water level elevation between the potentiometric surfaces presented on Figures 16 and 17. The map is shaded to show areas where there are downward (blue) and upward (red) differences in water level elevations between the overburden and the contact zone/ Upper Guelph Formation. Within the Study Area, water levels are directed upward from bedrock to overburden in areas along the Grand River from Belwood Reservoir downstream to the area southwest of Elora, as well as areas of Irvine Creek near the Grand River, and portions of Swan Creek where rivers and streams are eroded into the bedrock surface. Water levels are downward from overburden to bedrock where fine-grained till is interpreted to exist, and also along the interpreted buried bedrock valleys in the Fergus area, and south of Wells E3 and E4.

Figure 20 illustrates the vertical head difference between the shallow (contact zone and Upper Guelph) and deep (Lower Guelph and underlying formations) bedrock within the Study Area. This map was created by subtracting the Shallow (contact zone and Guelph Formation; Figure 17) and Deep Bedrock (Lower Guelph and underlying formations; Figure 18) potentiometric surfaces. As the overburden is thick and overburden aquifers exist in the areas west of Elora, few water wells with observed water levels that extend into the lower Guelph Formation are present in the western third of the Study Area. As such, the vertical head difference map illustrated on Figure 20 is not available in the western third of the Study Area.

As illustrated on Figure 20, water levels are downward from shallow to deep bedrock around many of the production wells in the Fergus and Elora area, because many wells are pumping water from the deeper bedrock formations, enhancing the downward flow. Water levels are downwards from shallow to deeper bedrock units across much of the Study Area with the exception of the areas located south of the Grand River where bedrock outcrops at surface and groundwater discharges to streams and creeks. Water levels are mapped to be slightly upwards (< 5 m) from the deep bedrock to the shallow bedrock in the northern reaches of the Township of Centre Wellington. However, water levels are directed downward between the overburden and shallow bedrock in this area, suggesting the upward head difference in the bedrock may be erroneous. Downward gradients are conceptualized in this area, so the upward head difference may be due to challenges with long open boreholes/ wells in this area.

2.7 Summary of Advances Made to the Hydrostratigraphic Characterization

As outlined on Table 1, a large number of geology, hydrogeology and water resources studies have been completed over the past 20 years in the Centre Wellington area. The reports outlined in Table 1 were reviewed and used to develop a conceptual model of the geology, hydrogeology and hydrology within the Study Area.

Golder (2013) conducted a detailed assessment of the capacity of the municipal water supplies in Centre Wellington. The study had different objectives than the Tier Three Assessment, and it was based on a conceptual model of the groundwater flow system at the time. The Tier Three Assessment used many of the same data sources (i.e., water level and pumping data from Centre Wellington's pumping and monitoring wells, domestic water well information from the Province, etc.); however, the Tier Three Assessment capitalized on studies recently completed in the area by the OGS. Specifically, Frank Brunton of the OGS has studied the bedrock units in this area since 2008, and he further refined and characterized the spatial continuity of bedrock units across the Study Area. The conceptual model applied by Golder (2013) included characterization of the Guelph, Eramosa and Amabel Formation, whereas the current conceptual model includes the Guelph, Eramosa, Goat Island, Gasport and lower bedrock formations. The geologic units were then translated to hydrostratigraphic units that will be applied in the groundwater flow model in the following phase of the Tier Three Assessment.

In addition, Golder (2013) subdivided the overburden into three layers, two aquifers and one aquitard. This was suitable for the objectives of their study. Matrix chose to further subdivide the overburden into a total of nine hydrostratigraphic layers using the overburden conceptual model developed by Burt and Dodge (2016). In addition, hydraulic data that was assembled by the OGS (Priebe et al 2017) will help inform the properties of the bedrock units within the Study Area in the subsequent groundwater flow modelling portion of the Tier Three Assessment.

3 WATER SUPPLY SYSTEMS AND ESTIMATED DEMANDS

The Study Area contains twelve (12) active groundwater PTTWs which includes both municipal and non-municipal permitted demands. Characterizing and quantifying the amount of water these permitted water takings remove from area aquifers is important in assessing the long-term reliability of the municipal supplies.

3.1 Municipal Water Supply Systems

The Fergus and Elora municipal water supply systems rely solely on groundwater for their potable water supplies. The separate water distribution systems of the two towns were combined into a single, Centre Wellington distribution system in October, 2005 via the Aboyne Booster Station. The distribution system also includes four water storage towers (two in Fergus and two in Elora). Water treatment occurs within the pump house for each active municipal well. The current water supply system provides drinking water to approximately 19,330 residents in Elora and Fergus (MOECC 2016a).

There are currently nine municipal bedrock wells in the towns of Fergus and Elora that have a PTTW (Figure 21). Six of those wells are in Fergus (Wells F1, F2, F4, F5, F6 and F7), and three are in Elora (Wells E1, E3, and E4). Wells F3 and E2 were previously decommissioned. Of the existing nine wells, only Fergus Well F2 is designated groundwater under direct influence of surface water (GUDI; Blackport 2002b), but it is currently inactive and could be used in the future if there is a need.

3.1.1 Fergus Municipal Wells

Well F1 lies on the southeast side of the Grand River, on Queen Street East (Figure 21). The land surrounding this well is primarily urban with ground surface elevation of approximately 398 m asl. Well F1 was drilled in 1935 (Blackport 2002b) and the available well record (Appendix B) shows a total depth of 79.5 m bgs, with bedrock encountered at 2 m bgs. The well was cased to 19.9 m bgs. Historically, this well encountered elevated TCE concentrations in 1989 and an air stripper was installed in 1990 to remove dissolved TCE (Terraqua 1991; Blackport 2002b). TCE concentrations were interpreted to be declining in a recent study (Golder 2013); however the project team did not review the TCE data to confirm those findings as it was not within the scope of this study. Observed chloride concentrations are variable and appear to be increasing at this well, but remain below the aesthetic objective of 250 mg/L (Golder 2015a).

Well F2 is located on St. Andrew Street East, in an urban area on the northwest side of the Grand River with a ground surface elevation of 402 m asl (Figure 21). Well F2 was completed in 1945 to a depth of 76.5 m bgs with dolostone bedrock being encountered 3.3 m bgs and casing installed to 3.6 m bgs. Well F2 is a designated GUDI well and a packer was installed to prevent shallow bedrock flow from entering the deeper bedrock aquifer. While Well F2 is part of the Centre Wellington PTTW, it has only been sporadically pumped for testing purposes since 2008 (Golder 2013).

Well F4 is located in an industrial area, approximately 1.1 kilometres northwest of the Grand River on Gartshore St, at a ground surface elevation of approximately 424 m asl (Figure 21). Well F4 was drilled in 1972 to a depth of 129.5 m bgs, with bedrock encountered at 78 m bgs and casing set to 80.5 m bgs. Golder (2013) notes elevated iron concentrations are present in water produced from this well.

Well F5 is located approximately 1.0 kilometres south of the Grand River on Scotland Street, at a ground surface elevation of approximately 421 m asl (Figure 21). The surrounding land use is mixed: Centre Wellington District High School is directly to the south of the well, suburban residences are located directly west, directly north of the well is a wetland/woodlot, and to the east the land is predominantly agricultural. Well F5 was drilled in 1975 to a depth of 124.4 m bgs, with bedrock encountered at 20.1 m bgs. The well is cased to 34.1 m bgs.

Well F6 is located at the edge of an upland wetland complex approximately 2.2 kilometres northwest of the Grand River near the corner of Gartshore Street and Sideroad 10 (Figure 21). Ground surface elevation at Well F6 is approximately 424 m asl. The Irvine Creek Wetland Complex exists just north of the well (Figure 4) and a snow disposal site is found east of the well. Agricultural land use dominates the surrounding area. Well F6 was drilled in 1989 to a depth of 122.5 m bgs, with bedrock encountered at 25.6 m bgs. It is cased down to 33.4 m bgs. Golder (2013) notes sulphate concentrations at this well are often above the aesthetic objective, though these are thought to be natural occurring. Chloride concentrations have been observed to be variable and may be increasing at this well but are currently less than 50% of the aesthetic objective of 250 mg/L (Golder 2015a).

Well F7 is located on Beatty Line in the northwest corner of Fergus, approximately 1.9 kilometres northwest of the Grand River (Figure 21). It is located in a primarily residential area (Figure 2) with agricultural lands located west of Beatty Line and the Irvine Creek Wetland Complex located north of the well (Figure 4). Ground surface at Well F7 is approximately 419.3. Well F7 was drilled in 1999 to a depth of 138.7 m bgs. Bedrock was encountered at approximately 21 m bgs. It was originally cased to a depth of 21.8 m bgs, however turbidity issues were almost immediately noted and following a 2001 investigation (AGL 2002b), the casing was extended down to 47.3 m bgs. Despite this, turbidity remained an issue at the well and packer tests conducted in 2009 (AGL 2009) demonstrated that a packer may be able to separate the turbidity-producing zone from other zones at depths. In April 2012, two nitrogen filled packers were added to the well from 63.0 to 66.9 m bgs to reduce turbidity (MOECC 2016a; Golder 2013). Recent reporting (Golder 2013) suggests turbidity is not an issue for Well F7, indicating the packer is effective.

The well records for Wells F1, F2, F4, F5, F6, and F7 are provided in Appendix B. All Fergus wells except Well F1 and F2 are interpreted to be cased into the Guelph Formation and open across the Guelph and Goat Island formations, and upper portions of the Gasport Formation. Well F1 and F2 are shallower than the others and cased into the Guelph Formation and open across the Guelph Formation and upper portion of the Goat Island Formation. Given the current understanding of the geologic units present in the Study Area, the Eramosa Formation was not interpreted to exist beneath the Fergus area.

3.1.2 Elora Municipal Wells

Well E1 is located on Aqua Street, approximately 500 m northeast of Irvine Creek and 800 m northwest of the Grand River, in a residential area of Elora (Figure 21). The well was drilled in 1949 to a depth of 129.8 m bgs, and cased to the top of bedrock at a depth of 9.4 m bgs. Additional work was conducted on the well in 2009 and resulted in a deeper casing extending to a depth of 19.8 m bgs. Both the original and revised well records for Well E1 are provided in Appendix B.

Well E3 is located on First Line, approximately 1.1 kilometres southeast of the Grand River where land use is primarily agricultural (Figure 2), although a manufacturing facility is located immediately north of the well (Figure 21). E3 was drilled in 1991 to a total depth of 121.9 m bgs, with bedrock encountered at 13.1 m bgs. It was originally cased to a depth of 13.7 m bgs; however cascading water in the shallow bedrock and observed lack of supply at a private well prompted additional casing and a packer to be installed to seal off the upper bedrock interval. The casing now extends to a depth of 30.2 m bgs (Terraqua 1992a). An increasing trend in chloride concentrations has been observed for this well (Golder 2013). The original well record for Well E3 is provided in Appendix B.

Well E4 is located south of Elora on a section of the Cottontail Rd Trail, in between Wellington 21 Road and Side Road 4 (Figure 21). Surrounding land use is primarily agricultural with an unnamed woodlot/wetland present to the south and east. Well E4 was drilled in 2002 to a total depth of 128.0 m bgs, with bedrock encountered at 23.5 m bgs and casing installed to a depth of 25.0 m bgs. The well record for Well E4 is provided in Appendix B.

All three Elora wells are interpreted to be cased into the Guelph Formation and Wells E3 and E4 are open across the Guelph Formation and Goat Island Formations. Well E1 is open across the Guelph and Goat Island formations, and extends into the Gothic Hill Member of the Gasport Formation. Given the current understanding of the geologic units present in the Study Area, the Eramosa Formation was not interpreted to exist beneath the Fergus area.

3.1.3 Arthur and Marsville Municipal Wells

In addition to Fergus and Elora, the municipal groundwater supply systems of Arthur (Township of Wellington North) and Marsville (Township of East Garafraxa) are located in the Study Area (Figure 1). Three groundwater wells are located in Arthur (Wells 7b, 8a, and 8b) and one is located in Marsville (Well 1).

3.2 Municipal Water Demands

The following sections summarize the reported municipal water demands within the Study Area.

3.2.1 Centre Wellington System Municipal Demands

The total permitted capacity of the Centre Wellington water supply system is 15,031 m^3/day under PTTW 4856-9KBH5A, which expires in June 2024 (Table 9). The total average pumping from all wells in 2016 was 5,422 m^3/day, representing 36% of the permitted amount. Each well has a permit that provides Centre Wellington the flexibility to pump a well at its permitted rate to sustain municipal demands during peak periods or while other municipal wells are shut down temporarily for maintenance. Golder (2013) suggested that all municipal wells in Centre Wellington would be unable to pump simultaneously at their permitted rates without lowering the pump intake settings in three of the municipal wells. Subsequent phases of this Tier Three Assessment will assess the ability of the municipal wells to meet their future municipal water demands.

In 2016, approximately 63% of the water demand was supplied by wells in Fergus, while 37% was supplied by the wells in Elora. Pumping at Wells F1 and E1 accounted for 42% of the total average 2016 demand (Table 9).

TABLE 9 Township of Centre Wellington Water Supply Wells

Town	Well Name	Permit Number	Permitted Rate (m^3/day)	2016 Average Taking (m^3/day)
Fergus	F1	4856-9KBH5A (exp. Jun 30, 2024)	1,833	1,094
	F2		409	---
	F4		1,964	889
	F5		1,963	131
	F6		1,964	475
	F7		1,964	820
Elora	E1		1,741	1,195
	E3		1,964	570
	E4		1,228	249
		Total	**15,031**	**5,422**

Average monthly total pumping for the combined Centre Wellington water supply system is illustrated on Figure 22, along with total pumping from Fergus and Elora municipal wells. This was calculated by Township of Centre Wellington staff using their supervisory control and data acquisition (SCADA) flow volume data. Monthly average demands for the combined Centre Wellington system ranged from 3,800 m^3/day to 6,000 m^3/day over the 10 year record with characteristic summertime peak demands and wintertime baseline demands. The average monthly pumping for Centre Wellington increased gradually from approximately 4,800 m^3/day in 2012 to 5,422 m^3/day in 2016.

3.2.2 Arthur and Marsville Municipal Demands

The demands from the Arthur and Marsville wells were summarized in the 2016 annual reporting (DWCo. Ltd 2017; Township of Wellington North 2017). On average, Arthur and Marsville take 15% and 14% of their permitted rates, respectively (Table 10). Figure 23 presents the location, purpose, and 2016 reported takings.

TABLE 10 Arthur and Marsville Water Supply Wells

Town	Well Name	Permit Number	Permitted Capacity (m^3/day)	2016 Average Taking (m^3/day)
Arthur	Well 7b	8202-9DNKD3 (expiry May 31, 2024)	1,965	335
	Well 8a		2,261	316
	Well 8b		2,261	317
Marsville	Well 1	0601-88MKJ7 (expiry May 31, 2020)	182	25
		Total	**6,669**	**993**

3.3 Non-Municipal Water Demands

The following sections summarize the reported and estimated non-municipal water demands within the Study Area. Two datasets were used to estimate non-municipal permitted water demands; the PTTW and the Water Taking and Reporting System (WTRS) datasets (accessed in 2017). The databases and the methods used to develop estimates of consumptive water use are described in the following sections. The definition of consumptive water use is the amount of water withdrawn from a particular source (e.g., watercourse or aquifer) and not directly returned to that same source.

3.3.1 Permit To Take Water Data

With some exceptions, all persons or organizations withdrawing water at a rate greater than 50,000 L/d, must apply for, and be granted, a PTTW from the MOECC. Permits are not required for domestic water use, livestock watering, and water taken for firefighting purposes, even if they exceed the 50,000 L/d rate. Information regarding each PTTW is stored within the PTTW database, including: name of the person/organization; maximum amount of water that can be withdrawn; coordinates of taking; and the specific purpose of the water withdrawal. The PTTW database used for this Tier Three Assessment was downloaded from the MOECC website in February 2017.

The following permit data was removed from the PTTW dataset to focus on the best available permit data within the Study Area:

1. The Middlebrook Well (Nestle) was noted as expired and inactive in the PTTW database; however, it was retained for subsequent analysis (see additional details in Section 3.3.6). No other expired or inactive permits were removed within the Study Area.

2. Municipal water taking permits for Centre Wellington were removed from the dataset as reported water takings (rather than permitted rates) were available and used to characterize municipal water demands.

3. Three temporary permits for construction dewatering were removed from the dataset as they represented short-term construction of underground utilities in the Fergus area, and are not considered representative of long-term existing water demands in the Study Area.

From this refined dataset, consumptive water demands were estimated (as discussed further in Section 3.3.2) by combining the maximum permitted withdrawal rates with the number of days each taking was permitted to pump. This volume was distributed across the months in which the taking was interpreted to be active, and this resulted in an estimate of the amount of water pumped. Consumptive use factors, from a document prepared for the MNRF (Kinkead Consulting and AquaResource 2009), were then applied to the volume withdrawn to generate consumptive estimates. In the end, only one water source from an aggregate operation in the Study Area (permit 4348-9NYNX3) was calculated using the permitted rates in this manner; the remaining sources had reported values noted in the WTRS dataset (Section 3.3.2).

3.3.2 Water Taking and Reporting System Data

Historically, the PTTW program did not require permit holders to report their actual pumping rates, only the maximum potential water taking. This led to challenges in accurately estimating water use from information stored within the PTTW database. As actual water use is typically less than the maximum permitted rate, water use estimates generated using maximum permitted rates can be conservatively high. Obtaining more detailed water taking information, including actual pumping rates, can reduce this error, and produce more accurate estimates of water use.

In January 2005, the Water Taking and Transfer Regulation came into effect (O.Reg. 387). This regulation modified the PTTW program by requiring, among other things, mandatory monitoring and reporting of water takings by permit holders to the WTRS. The monitoring and reporting requirements were phased in over a three year period, with all water users captured under this requirement in 2008. Where available, reported WTRS pumping rates from permitted takers represents improved estimates of non-municipal demand as compared to estimates derived using information contained within the PTTW dataset.

The permits were reviewed in terms of the source of water for the permit. There were three municipal PTTWs, and nine non-municipal PTTWs that source their water from groundwater (or both groundwater and surface water) sources within the Study Area (Appendix C). Each permit may contain multiple individual sources (e.g., wells), and in our Study Area, a total of 26 non-municipal, permitted groundwater sources are present (Figure 23). Twenty-five (25) of 26 sources had reported pumping rates captured within the WTRS, and the one remaining source was estimated using the methodology outlined in Section 3.3.1. An additional seven non-municipal permits (8 intakes) sourced their water from surface water sources (Figure 23). Four of these permits had reported values cited in the WTRS dataset, and three permits were not reported in the WTRS dataset.

Reported monthly pumping rates for each source in the WTRS dataset were examined on a year by year basis from 2012 to 2015 to determine if the most recently available WTRS taking data (2015) was available or representative of average long term demand. For these takings, the 2015 reported taking was determined to be representative of the average long term taking, with the exception of two sources: Permit 8304-6XWRVZ’s 2015 reported takings from sources under this permit were far lower than previous years, and therefore, the 2014 rates were determined to be a representative demand for this permitted taker. Similarly, Source “PW-1” for PTTW 1733-8QKR4S only reported taking in the WTRS for 2012, and as such the 2012 rate was selected as a representative demand for this source.

The WTRS dataset provided by the MOECC contains reported monthly water takings; however, some water that is withdrawn from an aquifer is returned to that aquifer and is not consumed. Consumptive use refers to the amount of water removed from an aquifer of interest and not returned to that same aquifer within a reasonable period of time. For example, a shallow well used for irrigation will extract a set amount of water, but a large portion of that water will be returned to the shallow aquifer via groundwater recharge. To calculate the consumptive use of WTRS reported takings, a consumptive factor related to the water taking purpose noted in the PTTW was applied. The consumptive use factors were obtained from Kinkead Consulting and AquaResource

(2009). The best estimate of current consumptive use for the permit takers that did not contain data in the WTRS dataset was derived via the method described in Section 3.3.1.

3.3.3 Additional Water Demand Data

Additional pumping data from various sources was also utilized to verify WTRS rates and improve the accuracy of existing non-municipal water demand. Data for the Highland Pines Campground wells were provided by Highland Pines and this data corroborated the reported WTRS taking for these wells in 2015. Highland Pines Campground also provided additional useful information on well and casing depths.

Data from the Pine Meadows Retirement Community was also provided in the form of a 2016 pumping log book provided by Pine Meadows' consultant. The total pumped volume in 2016 was interpreted to be representative of current demands, and this data was not contained in the WTRS dataset. Pine Meadows' consultant also provided useful information on well and casing depths.

3.3.4 Agricultural Water Takings

An agriculture operation in southeast of Elora on Wellington Rd. 7 has approximately 20 barns and as such, its water demands were considered in this study. Livestock watering does not require a permit, so the water takings associated with this operation were not included in the PTTW or WTRS datasets. The owners of the poultry farm provided an estimate of water taking based on the number and size of their barns and this estimate is considered representative of current water takings. The demand was divided among three wells interpreted using air photos to lie on the property.

Matrix is currently working with Wellington Source Water to refine the agricultural water takings across the Study Area, and this data will be included in the subsequent groundwater flow modelling tasks of the Tier Three Assessment. The methodology used to estimate the water demands will be outlined in a future Tier Three report.

3.3.5 Estimated Consumptive Demands

Figure 23 illustrates the location, purpose, and magnitude of the 36 identified non-municipal water takings within the Study Area. Table 11 provides a summary of this information and includes the maximum permitted rate and consumptive demand by specific purpose for groundwater takings. This summary lists the consumptive use estimates using values listed in the WTRS and those derived from the PTTW database for the one permit where reported rates were unavailable. Additional details of each taking are available in Appendix C.

TABLE 11 Permitted Rates and Consumptive Non-Municipal Demands in the Study Area

Specific Purpose	# of Wells or Intakes	Maximum Permitted Average Annual Rate (m^3/day)	Reported Demand (m^3/day)	Consumptive Rate (m^3/day)
Groundwater Takings				
Aggregate Washing	2	4,010	-	436

Specific Purpose	# of Wells or Intakes	Maximum Permitted Average Annual Rate (m^3/day)	Reported Demand (m^3/day)	Consumptive Rate (m^3/day)
Aquaculture	6	10,143	4,779	4,779
Campgrounds	5	1,024	50	50
Communal (Pine Meadows)	2	1,571	117	117
Golf Course Irrigation	6	2,261	61	52
Remediation	5	224	43	43
Agriculture/ Livestock Watering	3	-	-	280
Surface Water Takings				
Industrial	1	588,888	-	0
Agriculture- Field/Pasture Crops	1	2,423	7	6
Wetlands/ Wildlife Conservation	6	801,581	-	0
Total	**36**	**19,233 (Groundwater) 1,390,469 (Surface water)**		**5,756**

Reported water demands for groundwater and surface water permits are far lower than the maximum permitted pumping rates listed in the PTTW dataset. In all of the groundwater takings the reported rates are much lower than the permitted rates. Most of the permitted water takings were interpreted to be 100% consumptive as the water is removed from groundwater and returned to the surface water system (via discharge, waste water treatment plants or septic systems). The exception is the golf course irrigation which is interpreted to be 85% consumptive (Kinkead Consulting and AquaResource 2009); this assumes 85% of the water pumped is lost to evapotranspiration, with 15% infiltrating to the deeper groundwater aquifers where the water was sourced.

The industrial surface water taker is a hydroelectric power generator that has a permit to temporarily divert Grand River water through a turbine and return the same volume of water back into the Grand River. As there is no water lost in the diversion process to turn the turbine the taking is considered non-consumptive. Similarly, the wetland and wildlife conservation surface water takings are permits for the construction of dams on water courses. The permitted takings are large, but non-consumptive as the water is not removed from the stream or wetland. Review of the actual water takings and consumptive uses highlights the value of effective understanding and assessment of demand volumes and rates within a Study Area.

3.3.6 Other Non-Permitted Water Demands

Other future potential water demands considered in the Tier Three Assessment process include water demands from the Middlebrook Well, an artesian well located approximately 2 km southwest of Elora. This well has a static head of approximately 14 m above ground surface (ags) and if left to flow freely, would produce water at an estimated rate of approximately 4,536 m^3/day (Golder 2015c). A long-term (30-day) pumping test was conducted on the well in October and November of 2004, at an average rate of 1,637 m^3/day. Gartner Lee (2005) indicated that based on the results of the test, this rate is sustainable over the long term. In 2017, Nestle Waters Canada (Nestle) purchased the property from the Middlebrook Water Company and took ownership of the well. Before the acquisition by Nestle, the Middlebrook Well was permitted to extract 1,637 m^3/day (PTTW 5671-8B9KQ2); however, the actual average daily takings for each month between 2011 and 2015 ranged from

0 to 23 m^3/day (WTRS data; accessed 2017). Reported water demand data before 2011 were not available. The Middlebrook permit expired on October 31, 2015. Nestle submitted a temporary PTTW application to the MOECC in July 2015 to conduct a constant rate pumping test of the well at a maximum rate of 1,637 m^3/day for up to 30 days. Given all the above information, in subsequent phases of this Scoped Tier Three Assessment, the Middlebrook Well will be estimated to pump at a rate of 1,637 m^3/d.

Following submission of the temporary PTTW application for the pumping test to the MOECC, a two-year moratorium on new and expanded water bottling operations, including hydraulic testing was instituted. Consequently, Nestle's application for a temporary PTTW is currently on hold.

Overall, the change in water levels in municipal wells, and discharge to sensitive surface water features, due to groundwater withdrawal from permitted and non-permitted water takers will be evaluated in subsequent phases of the project.

3.3.6.1 Domestic Water Taking in the Centre Wellington Area

Non-permitted takings within the Study Area include rural domestic water users, where municipal infrastructure does not exist. Rural residences in the Centre Wellington area extract water primarily from bedrock aquifers, and return water to the shallow groundwater flow system via individual septic systems. As the water is removed from the deep bedrock aquifer system and returned to the shallow groundwater flow system, it may be considered to be fully consumptive for the bedrock aquifer.

Matrix reviewed the MOECC WWIS to estimate the number of domestic water supply wells within 1 km of a Fergus or Elora Well (as well as the cluster of wells in the Salem area). Wells in the WWIS represent water takings for domestic water use, and in some cases agricultural water use. Some of these areas may predate municipal servicing and are no longer in use, or the wells may be used sporadically for lawn watering or similar purposes. There are approximately 940 water wells within 1 km of Fergus and Elora (including Salem) that may be actively used for domestic water use. If we estimate a pumping rate of 251 L/d per household (ECCC 2017), this equates to an estimated total demand of 230 m^3/d from the Fergus, Elora and Salem area, with approximately 70 m^3/d extracted from the Salem area. This water use represents approximately 4% of the total municipal water use within the Fergus and Elora area, and less than 2% of the total permitted water use within the Study Area. While these takings are considered low, these values will be considered (in aggregate) in future stages of the Scoped Tier Three Assessment.

4 GROUNDWATER TESTING AND MONITORING

Data from hydraulic testing is available for the Study Area from both municipal and non-municipal sources. The following sections describe this data.

4.1 Hydraulic Test Data

A number of hydraulic tests (i.e., pumping, step and slug tests) have been conducted on municipal, private or monitoring wells in the Centre Wellington area, and analysis of the test results provides estimates of aquifer parameters such as hydraulic conductivity, transmissivity, or storativity values. Available step-test data can also be used to estimate non-linear well loss within municipal wells, which represent the amount of drawdown that arises due to well inefficiencies caused by well construction characteristics and well condition (e.g., entrance losses and turbulent flow around pump fittings).

Two of the more extensive or long-term testing programs include shutdown/pumping tests of the Elora and Fergus municipal wells conducted in late 2012 and early 2013 (Golder 2013) and a 30-day pumping test conducted in 2004 on the Middlebrook Well (Gartner Lee 2005). The Elora and Fergus shutdown/pumping tests consisted of three tests; the first test involved shut down of all municipal wells in Elora and then a new well was restarted every four hours until all three wells were operating. The same process was repeated for the wells in Fergus. The second test consisted of shut down of all municipal wells in Elora, but then the wells were restarted at approximately the same time, and the same test was undertaken in Fergus. The hydraulic third test consisted of testing individual municipal wells by turning them off for 24 hours, pumping them for 24 hours and then turning them off for another 24 hours. Water levels in the pumping wells and monitoring wells were collected throughout the tests and estimates of transmissivity were calculated for the bedrock aquifers based on the water level responses. In Fergus, transmissivity of the bedrock aquifer ranged from 52 to 395 m^2/d. Similarly, transmissivity of the bedrock aquifer in Elora ranged from 38 to 158 m^2/d (Golder 2013).

Other shorter-term testing was conducted on the production wells as part of smaller scale hydrogeological testing programs over the years. These tests and associated historical estimates of hydraulic parameters are summarized in Table 12, along with the references of where the estimates were sourced from.

The long-term hydraulic test at the Middlebrook Well that took place in the fall of 2004 involved allowing the well to flow at a rate of 1,637 m^3/d for 30 days (Gartner Lee 2005). As the well is naturally artesian with a static head of approximately 14 m above ground surface, this rate was achieved without the use of a pump. The water level response was monitored at the pumping well, six nearby wells that were instrumented with data loggers, a staff gauge in the Grand River and mini-piezometer in Cascade Creek. During the same study, packer testing was conducted on Well OW1, located near the Middlebrook Well, which provided estimates of hydraulic conductivity with depth, ranging from 2×10^{-7} to 1×10^{-8} m/s. Previous pumping tests conducted at the Middlebrook Well estimated that transmissivity of the bedrock ranges from 100 to 205 m^2/d (Table 12; Naylor 2001). Flow meter profiling conducted on the Middlebrook Well identified the bulk of the water flowing into the well is derived from the lowermost 2.5 m of the well, and above this zone, there are very few fractures and groundwater flow into the well is limited (Lotowater 2015b).

TABLE 12 Summary of Hydraulic Tests and Parameter Estimates

Well	Interpreted Unit[1]	Tested Bedrock Interval (Elevation; m asl)	K (m/s)	T (m^2/d)	S (-)	Type of Test (reference)
OW2 (near F1)	Guelph Fm	394.1 to 367.2	3.9×10^{-8} to 5.5×10^{-7}	0.2 to 5	5.2×10^{-4} to 5.6×10^{-2}	Packer Testing (Terraqua 1991)
OW3 (near F1)	Guelph Fm	392.1 to 366.8	9.7×10^{-8} to 1.7×10^{-6}	0.1 to 1	0.1 to 0.9	
OW6 (near F1)	Guelph Fm	391.5 to 366.0	1.5×10^{-7} to 4.6×10^{-6}	0.1 to 31	1.1×10^{-4} to 6.3×10^{0}	
Well 4	Guelph Fm	unknown to 358.5[2]	n/a	134	n/a	24 hour pumping test of F1 (Golder 2013)
F1	Guelph Fm to Goat Island Fm, Ancaster Mbr	376.9 to 317.3	n/a	134	n/a	
F2	Guelph Fm	399.2 to 365.8 (above packer)	n/a	67	n/a	24 hour pumping test of F2 (Golder 2013)
	Guelph Fm to Goat Island Fm, Ancaster Mbr	365.8 to 326.3 (below packer)	n/a	71	n/a	
	Guelph Fm to Goat Island Fm, Ancaster Mbr	376.3 to 326.3 (below packer)	1.2×10^{-5} to 9.0×10^{-5}	41 to 311	n/a	72 hour pumping test (Blackport 2005)
	Guelph Fm to Goat Island Fm, Ancaster Mbr	399.2 to 326.3	n/a	77 to 83	1.3 to 2.3	61 hour pumping test (Terraqua 1992b)
F4	Guelph Fm to Gasport Fm, Gothic Hill Mbr	344.2 to 295.2	n/a	52	n/a	24 hour pumping test of F4 (Golder 2013)
MW6-12A	Goat Island Fm, Ancaster Mbr	325.0 to 318.9	n/a	190	n/a	
MW3-11A	Goat Island Fm, Niagara Falls Mbr	310.0 to 303.9	n/a	395	n/a	24 hour pumping test of F5 (Golder 2013)
MW3-11B	Guelph Fm	382.8 to 376.7	n/a	395	n/a	
F5	Guelph Fm to Gasport Fm, Gothic Hill Mbr	387.1 to 296.8	n/a	60	n/a	
			n/a	74 to 147	n/a	24 hour pumping test (Hydrology Consultants 1975 *in* Golder 2010a)
MW5-11A	Goat Island Fm, Niagara Falls Mbr to Gasport Fm, Gothic Hill Mbr	302.8 to 296.7	n/a	108	n/a	24 hour pumping test of F6 (Golder 2013)
MW5-11B	Guelph Fm	385.4 to 379.3	n/a	109	n/a	
F6	Guelph Fm to Gasport Fm, Gothic Hill Mbr	390.4 to 301.5	n/a	139	n/a	
			n/a	26 to 64	0.1 to 30.6	72 hour pumping test (Terraqua 1992c)
	Guelph Fm to Goat Island Fm, Ancaster Mbr	390.4 to 317.4	n/a	45	n/a	Step and 24 hour pumping tests (IWS 1989)
	Guelph Fm to Gasport Fm, Gothic Hill Mbr	390.4 to 301.5	n/a	37	n/a	

Well	Interpreted Unit[1]	Tested Bedrock Interval (Elevation; m asl)	K (m/s)	T (m^2/d)	S (-)	Type of Test (reference)
MW4-12A	Goat Island Fm, Ancaster Mbr to Niagara Falls Mbr	305.9 to 299.8	n/a	65	n/a	24 hour pumping test of F7 (Golder 2013)
MW4-12B	Guelph Fm	387.0 to 380.9	n/a	71	n/a	
F7	Guelph Fm to Gasport Fm, Gothic Hill Mbr	348.5 to 280.8	n/a	81	n/a	
	Guelph Fm to Gasport Fm, Gothic Hill Mbr	372.2 to 280.8	n/a	49 to 112	n/a	6 hour, 14 hour and 72 hour pumping tests (AGL 2002b)
MW2-11A	Goat Island Fm, Niagara Falls Mbr	284.4 to 279.4	n/a	87	n/a	24 hour pumping test of E1 (Golder 2013)
MW2-11B	Guelph Fm	378.2 to 372.1	n/a	158	n/a	
E1	Guelph Fm to Gasport Fm, Gothic Hill Mbr	385.5 to 275.3	n/a	78	n/a	
MW1-12A	Goat Island Fm, Niagara Falls Mbr	281.7 to 275.7	n/a	72	n/a	24 hour pumping test of E3 (Golder 2013)
E3	Guelph Fm to Goat Island Fm, Niagara Falls Mbr	364.4 to 272.6	n/a	115	n/a	
	Guelph Fm to Goat Island Fm, Niagara Falls Mbr	380.9 to 272.6	n/a	49 to 320	0.2 to 0.3	Step and 48 hour pumping tests (Terraqua 1992a)
Well 17	Guelph Fm	unknown to 323.6[2]	n/a	120	n/a	24 hour pumping test of E4 (Golder 2013)
E4	Guelph Fm to Goat Island Fm, Niagara Falls Mbr	359.6 to 256.6	n/a	38	n/a	
			n/a	50	n/a	96 hour pumping test (AGL 2002)
Middlebrook	Goat Island Fm, Niagara Falls Mbr	260.6 to 258.1	n/a	300	n/a	Independent analyses of data from Gartner Lee 2005
	Guelph Fm to Goat Island Fm, Ancaster Mbr	356.9 to 256.7	n/a	100 to 205	n/a	18 hour and 7 day pumping tests (Naylor 2001)
OW1 (Near Middlebrook)	Guelph Fm	351.9 to 348.8[3]	2×10^{-7}	n/a	n/a	Packer Testing (Gartner Lee 2005)
		348.8 to 345.8[3]	1×10^{-8}	n/a	n/a	
		345.8 to 342.7[3]	8×10^{-8}	n/a	n/a	
		342.7 to 339.7[3]	9×10^{-8}	n/a	n/a	
MW08-T3-02	Gasport Fm	308.0 to 298.0[4]	9×10^{-6}	n/a	n/a	Discrete hydraulic testing (Priebe, Neville and Brunton 2017)
	Gasport Fm	318.0 to 308.0[4]	5×10^{-6}	n/a	n/a	
	Goat Island Fm, Ancaster Mbr to Gasport Fm	328.0 to 318.0[4]	4×10^{-6}	n/a	n/a	
	Eramosa Fm, Reformatory Quarry Mbr to Goat Island Fm, Niagara Falls Mbr	339 to 329[4]	1×10^{-6}	n/a	n/a	
	Guelph Fm to Eramosa Fm, Reformatory Quarry Mbr	349 to 339.0[4]	4×10^{-5}	n/a	n/a	
MW08-T3-04	Guelph Fm to Goat Island Fm, Ancaster Mbr	352.9 to 342.9[4]	2×10^{-7}	n/a	n/a	

Well	Interpreted Unit[1]	Tested Bedrock Interval (Elevation; m asl)	K (m/s)	T (m^2/d)	S (-)	Type of Test (reference)
	Guelph Fm	386.9 to 376.9[4]	1×10^{-6}	n/a	1.3	
MW08-T3-05	Goat Island Fm, Niagara Falls Mbr	367.4 to 361.4[4]	6×10^{-7}	n/a	n/a	
	Goat Island Fm, Niagara Falls Mbr	373.4 to 367.4[4]	4×10^{-5}	n/a	n/a	
	Goat Island Fm, Niagara Falls Mbr	379.4 to 373.4[4]	6×10^{-5}	n/a	n/a	
	Goat Island Fm, Niagara Falls Mbr	385.4 to 379.4[4]	7×10^{-6}	n/a	n/a	
	Goat Island Fm, Niagara Falls Mbr	391.4 to 385.4[4]	1×10^{-5}	n/a	n/a	
	Eramosa Fm, Reformatory Quarry Mbr to Goat Island Fm, Niagara Falls Mbr	397.4 to 391.4[4]	1×10^{-5}	n/a	n/a	
	Guleph Fm to Eramosa Fm, Reformatory Quarry Mbr	403.4 to 397.4[4]	2×10^{-6}	n/a	n/a	
	Guelph Fm	409.4 to 403.4[4]	7×10^{-6}	n/a	n/a	
Marsville TW1/71	Guelph Fm to Eramosa Fm, Reformatory Quarry Mbr.	396.8 to 427.2	n/a	77	4.1×10^{-5}	24 hour pumping test of Marsville TW1/71 (Beatty 1971)
Arthur Well 7B	Fine to coarse sand, gravel	392.8 to 389.7[6]	n/a	104 to 864	7.0×10^{-3}	24 hour pumping test of Arthur Well 7B (Burnside 1998)
Arthur Well 8A	Gravel and sand	406.5 to 400.4[6]	n/a	1,378	1.5×10^{-3}	8 hour pumping tests of Arthur Well 8A and 8B (Burnside 2004)
Arthur Well 8B		406.2 to 400.1[6]	n/a	1,181	6.5×10^{-4}	
Stodlak Well (Arthur Obs Well)		Unknown to 405.6[6]	n/a	984 to 1,088	n/a	
Arthur TW4/02		404.5 to 397.5[6]	n/a	551	3.6×10^{-4}	
			n/a	436.2 to 1,078	2.6×10^{-4}	72 hour pumping test of Arthur TW4/02 (Burnside 2003)
Stodlak Well (Arthur Obs Well)		Unknown to 405.6[6]	n/a	906	2×10^{-5}	
Overburden monitoring wells (various)	Sandy silt till		2.3×10^{-8} to 5.2×10^{-7}	n/a	n/a	Slug test (CVD 2015)
	Weathered bedrock		2.7×10^{-5}	n/a	n/a	
	Gravelly clay		6×10^{-9}	n/a	n/a	Slug test (Golder 2013)
	Silty sand		3×10^{-8} to 1×10^{-4}	n/a	n/a	

Well	Interpreted Unit[1]	Tested Bedrock Interval (Elevation; m asl)	K (m/s)	T (m^2/d)	S (-)	Type of Test (reference)

Notes:
n/a – data not available
K – hydraulic conductivity (the ease with which a fluid (usually water) can move through porous media or bedrock)[5]
T – transmissivity (the ease with which a fluid can move through a unit width of aquifer under a unit hydraulic gradient)[5]
S – storativity (volume of water released from storage per unit area of the aquifer per unit decline in hydraulic head)[5]
[1] – Interpreted unit based on conceptual model created for this study
[2] – Total depth based on Golder (2010a). Top of open bedrock interval not available
[3] – Interpreted unit and elevation test interval from Gartner Lee (2005)
[4] – Interpreted unit and elevation test interval from Priebe, Neville, and Brunton (2017)
[5] - Schwartz and Zhang (2003)
[6] – Interpreted screen interval elevation tested in overburden

4.2 Municipal Water Quality Data

Review of water quality concentration trends over time can help shed light on the source of water (shallow overburden or deep bedrock) as well as the potential interaction between surficial sources of contamination and underlying bedrock aquifers.

Raw water quality data collected from the Centre Wellington municipal wells is sampled and tested for microbiological parameters, organics, and inorganics as per O.Reg 170/03 for Drinking Water Systems. The following sections briefly describe a few water quality trends identified in the Elora and Fergus municipal wells.

4.2.1 Elora

Water quality in the Elora municipal wells is generally good with no water quality issues observed at Well E1, with chloride, sodium, nitrate, and sulphate concentrations below regulatory thresholds. Sulphate concentrations at Well E1 (400 mg/L) and Well E4 (300 mg/L) are higher than at Well E3 (40 mg/L) but are considered naturally occurring in the bedrock (Golder 2015a, 2013, 2010a). Sulphate concentrations at Well E4 have increased with increased pumping at the well indicating the bulk of the water is derived from bedrock sources with less of an influence from the overburden system (Golder 2015a).

Chloride concentrations are increasing at Well E3 from less than 40 mg/l in 2000 to 155 mg/L in 2014 and 2015 (Golder 2015a). The source of the chloride at Well E3 was investigated and determined to be anthropogenic, (i.e., attributed to road salting or other surficial sources of chloride) rather than derived from naturally occurring sources in the bedrock.

Overall, the chloride, sodium, nitrate and sulphate concentrations within Elora are below the aesthetic and maximum allowable concentrations in all three wells in Elora. (Note: aesthetic objectives (AO) for chloride = 250 mg/L, sodium = 200, and sulphate = 500 mg/l and the maximum allowable concentration for nitrate is 10 mg/L Nitrate-N).

4.2.2 Fergus

Water quality in the Fergus municipal wells is also generally good with specific water treatment in place at Well F1 for the historical presence of trichloroethylene (TCE), and at Well F4 for naturally occurring iron concentrations that are above the AO of 0.3 mg/L. Other notable observations include:

- elevated hardness at Well F1 where concentrations exceed 500 mg/L and elevated sulphate concentrations which are generally less than the AO
- increased iron concentration at higher pumping rates at Well F2
- elevated manganese (AO = 0.05 mg/L), potentially increasing aluminum above operational guidelines (0.1 mg/L) at Well F5
- naturally occurring sulphate concentrations above the AO and variable, naturally occurring iron concentrations at Well F6

- potential iron issues at Well F7 where concentrations exceed the AO

All of the above observations are water quality characteristics that are indicative of water that is sourced from carbonate bedrock aquifers.

Chloride trends in Wells F1 and F6 were flagged as possibly increasing due to observations of elevated and variable concentrations (Golder 2015a). Before 2009, chloride concentrations were steady around 40 mg/L at Well F6, and thereafter concentrations increased to approximately 80 mg/L. Similarly, chloride concentrations at Well F1 reached a maximum concentration of 86 mg/L in 2003 and reached up to 119 mg/L in 2015. The source of chloride was investigated in 2015 and it was concluded that the source is anthropogenically-derived from surficial sources for Well F1, and derived from natural bedrock sources at Well F6 (Golder 2015a). The analysis also indicated that the groundwater in Well F1 and F6 may be primarily from overburden and shallow bedrock sources, despite the depth of the wells into the underlying deep bedrock aquifers (Golder 2015a).

4.2.3 Pathogens and Viruses

Another assessment of the potential interaction between shallow sources of contamination and the underlying bedrock aquifers was a review of raw water quality for pathogens and viruses. Allen et al. (2017) conducted a study that tested water quality samples for viruses in 22 fractured bedrock wells across Wellington County, including 6 of the municipal wells in Centre Wellington (Well E1, E3, E4, F1, F4, and F5). The wells were sampled six times, over an 8 month period (June 2012 to January 2013), and the authors of the study looked for factors that may contribute to virus susceptibility in wells. In Elora, a virus was detected in the raw water collected from Wells E1 (Human polyomavirus) and E3 (GII norovirus) in November 2012. In Fergus, a virus (Adenovirus A) was detected in the raw water from Wells F1 and F5 in July and August 2012, respectively.

The study concluded that viruses were more likely to be detected in wells with long open bedrock hole intervals however, virus concentrations decreased as open interval lengths and well depth increased. It was also found that the concentration of viruses increased where there was increased precipitation in the days leading up to the sampling.

It is worth noting that the Township treats all water from groundwater supply wells with chlorine, the recognized treatment in Ontario for bacteria, viruses, and pathogens, in accordance with Provincial legislation and regulations. The Township’s drinking water disinfection program meets the current MOECC standard for treatment (2 log inactivation; 99% removal of viruses), as well as the preliminary guidance for enhanced treatment (4 log inactivation; 99.99% removal). Chlorine levels used to treat Centre Wellington’s drinking water are continuously monitored to ensure a safe drinking water supply. If the chlorine residual level falls below a safe operating level in a municipal well, the well is shut down automatically until the chlorine residual returns to safe levels; consequently, untreated or inadequately treated water never enters the distribution system.

4.2.4 Summary

The presence of viruses in raw water in Wells F1 and E3, and the observed concentrations of TCE and chloride in the two wells suggest that while these wells are completed in bedrock units over 100 m below the ground surface, a portion of the water is derived from relatively shallow fractured bedrock zones in the upper portion of the bedrock. Two GUDI assessments were performed on Well F1; both studies stated the well was not GUDI and determined the majority of water is derived from the deep bedrock aquifer, over 60 m below the ground (Blackport 2002b, 2003).

Although viruses were detected in the raw water during the Allen et al. (2017) study, the Ontario Drinking Water Standards do not list a standard for viruses and sampling for viruses is not a requirement of the Safe Drinking *Water Act* or associated regulations. The operation of a municipal drinking water system is regulated by the Safe Drinking *Water Act*, associated regulations and guidance including the Ontario Drinking Water Standards. Therefore, the Township has notified the Ontario Ministry of the Environment and Climate Change's Safe Drinking Water Branch regarding the results of this study, and are awaiting direction.

4.3 Municipal Groundwater Level Data

4.3.1 Centre Wellington

Under the MOECC PTTW process, many municipal water systems are required to carry out groundwater monitoring programs. The collection and inspection of groundwater level monitoring data in and around municipal well fields aids in the understanding of the effects of municipal pumping both temporally (i.e., seasonally) and spatially (i.e., across the well field). Often these monitoring efforts help to identify potential negative impacts that extreme groundwater level change can bring to sensitive receptors such as other municipal supply wells, private wells, and groundwater-fed surface water features (e.g., rivers, ponds, and wetlands). In the Township of Centre Wellington, groundwater levels are monitored in both the municipal pumping wells (Wells F1, F2, F4, F5, F6, F7, E1, E3, and E4) and municipal monitoring wells (MW1-12, MW2-11, MW3-11, MW4-12, MW5-11, MW6-12, MW-Well 4, MW-Well 17, and MW-Well 19; Figure 21).

The Township of Centre Wellington provided municipal pumping well water levels from 2001 to 2008 (monthly average levels), 2006 to 2010 (daily manual levels) and 2010 to 2016 (hourly SCADA levels). Daily manual (2006 to 2010) and daily maximum and minimum levels (2010 to 2016) were extracted from this dataset, converted to elevations and plotted against average monthly pumping data for each of the nine municipal wells. Groundwater elevations and pumping for Well F1 are presented in Figure 24 as an example of the type of data assembled. As shown, average monthly pumping has varied over the 14 year record from 0 to 1,500 m^3/d, with water levels generally decreasing seasonally in the summer and early fall with increased summer demands, and increasing levels in the winter due to decreased demands. There is approximately a 20 m difference between daily maximum and minimum (pumped) water levels. Additional hydrographs depicting water level and pumping data for the remaining municipal wells is outlined in Appendix D (Figures D1 to D7). Note that Well F2 is not currently in use, but water levels are still routinely collected above and below an installed packer. This data was not available at the time of this reporting but will be incorporated into future stages of the project.

The Township of Centre Wellington provided manual water level elevation data, along with hourly transducer data for their nine municipal monitoring wells from 2012 to 2016. Table 13 summarizes which municipal well is being monitored by which monitoring well and Appendix D provides hydrographs of each municipal monitoring well (Figures D8 to D15). For example, Figure D14 presents average monthly groundwater elevation data for 2012 to 2016 for monitoring well MW1A/B/C-12, which is a monitoring well nest near Well E3. Water levels respond to pumping at Well E3 (e.g., increased pumping from 2015 to 2016) most prominently in the deepest interval (A), with a more muted response in the upper monitoring wells. In general, water levels at each interval vary by 5 m or less over the 5 year record. There is an observed downward gradient between the overburden (C) and deep bedrock (A) flow systems.

TABLE 13 Municipal Monitoring Wells and Associated Municipal Wells

Monitoring Well	Elevation of Municipal Monitoring Intervals (m asl); Interpreted Units			Municipal Well Monitored	General Comments on Difference in Water Level Elevations
	A	B	C		
MW1-12	276 to 282; Niagara Falls	361 to 367; Guelph	390 to 393; Overburden	Well E3	Water level elevations for the overburden monitor are 6 m higher than the Guelph and 20 m higher than the Niagara Falls; Figure D14).
MW2-11	279 to 284; Niagara Falls	372 to 378; Guelph	396 to 399 Overburden	Well E1	Water level elevations for the overburden monitor are approximately 25 m higher than the water levels in the Guelph and Niagara Falls, which have similar water level elevations (Figure D13).
MW3-11	304 to 310; Goat Island (Niagara Falls)	377 to 383; Guelph	401 to 404; Overburden	Well F5	Water level elevations for the overburden are 12 m higher than the Guelph, which are very similar water levels to the Niagara Falls (Figure D10).
MW4-12	300 to 306; Goat Island (Niagara Falls to Ancaster)	381 to 387; Guelph	404 to 407; Overburden	Well F7	Water level elevations for the overburden are 11 m higher than the Guelph, which are 2 m higher than the Niagara Falls/Ancaster (Figure D12).
MW5-11	297 to 303; Goat Island (Niagara Falls) to Gasport	379 to 385; Guelph	406 to 409; Overburden	Well F6	Water level elevations for the overburden are more than 10 m higher than the Guelph, which are very similar water levels to the Gasport/Niagara Falls (Figure D11).
MW6-12	319 to 325; Goat Island (Ancaster)	384 to 390; Guelph	406 to 408; Overburden	Well F4, F6	Water level elevations for the overburden are more than 13 m higher than the Guelph, which are more than 3 m higher than the Ancaster (Figure D9).
Well 4	359*; Guelph	-	-	Well F1	Water level elevations in the Guelph vary from 376 to 380 m asl over the 5-year record and appear to respond with pumping at F1 (Figure D8).
Well 17	324*; Guelph	-	-	Well E4	Water level elevations in the Guelph vary from 373 to 390 m asl over the 5-year record and appear to respond with pumping at E4 (Figure D15).

*monitoring interval not available, value represents bottom of well

4.3.2 Arthur

In the Town of Arthur, groundwater levels are monitored in all three municipal pumping wells (Wells 7B, 8A, and 8B) and four monitoring wells (TW4/02, MN-MW1/00, Voisin Well, and O'Donnell Well; Figure 21). Historical water level monitoring data from these wells was provided by R.J. Burnside Associates Ltd. (Burnside).

Daily average SCADA water level elevations were plotted for each of the three municipal wells from 2005 to 2016 (Figures D16, D17 and D18; Appendix D). As shown, average daily water levels ranged between 424 and 437 m asl for Well 7B, while Well 8A and 8B located 3.5 km to the southeast have average water levels that range between 441 to 448 m asl, and 444 to 448 m asl, respectively.

Water level data from transducers in the Arthur monitoring wells are presented in Figure D19. The Voison and O'Donnell private wells are located near Well 7B and exhibit groundwater elevations similar to Well 7B (430 to 438 m asl). Monitoring wells WN-MW1/00 and TW4/02 are located near Well 8A and 8B and exhibit water level elevations that are similar to those municipal wells (445 to 449 m asl), and Well TW4/02 records water levels that rise and fall as the municipal wells cycle off and on.

4.4 Non-municipal Water Level Data

In addition to municipal monitoring data, water level elevations are being monitored in other sites across the Study Area (Figure 21). These datasets were consulted in the characterization phase of work, and they will be used during future phases of this project. The datasets used in this study are outlined in the following sections.

4.4.1 Grand River Conservation Authority Groundwater Monitoring

The GRCA maintains a network of groundwater monitoring wells within the Grand River Watershed. Some of these wells are affiliated with the PGMN network and others are maintained outside that network. There are no PGMN wells located within our Study Area; however, one GRCA monitoring well, the Ennotville Well (Figure 21), is present within the Study Area and a transducer within that well has been collecting hourly water level data since 2012. This data was not available at the time of this reporting but will be incorporated during future phases of this project. The well is a 19.4 m deep overburden well that was drilled by the OGS (Burt and Dodge 2016).

4.4.2 Ontario Geological Survey Monitoring

There are a few wells within the Study Area that were cored by the OGS and currently have water levels recorded manually on a monthly basis and continuously by transducers. This data was not made public by the OGS at the time of this report; however, these water levels, especially the data for DDH-5, located west of Elora near the Middlebrook Well, will be reviewed and incorporated into the numerical modelling phase of this project.

4.4.3 Site-specific Permit To Take Water Monitoring

4.4.3.1 Highland Pines

Many PTTWs within the Study Area have site-specific monitoring at their locations, and the Highland Pines Campground near Belwood Reservoir provided monitoring data for the study. Highland Pines has monitored groundwater levels from 12 wells as part of their permitted water taking. Thirteen years (2003-2015) of water level data from 4 of the 12 wells (i.e., TW-2, Deep Phase 2 Well, Deep Office Well, and Deep E Section Well; Figure 21) are provided in Appendix E (Figure E1) alongside the local pumping rates onsite from 2006 to 2016. The wells are all completed in bedrock and all show slightly lower water levels during peak summertime water use, and higher water levels in the spring and fall when demands are lower. Observed water level elevations for the four monitoring wells range between 412 and 430 m asl and total average monthly pumping ranges from 0 to 170 m^3/d.

4.4.3.2 Nestle

Nestle provided water level monitoring data for the Middlebrook Well (2011 to 2017), a nearby observation well OW2 (2016 to 2017) and five private wells (2015 to 2017) for the Scoped Tier Three Assessment (Figure 21). The Middlebrook Well is approximately 110 m deep, and is an artesian bedrock well with water levels that varied from 374 to 389 m asl (6 to 21 m ags) between 2011 and 2017, with subtle variations in seasonal water levels (Appendix E; Figure E2). Naylor (2001) suggested that the presence of soft and fractured limestone (dolostone) below 103 m bgs may contribute the majority of flow of this well. This comment is supported by more recent caliper logging of the well (Golder 2015b) and downhole camera photos (Lotowater 2015b), which identified the presence of large fractures and cavities in the lowermost 2.5 m of the well.

Nearby Well OW2 is not an artesian well, and is completed in a shallower bedrock horizon to a depth of 61.0 m bgs. The water level for this well is approximately 18 m lower than that of the Middlebrook Well and varied between 362 and 367 m asl in 2016 and 2017 (Appendix E; Figure E2). Currently, the source of the artesian conditions at the Middlebrook Well is not well understood.

Private Wells 2, 3, 4, and 5-Shallow/Deep are all completed in the bedrock to depths ranging from 36 to 158 m bgs. (Completion details were not known for Private Well 1 at the time of the report writing). Water levels in these wells range from 350 m asl (Private Well 3) to 415 m asl (Private Well 1) and all water levels are below ground surface.

4.4.4 Dewatering Projects Monitoring

The Township of Centre Wellington provided groundwater level monitoring data collected as part of two dewatering projects that occurred along Side Road 18 and Side Road 19 in the Town of Fergus during excavations for municipal sewer and water installations in 2010, 2011, and 2014. The sand and gravel unit that was dewatered is interpreted to correlate with the Grand River Outwash sediments outlined in Section 2.4.4.9.

These sands and gravels are spatially discontinuous across the area, but interpreted to be coarse-grained. Water level data from a subset of four monitoring wells from the two programs are provided in Appendix E.

At Side Road 18, this includes three shallow (<5 m bgs) overburden dug wells (SR18-46, -114, and -961 HWY6; Figure 21) and one drilled, assumed bedrock well (32 m bgs; SR18-162; Figure 21). Pumping occurred at two locations along Side Road 18 during the spring and fall in 2014 where dewatering rates ranged from 700 to 3,100 m^3/day. Water levels were automatically recorded in the shallow wells ranging between approximately 420 and 424 m asl between 2006 and 2015, (Figure E3). Water levels from the deeper well ranged from 402 to 412 over the 2005 to 2013 record (Figure E4). Both shallow and deep water levels show regular variability due to domestic use in the area.

Automatic and manual water level datasets for three shallow (<6 m bgs) overburden wells (SR19-MW1, -P3, and -P36; Figure 21) and one deeper (>50 m bgs) bedrock well (SR19-MW4; Figure 21) are provided in Appendix E from 2010 to 2011. Dewatering occurred at various locations in summer and fall of 2010 and spring and summer of 2011, with pumping ranging from 1 to 2,400 m^3/day during that period. In the shallow wells, water levels varied between 414 and 419 m asl (Figure E5), while levels varied between 386 and 396 m asl in the deeper bedrock well (Figure E6). Note that the datasets shown in Figures E5 and E6 were digitized from report hydrographs (Golder 2011b), may not exactly represent the levels at a given snapshot in time. Focus was on capturing the general water level trends over time.

Pumping data from these projects will be used to provide insight on the transmissivity of hydrostratigraphic units in this area of Fergus during the numerical modelling phase of the Tier Three Assessment.

5 SUMMARY AND CONCLUSIONS

The physical setting in the Study Area is characterized by Quaternary-aged overburden sediment deposited during the Late Wisconsinan as glacial ice lobes advanced and retreated across the area. Beneath the overburden lie Paleozoic bedrock units that vary in thickness across the Study Area. The geologic characterization conducted in this Tier Three Assessment incorporated detailed overburden mapping conducted by the OGS in the eastern half of the Study Area (Burt and Dodge 2016). The overburden geologic characterization and interpretations from Burt and Dodge (2006) were carried through to the western portion of the Study Area through the generation and interpretation of overburden cross-sections.

The spatial distribution and continuity of the bedrock units beneath the Study Area was developed in cooperation with Frank Brunton at the OGS and the interpretations presented in this report represent the current understanding of the distribution of bedrock formations within the Study Area. This enhanced understanding of the distribution of the hydrostratigraphy on a regional and local-scale sets the foundation for subsequent phases of the Tier Three Assessment. Specifically, the interpreted elevations at the tops of the hydrostratigraphic units, as well as our understanding of the geologic history of the area, will form the basis of the three-dimensional hydrostratigraphic layer structure of a groundwater flow model that will be developed in the next phase of the assessment.

Streamflow gauge data for three long-term stream gauges were evaluated to improve the understanding of the variations in groundwater recharge across the Study Area. The mapped surficial geologic units in the three gauged catchments are diverse. Irvine Creek catchment is predominately till (78%), the Speed River near Armstrong Mills is predominantly (60%) sand and gravel, and the Eramosa River above Watson is a mix of sand and gravel and till. As such, the flow characteristics of the three catchments also differ. Irvine Creek catchment displays a flashier response to rainfall events, and the Speed River at Armstrong Mills catchment has a larger baseflow component; the hydrologic regime of the Eramosa River is baseflow dominated. As such, Irvine Creek catchment's baseflow component was estimated to be 25% of total streamflow, as compared to 41% and 56% on the Speed River and Eramosa River catchments, respectively. As such, low groundwater recharge rates are expected in the Irvine Creek catchment, and the highest recharge rates are expected in the Eramosa River at Watson catchment.

Water demand within the Study Area was assessed in detail and included review of municipal and non-municipal permitted water takings, as well as non-permitted water takings. The characterization of the water demands included a review of data contained within the PTTW database, the Water Taking and Reporting System dataset, data provided by permit holders and estimated demands for domestic and one large non-permitted agricultural water taker. Reported values were available for most permitted water takers in the Study Area, and consumptive use factors were applied to better estimate the water demands across the Study Area.

Water levels in Centre Wellington's pumping and monitoring wells were assembled into a dataset alongside water level data provided by select permit applicants and permit holders within the Study Area. In addition, the OGS recently published a report and data tables that summarize the hydraulic properties of the bedrock aquifers and aquitards present within the Study Area and beyond. The range of values will be used alongside the change in water levels over time in wells in the subsequent phases of the project as calibration water level targets for the groundwater flow model.

6 REFERENCES

Allen A., Borchardt M.A., Kieke Jr. B.A., Dunfield K.E., and B.L. Parker. 2017. "Virus occurrence in private and public wells in a fractured dolostone aquifer in Canada." *Hydrogeology Journal 25 (4)*: 1117-1136.

Anderson GeoLogic Ltd. (AGL). 2009. *Fergus Well F7 – Packer Testing.* Memorandum. September 11, 2009.

Anderson GeoLogic Ltd. (AGL). 2002a. *Hydrogeological Investigation Elora Test Well 4B (Cottontail Rd.) Township of Centre Wellington, Elora, Ontario*. Report prepared for Township of Centre Wellington. Elora, Ontario. September 2002.

Anderson GeoLogic Ltd. (AGL). 2002b. *Hydrogeological Investigation Fergus Test Well 7B (Allardice) Township of Centre Wellington*, *Fergus, Ontario*. Report prepared for Township of Centre Wellington. Elora, Ontario. June 2002.

AquaResource Inc. (AquaResource). 2009a. *Integrated Water Budget Report, Grand River Watershed*. Final Report, June 2009.

AquaResource Inc. (AquaResource). 2009b. *Tier 2 Water Quantity Stress Assessment Report, Grand River Watershed*. Final Report December 2009.

Armstrong D.K. and T.R. Carter. 2010. *The Subsurface Paleozoic Stratigraphy of Southern Ontario, Ontario Geological Survey*. Special Volume 7, 301p.

Armstrong D.K. and J.E.P. Dodge. 2007. *Paleozoic geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 219.*

Arnold J.G., Allen P.M., Muttiah R., and G. Bernhardt. 1995. "Automated base flow separation and recession analysis techniques." *Ground Water 33 (6)*: 1010-1018.

Arnold J.G. and P.M. Allen. 1999. "Automated methods for estimating baseflow and ground water recharge from streamflow records." *Journal of the American Water Resources Association 35 (2)*: 411-424.

Bajc A.F. and J. Shirota. 2007. "Three-dimensional mapping of surficial deposits in the Regional Municipality of Waterloo, Southwestern Ontario." *Ontario Geological Survey, Groundwater Resources Study* 3, 42p.

Bajc A.F., Russell H.A.J., and D.R. Sharpe. 2014. "A three-dimensional hydrostratigraphic model of the Waterloo Moraine area, southern Ontario, Canada." *Canadian Water Resources Journal 39 (2)*: 95-119.

Barnett P.J. 1992. "Quaternary Geology of Ontario." In: *Geology of Ontario: Ontario Geological Survey*. Thurston P.C., Williams H.R., Sutcliffe R.H., and G.M. Stott (Eds.). Ontario Geological Survey, Toronto: 1011-1090.

Beatty, B.W. 1971. *Report on the Availability of Ground Water, Thunderbird Estates Subdivision, Marsville, Ontario.* September 1971.

Blackport Hydrogeology Inc. (Blackport). 2002a. *Groundwater Management and Protection Strategies, Groundwater Management Study, Township of Centre Wellington.*

Blackport Hydrogeology Inc. (Blackport). 2002b. *Fergus Water Supply System Wells F1 and F2 GUDI Assessment, Township of Centre Wellington, Ontario*. Report prepared for Township of Centre Wellington. Elora, Ontario. March 2002.

Blackport Hydrogeology Inc (Blackport) and Waterloo Hydrogeologic Inc (WHI). 2002. *Water Resources Characterization Groundwater Management Study Township of Centre Wellington*. Report prepared for Township of Centre Wellington. Elora, Ontario. August 2002.

Blackport Hydrogeology Inc. 2003. *Fergus Water Supply System Additional GUDI Assessment Municipal Well F1, Township of Centre Wellington.* Report prepared for Township of Centre Wellington. Elora, Ontario. August 2003.

Blackport Hydrogeology Inc. 2005. *Town of Fergus Municipal Well F2 Well Integrity Testing and Pumping Test Data Assessment.* Report prepared for Triton Engineering Services Limited. Fergus, Ontario. October 2005.

Brintnell C. 2012. "Architecture and Stratigraphy of the Lower Silurian Guelph Formation, Lockport Group, southern Ontario and Michigan." Master of Science thesis. The University of Western Ontario. London, Ontario.

Brunton F. 2009. *Project Unit 08-004*. Update of Revisions to the Early Silurian Stratigraphy of the Niagara Escarpment: Integration of Sequence Stratigraphy, Sedimentology and Hydrogeology to Delineate Hydrogeologic Units in *Summary of Field Work and Other Activities 2009*, Ontario Geological Survey, Open File Report 6240, p. 25-1 to 25-20.

Brunton F. 2008. *Preliminary Revisions to the Early Silurian Stratigraphy of Niagara Escarpment: Integration of Sequence Stratigraphy, Sedimentology and Hydrogeology to Delineate Hydrogeologic Units.* In Summary of Field Work and Other Activities 2008, Ontario Geological Survey, Open File Report 6226, p. 31-1 to 31-18.

Brunton F.R. and C. Brintnell. 2011. *Final update of Early Silurian stratigraphy of the Niagara Escarpment and correlation with subsurface units across Southwestern Ontario and the Great Lake Basin.* in Summary of Field Work and Other Activities 2001, Open File Report 6270, p.35-1 to 30-11.

Brunton F.R., Brintnell C., Jin J., and A.M. Bancroft. 2012. *Stratigraphic architecture of the Lockport Group in Ontario and Michigan – A new interpretation of Early Silurian "Basin Geometries" & "Guelph Pinnacle Reefs."* Technical Paper No. 8 in 51st Annual Conference – Ontario–New York Oil & Gas Conference, October 23 to 25, 2012. Niagara Falls, Ontario. p.1-37.

R.J. Burnside and Associates (Burnside). 2004. *Hydrogeology Report in Support of Application for Permit to Take Water Town of Arthur Wells 8A and 8B*. February 2004.

R.J. Burnside and Associates (Burnside). 2003. *Exploration for a New Water Source for the Village of Arthur, Ontario, Hydrogeologic Report, Construction and Testing of TW4/02*. May 2003.

Burnside Environmental (Burnside). 1998. *Arthur Well 7B, Construction and Testing, Arthur Public Utilities Commission*. August 1998.

Burt A.K. and J.E.P. Dodge. 2016. *Three-dimensional modelling of surficial deposits in the Orangeville–Fergus area of southern Ontario.* Ontario Geological Survey, Groundwater Resources Study 15.

Chapman L.J. and D.F. Putnam. 1984. *The Physiography of Southern Ontario*. Third Edition. Special Volume 2. Ontario Geological Survey. Ministry of Natural Resources. July 9, 1984.

Chung & Vander Doelen Engineering Ltd (CVD). 2015. *Hydrogeological Assessment, Proposed Haylock Subdivision, 133 South River Road, Elora, Ontario.*

Cowan W.R. 1976. *Quaternary Geology of the Orangeville Area, Southern Ontario.* Ontario Division of Mines, Ministry of Natural Resources, Geoscience Report 141.

Dufferin Water Co. LTD (DWCo. Ltd). 2017. *Marsville Water Supply System, Small Municipal Residential Drinking Water System, Schedule 22, Summary Report.* For the period January 01, 2016 to December 31, 2016. Prepared for the Township of East Garafraxa.

Environment and Climate Change Canada (ECCC). 2017. Residential Water Use in Canada. Modified on April 10, 2017. https://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=7E808512-1

Freeze R.A. and J.A. Cherry. 1979. *Groundwater*. Prentice Hall. New Jersey. 604 pp.

Friends of the Grand River. 2002. *Mapping Water Temperature Variation in the Grand River in the lower Belwood Reservoir Tailwater Fishery.* October 2002.

Gao, C., Shirota, J., Kelly, R. I., Brunton, F.R., van Haaften, S. 2006. Bedrock topography and overburden thickness mapping, southern Ontario; Ontario Geological Survey, Miscellaneous Release--Data 207.

Gartner Lee Ltd. (Gartner Lee) 2005. *Middlebrook Water Source – Elora – Long Term Source Sustainability.* Prepared for Middlebrook Water Co. Inc. March 2005.

Golder Associates Ltd. (Golder). 2015a. *Township of Centre Wellington Municipal Wells F1, F6 and E3, Investigation of Chloride in Drinking Water*. December 2015.

Golder Associates Ltd. (Golder). 2015b. *Geophysical Record of Borehole: Middlebrook Well*. May 2015.

Golder Associates Ltd. (Golder). 2015c. *Pumping Test Program, Middlebrook Well – Category 3 Permit To Take Water Application*. July 20, 2015.

Golder Associates Ltd. (Golder). 2013. *Township of Centre Wellington: Well Field Capacity Assessment*. Prepared for the Township of Centre Wellington. Elora, Ontario. September 2013.

Golder Associates Ltd. (Golder). 2011a. *City of Guelph Tier Three Water Budget and Local Area Risk Assessment, Appendix A: Characterization Final Report*. July 2011.

Golder Associates Ltd. (Golder). 2011b. *Reconstruction of Sideroad 19, Burnett Court and Victoria Crescent, Hydrogeological Assessment for Permit To Take Water Number 4406-8FXJX7*. October 2011.

Golder Associates Ltd. (Golder). 2010a. *Township of Centre Wellington Preliminary Well Field Capacity Assessment and Proposed Testing Program.* Report prepared for Township of Centre Wellington. Elora, Ontario. December 2010.

Golder Associates Ltd. (Golder). 2010b. *Township of Centre Wellington Source Protection Vulnerability, Issues and Threats Assessment*. July 2010.

Golder Associates Ltd. (Golder). 2006. *County of Wellington Groundwater Protection Study.* September 2006.

Greenhouse, J.P. and P.F Karrow. 1994. "Geological and geophysical studies of buried valleys and their fills near Elora and Rockwood, Ontario." *Canadian Journal of Earth Sciences 31:* 1838-1848.

Hydrology Consultants Ltd. 1975. Report on Production Well No.5, Town of Fegus.

International Water Supply Ltd. 1989. Fergus Public Utilities Commission Report 1989 Groundwater Investigation Well No. 6.

Johnson M.D., Armstrong, D.K., Sandford, B.V., Telford, P.G., and Rutka, M.A. 1992. "Paleozoic and Mesozoic Geology of Ontario: in Geology of Ontario." *Ontario Geological Survey 4 (Part 2)*: 907- 1010.

Karrow P.F. 1973. "Bedrock topography in southwestern Ontario: a progress report." *Geological Association of Canada, Proceedings (25)*: 67-77.

Karrow P.F. 1968. *Pleistocene Geology of the Guelph Area, southern Ontario*. Ontario Geological Survey, Geological Report 61, 30 p.

Kinkead Consulting and AquaResource Inc. 2009. *Methodology for Identifying Large Consumptive Water Users: Great Lakes - St. Lawrence River Basin Sustainable Water Resource Agreement*. Report prepared for the Ontario Ministry of Natural Resources. Waterloo, Ontario. 2009.

Kunert, M., Coniglio, M., and Jowett, E.C. 1998. *Controls and age of cavernous porosity in Middle Silurian dolomite, southern Ontario*. Canadian Journal of Earth Sciences, 35: 1044-1053.

Kunert, M. and Coniglio, M. 2002. *Origin of vertical shafts in bedrock along the Eramosa River valley near Guelph, southern Ontario*. Canadian Journal of Earth Sciences, 39: 43-52.

Lake Erie Source Protection Committee (LESPC). 2015. *Grand River Source Protection Area Approved Assessment Report*. November 25, 2015.

Lee F.Y. 1975. "Geophysical Studies of a Buried Bedrock Channel in the Elora-Fergus Region of Southwestern Ontario." MSc. Thesis, Department of Earth Sciences, The University of Waterloo, 73p.

Lotowater Technical Services Inc. (Lotowater). 2016a. *Fergus Well 5 Geophysical Log.* July 2016.

Lotowater Technical Services Inc. (Lotowater). 2016b. *Well 5 Flow Distribution Profile.* August 2016.

Lotowater Technical Services Inc. (Lotowater). 2015a. *Elora Well E1 Geophysical Logging, Video and Flow Profile.* May 15, 2015.

Lotowater Technical Services Inc. (Lotowater). 2015b. *Middlebrook Well Video, Flow Profiling and Packer Testing (draft)*, prepared for Golder Associates Ltd., May 21, 2015.

Naylor Engineering Associates Ltd. 2001. *Hydrogeological Investigation: Proposed Middlebrook Water Company Facility, Lot 5, Concession A, Centre Wellington Township, County of Wellington, Ontario.* Report prepared for Mr. Richard Beckham of 1445036 Ontario Ltd. November 2001.

Ontario Geological Survey (OGS). 2010. *Surficial Geology of Southern Ontario*. Miscellaneous Release - Data 128 - Revised.

Ontario Ministry of Natural Resources and Forestry (MNRF). 2017. *Significant Wetlands and the Ontario Wetland Evaluation System.* http://www.web2.mnr.gov.on.ca/mnr/Biodiversity/wetlands/Significant_wetlands_and_OWES.pdf

Ontario Ministry of Natural Resources (MNR). 2012. *Land Information Ontario Data Description, Aquatic Resource Area Summary*. https://www.sse.gov.on.ca/sites/MNR-PublicDocs/EN/CMID/Aquatic%20Resource%20Area%20Summary%20-%20Data%20Description.pdf

Ontario Ministry of the Environment and Climate Change (MOECC). 2017. *Permit to Take Water Database*. Accessed in February 2015. http://www.ontario.ca/data/permit-take-water

Ontario Ministry of the Environment and Climate Change. (MOECC). 2016a. *Centre Wellington Drinking Water System Inspection Report*. July 2016.

Ontario Ministry of the Environment and Climate Change. (MOECC). 2016b. Technical Guidance Document for Hydrogeological Studies in Support of Category 3 Applications. May 2016. https://www.ontario.ca/page/technical-guidance-document-hydrogeological-studies-support-category-3-applications

Ontario Ministry of the Environment and Climate Change. (MOECC). 2015. *Technical Rules: Assessment Report, Clean Water Act, 2006*. November 20, 2008. Amended on December 12, 2008 (administrative amendments), November 16, 2009 (EBR Posting Number EBRO10-7573), December 2, 2013 (Technical Bulletin).

Ontario Ministry of the Environment (MOE). 2006. *Clean Water Act.* S.O. 2006, Chapter 22, Ontario Regulation 287/07. Royal Assent: October 19, 2006. URL: http://www.ontario.ca/laws/statute/06c22

Priebe E.H. and V.L. Lee. 2016. *Groundwater hydrochemistry data for multi-depth well sampling in the Early Silurian carbonates of the Niagara Escarpment cuesta.* Ontario Geological Survey, Miscellaneous Release—Data 337.

Priebe, E.H., Neville, C.J. and Brunton, F.R. 2017. *Discrete, high-quality hydraulic conductivity estimates for the Early Silurian carbonates of the Guelph region*; Ontario Geological Survey, Groundwater Resources Study 16.

Priebe, E.H., Neville, C.J. and Brunton, F.R. 2014. *Evaluating the influence of geological features on hydraulic conductivity variability in Early Silurian carbonate rock aquifers of the Guelph region*; in Summary of Field Work and Other Activities 2014, Ontario Geological Survey, Open File Report 6300, p.35-1 to 35-8.

Priebe E.H., Neville C.J., and F.R. Brunton. 2014. *Evaluating the influence of geological features on hydraulic conductivity variability in Early Silurian carbonate rock aquifers of the Guelph region*. in Summary of Field Work and Other Activities 2014, Ontario Geological Survey, Open File Report 6300, p. 35-1 to 35-8.

Schroeter & Associates. 2004. *GAWSER: Guelph All-Weather Sequential-Events Runoff Model, Version 6.5, Training Guide and Reference Manual.* Report prepared for the Ontario Ministry of Natural Resources and the Grand River Conservation Authority. 2004.

Schwartz F.W. and H. Zhang. 2003. *Fundamentals of Ground Water*. John Wiley & Sons, Inc. New York, New York.

Shifflet S. 2015. *Revised Water Demand and Tier 2 Water Quantity Stress Assessment, Irvine River Groundwater Assessment Area.* Prepared for Lake Erie Source Water Protection Region.

Spitz K. and J. Moreno. 1996. *A Practical Guide to Groundwater and Solute Transport Modeling*. John Wiley & Sons Inc. A Wiley Inter-Science Publication.

Terraqua Investigations Ltd. (Terraqua). 1992a. *Village of Elora Municipal Well 3 Water Supply Investigation, Draft*. Prepared for Village of Elora. March 1992.

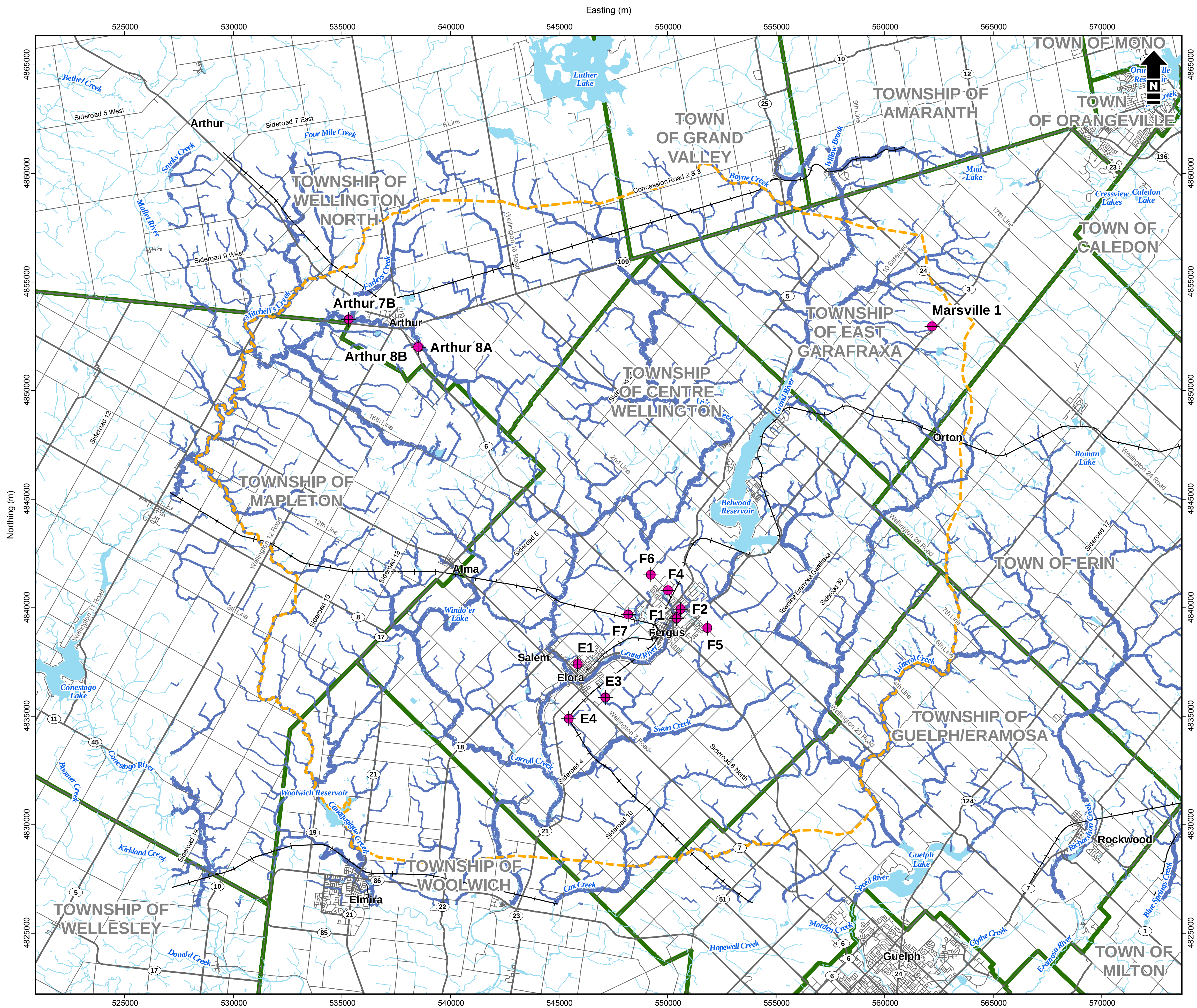
Terraqua Investigations Ltd. (Terraqua). 1992b. *Water Supply Investigation Town of Fergus Municipal Well 2*. Prepared for Fergus Public Utilities Commission. Fergus, Ontario. August 1992.

Terraqua Investigations Ltd. (Terraqua). 1992c. *Supplemental Water Supply Investigation Town of Fergus Public Utilities Commission Municipal Well 6.* Prepared for Fergus Public Utilities Commission. Fergus, Ontario. April 1992.

Terraqua Investigations Ltd. (Terraqua) 1991. *Investigation of TCE Contamination Town of Fergus, Draft Report*. Prepared for Fergus Public Utilities Commission. Fergus, Ontario. December 1991.

The Township of Wellington North. 2017. *Annual and Summary Report, For the Period of Jan. 1, 2016 to Dec. 31, 2016, for Arthur and Mount Forest Drinking Water Systems.* January 11, 2017.

Worthington, S.R.H. 2011. OPG's Deep Geologic Repository for Low and Intermediate Level Waste, Karst Assessment. Report submitted to the Nuclear Water Management Organization. March 2011. Accessible online at: http://www.opg.com/generating-power/nuclear/nuclear-waste-management/Deep-Geologic-Repository/Documents/GSR/4.1.9_Karst-Assessment.pdf



Study Area
Municipal Boundary
Water Body
Watercourse
Highway
Road
Railroad Trail
Municipal Well within the Study Area

Strahler Order

- 1
- 2
- 3
- => 4

Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministry of Municipal Affairs and Housing. Contains information licensed under the Open Government Licence – Ontario.

1:180,000
1,750 0 1,750 3,500 m
NAD 1983 UTM Zone 17N

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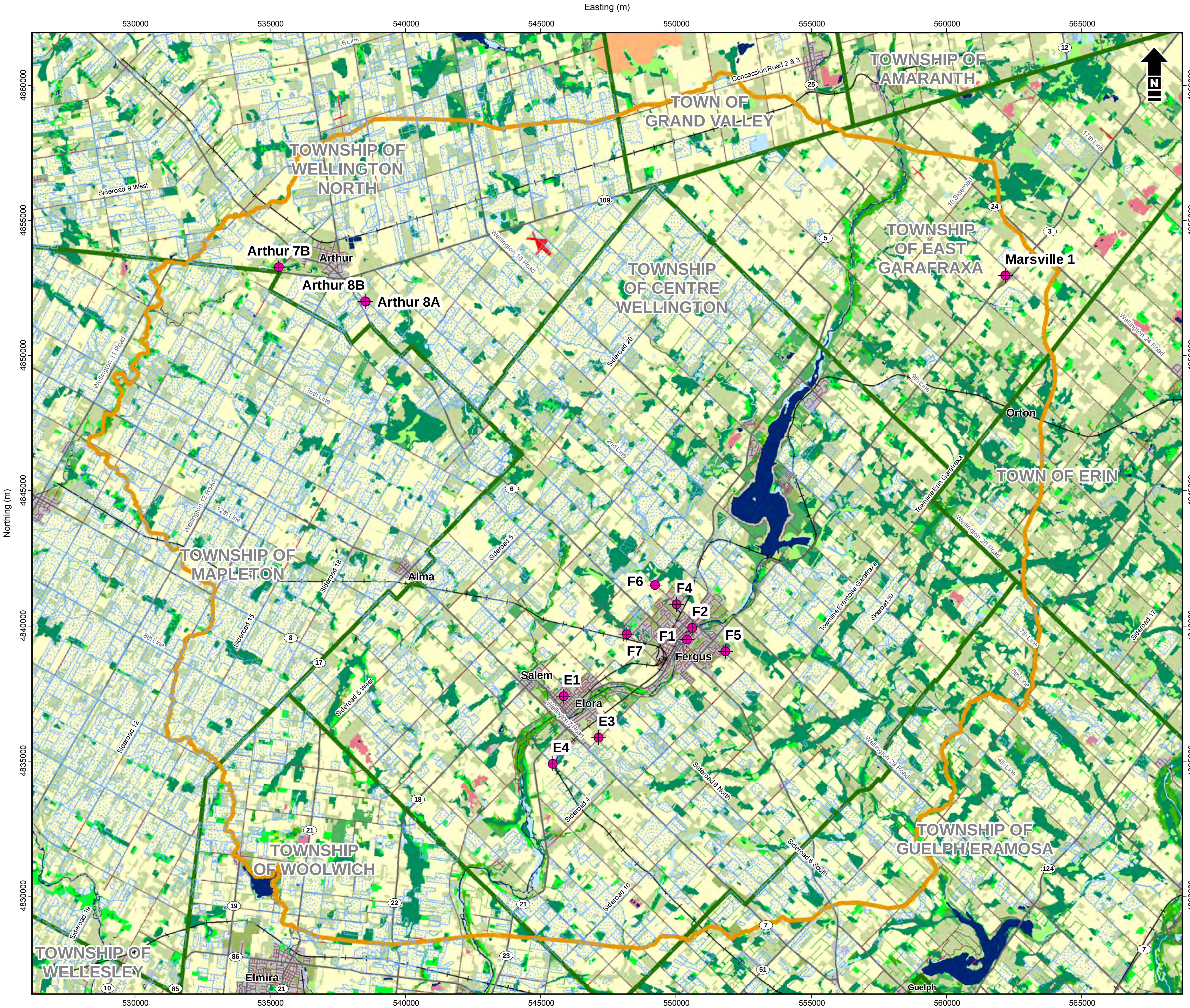
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Study Area

Date:	Project:	Technical:	Reviewer:	Drawn:
24 Nov 2017	23876	J. Melchin	P. Meyer	C. Curry

Figure 1



Study Area
Municipal Boundary
Systematic Tile Drainage Area
Highway
Road
Railroad Trail
Municipal Well

Land Cover

- Forest
- Coniferous Forest
- Mixed Forest
- Deciduous Forest
- Treed Swamp
- Thicket Swamp
- Bog
- Marsh
- Open Water
- Plantation
- Hedge Row
- Managed Agricultural Land
- Transportation
- Built Up Area - Pervious
- Built Up Area - Impervious
- Extraction - Aggregate
- Undifferentiated

1:145,000
1,400 0 1,400 2,800 m
NAD 1983 UTM Zone 17N

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Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Land Cover

Date:	Project:	Technical:	Reviewer:	Drawn:
24 Nov 2017	23876	J. Melchin	P. Meyer	C. Curry

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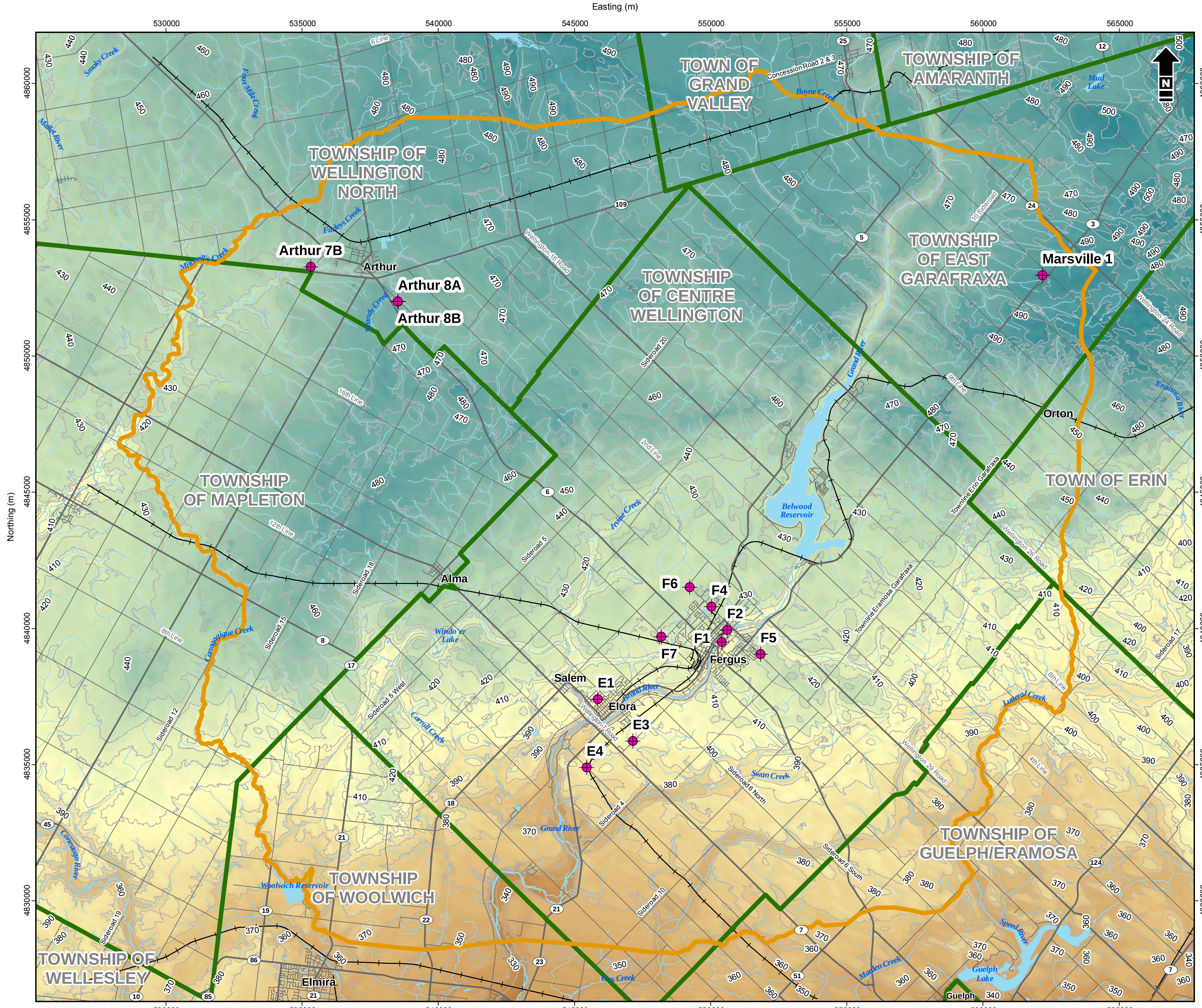
Figure 2



Study Area
Municipal Boundary
Water Body
Watercourse
Highway
Road
Railroad Trail
Elevation Contour (10m)
Municipal Well

Ground Elevation (masl)
High : 525.76
Low : 134.269

Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministry of Municipal Affairs and Housing. Contains information licensed under the Open Government Licence – Ontario.

1:145,000
1,400 0 1,400 2,800 m
NAD 1983 UTM Zone 17N

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Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Ground Surface Topography

Date:	Project:	Technical:	Reviewer:	Drawn:
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Figure 3

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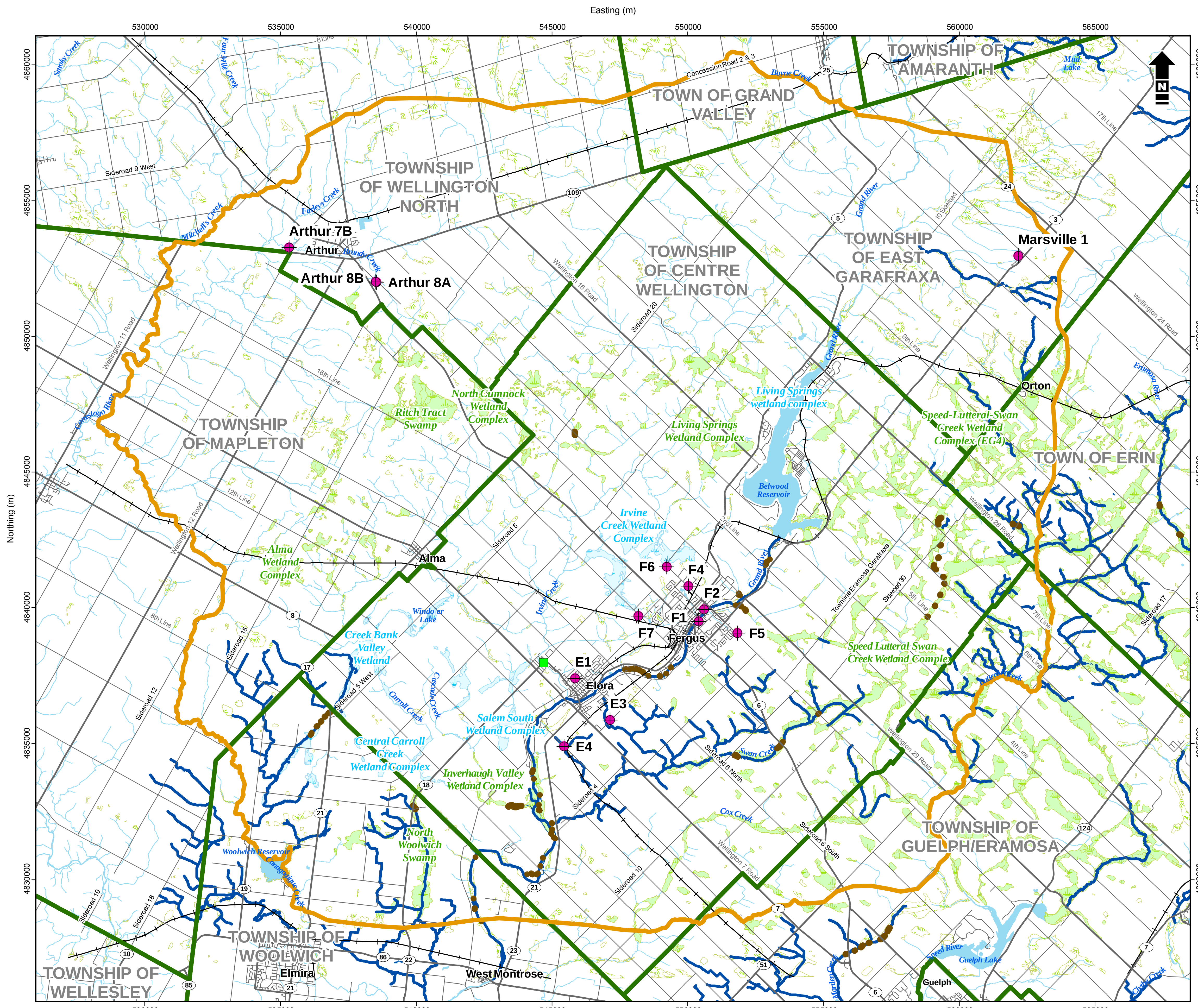

Study Area
Brook and Brown Trout Spawning Area
Municipal Boundary
MNR Mapped Provincially Significant Wetland
Other Mapped Evaluated Wetland
Non-Evaluated Wetland
Water Body
Watercourse
Coldwater Stream
Highway
Road
Railroad Trail
Municipal Well
Water Survey of Canada Gauge

1:145,000
1,400 0 1,400 2,800 m
NAD 1983 UTM Zone 17N

Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministry of Municipal Affairs and Housing. Contains information licensed under the Open Government Licence – Ontario.

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Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Surface Water and Ecological Features

Date:	Project:	Technical:	Reviewer:	Drawn:
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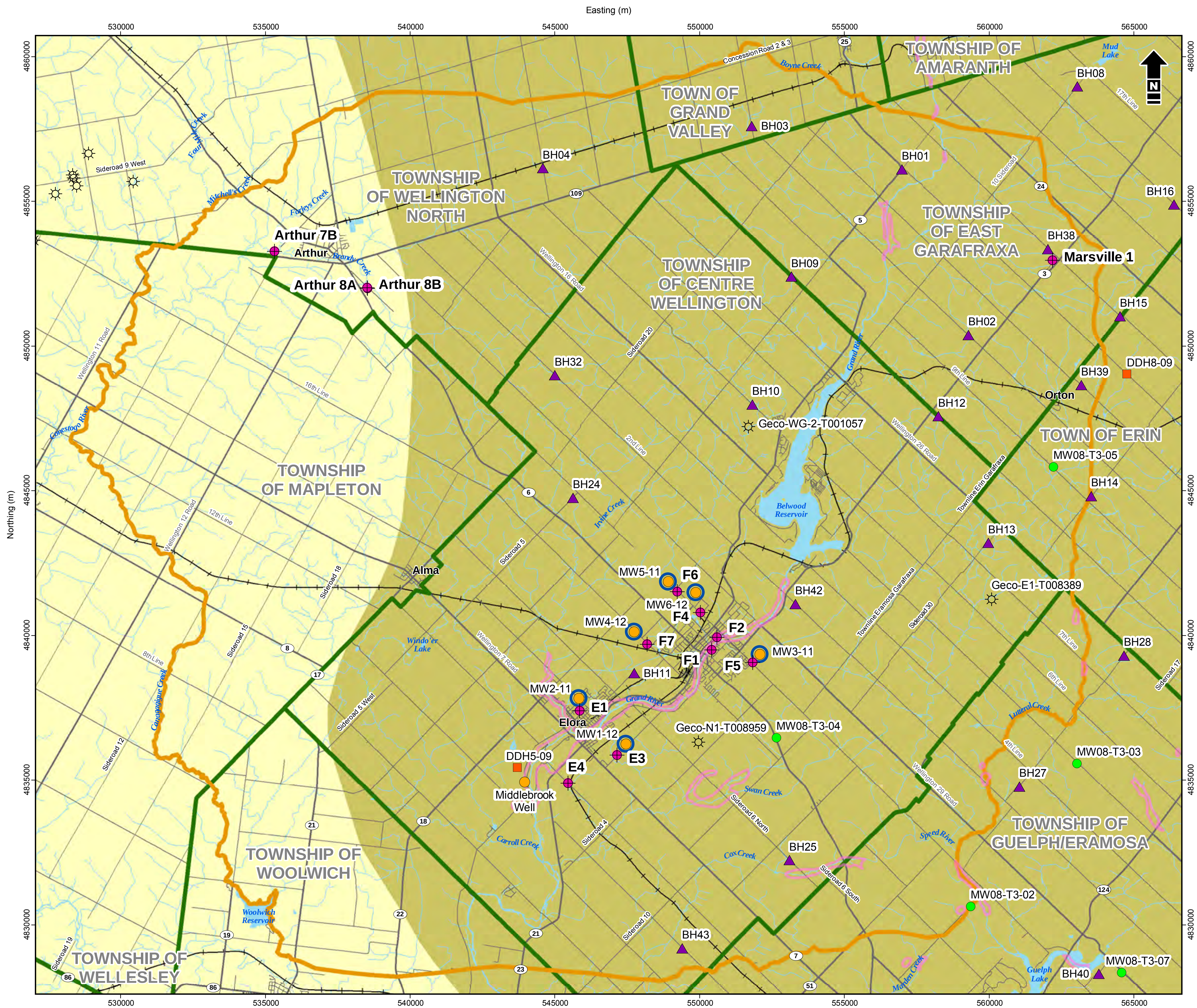
Figure 4

I:\GrandRiverCA\23876\FiguresandTables\T3\2017\Report\CharacterizationReport\Figure-4-Surface_Water_and_Ecological_Features.mxd



Study Area
Municipal Boundary
Water Body
Watercourse
Highway
Road
Railroad Trail
Municipal Well
OGS High Quality Overburden Corehole
OGS High Quality Bedrock Corehole
Guelph Tier Three Bedrock Well
Well with Geophysical Data
Oil and Gas Well
Multi-level Monitoring Well

Geology

Bedrock Outcrop

Subcropping Bedrock Geology

Guelph Formation
Salina Group

Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministy of Municipal Affairs and Housing. Bedrock Geology from Armstrong, D.K. and Dodge, J.E.P. 2007. Paleozoic geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release--Data 219. ISBN 978-1-4249-4526-9. Contains information licensed under the Open Government Licence – Ontario. Surficial Geology from the Ontario Geological Survey 2010. Surficial geology of Southern Ontario; Ontario Geological Survey, Miscellaneous Release--Data 128-REV.

1:135,000
m
1,300 0 1,300 2,600
NAD 1983 UTM Zone 17N

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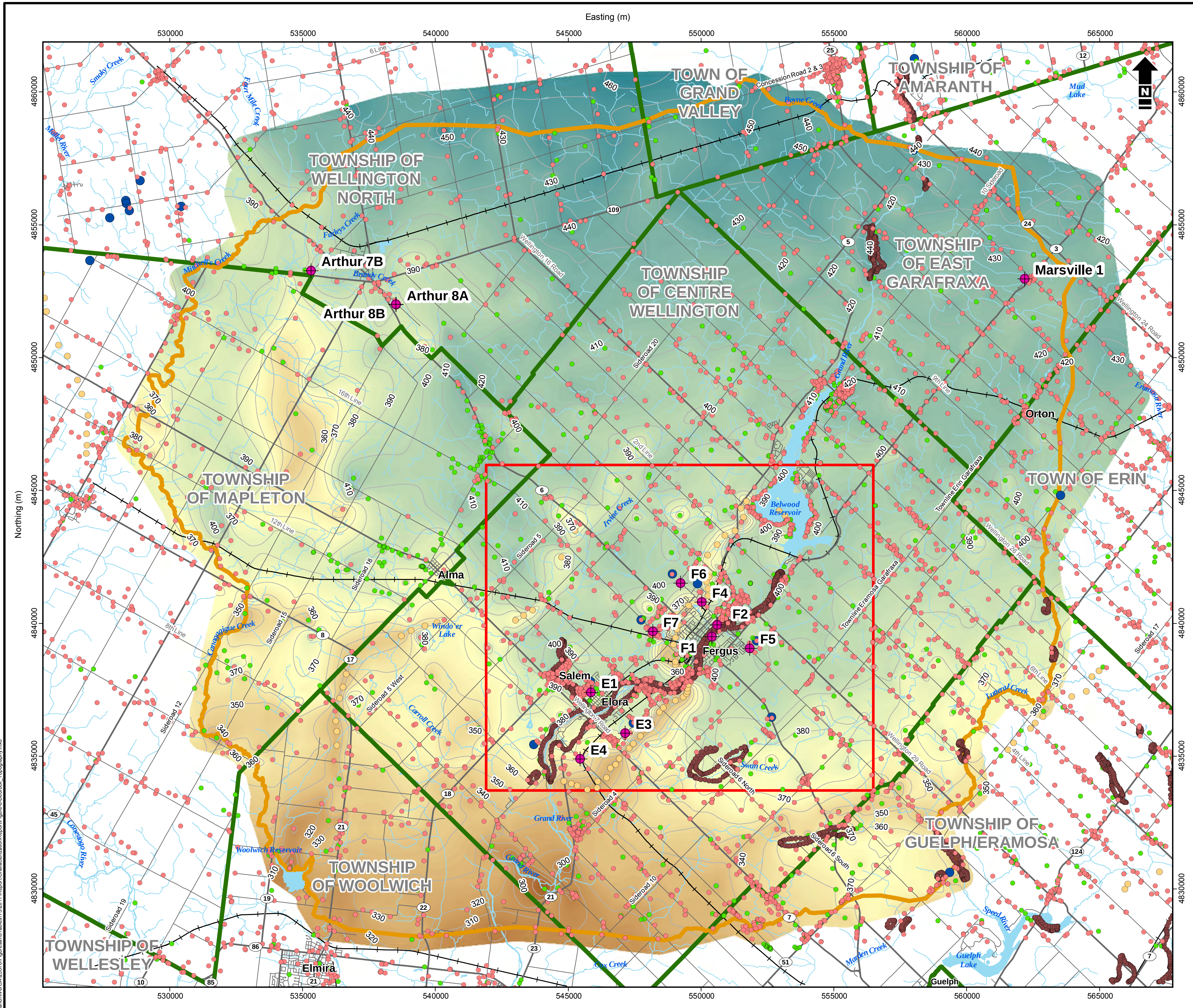
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Bedrock Geology

Date: 24 Nov 2017	Project: 23876	Technical: J. Melchin	Reviewer: P. Meyer	Drawn: C. Curry

Figure 5



Study Area
Municipal Boundary
Figure 7 Extent
Water Body
Watercourse
Highway
Road
Railroad Trail
Elevation Contour (10m)
Municipal Well

Bedrock Topography (masl)

High : 473.968

Low : 271.606

Bedrock Point Used in Analysis

Low Quality Data Point
Thalweg Control Point
Bedrock Outcrop
Overburden Push Down Point
High Quality Data Point

1:145,000

1,400 0 1,400 2,800 m

NAD 1983 UTM Zone 17N

Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministry of Municipal Affairs and Housing. Contains information licensed under the Open Government Licence – Ontario.

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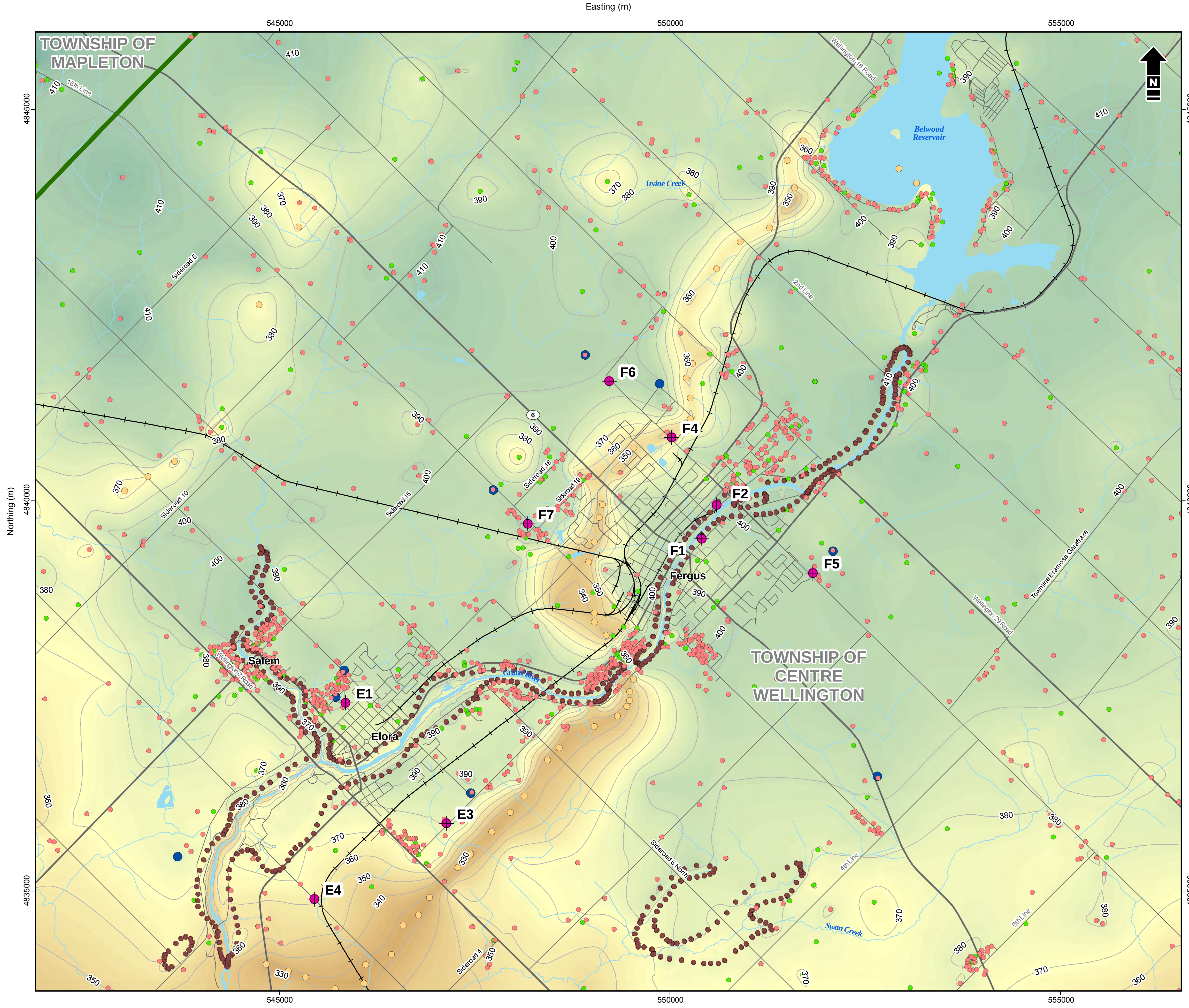
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Bedrock Topography

Date:	Project:	Technical:	Reviewer:	Drawn:
24 Nov 2017	23876	J. Melchin	P. Meyer	C. Curry

Figure 6



Municipal Boundary
Water Body
Watercourse
Highway
Road
Railroad Trail
Elevation Contour (10m)
Municipal Well

Bedrock Topography (masl)
High : 470
Low : 270

Bedrock Point Used in Analysis
Low Quality Data Point
Thalweg Control Point
Bedrock Outcrop
Overburden Push Down Point
High Quality Data Point

1:50,000
500 0 500 1,000 m
NAD 1983 UTM Zone 17N

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Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Interpreted Bedrock Valley

Date:	Project:	Technical:	Reviewer:	Drawn:
20 Oct 2017	23876	J. Melchin	P. Meyer	C. Curry

Figure 7

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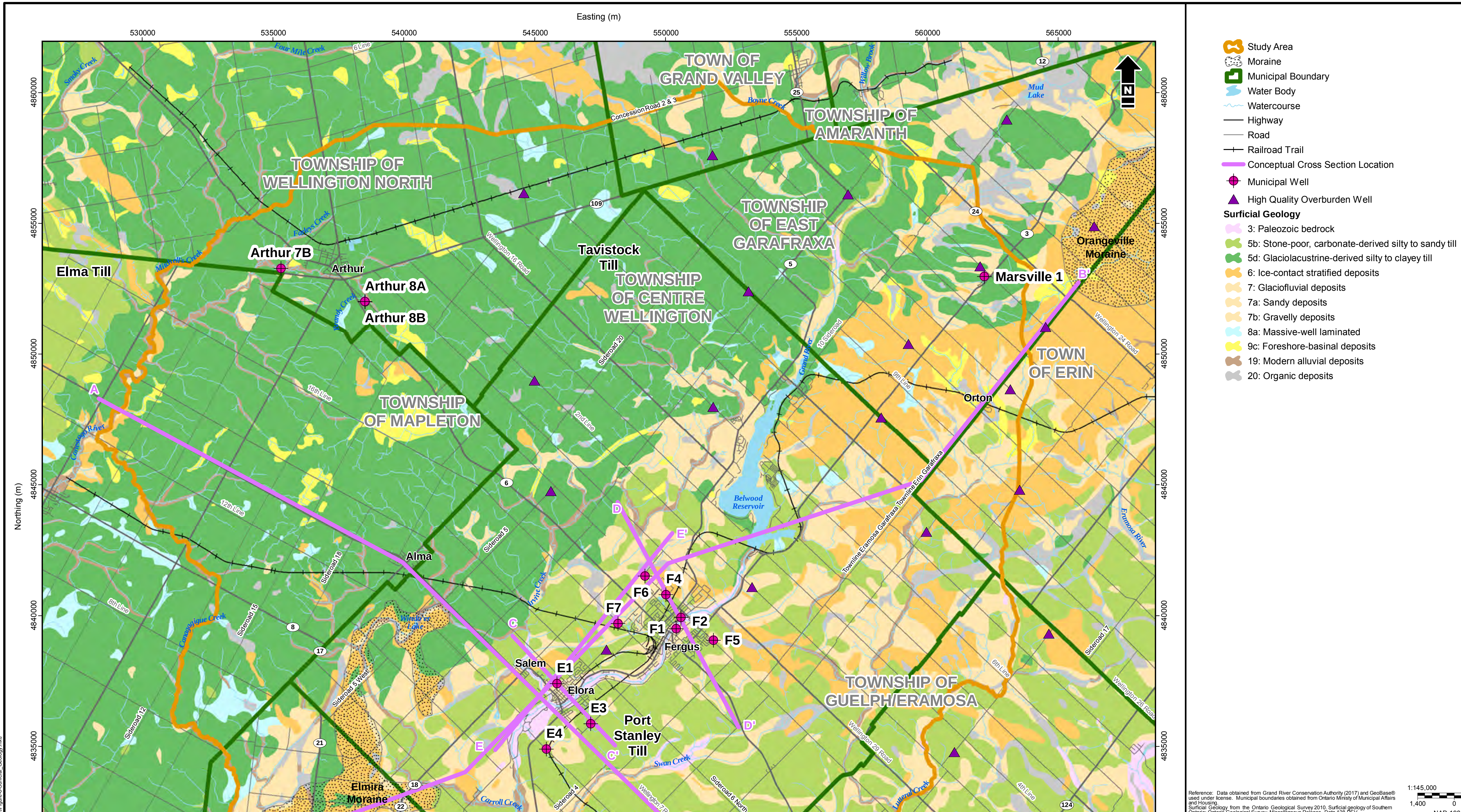

Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministry of Municipal Affairs and Housing. Surficial Geology from the Ontario Geological Survey 2010, Surficial geology of Southern Ontario; Ontario Geological Survey, Miscellaneous Release–Data 128-REV. Contains information licensed under the Open Government Licence – Ontario.

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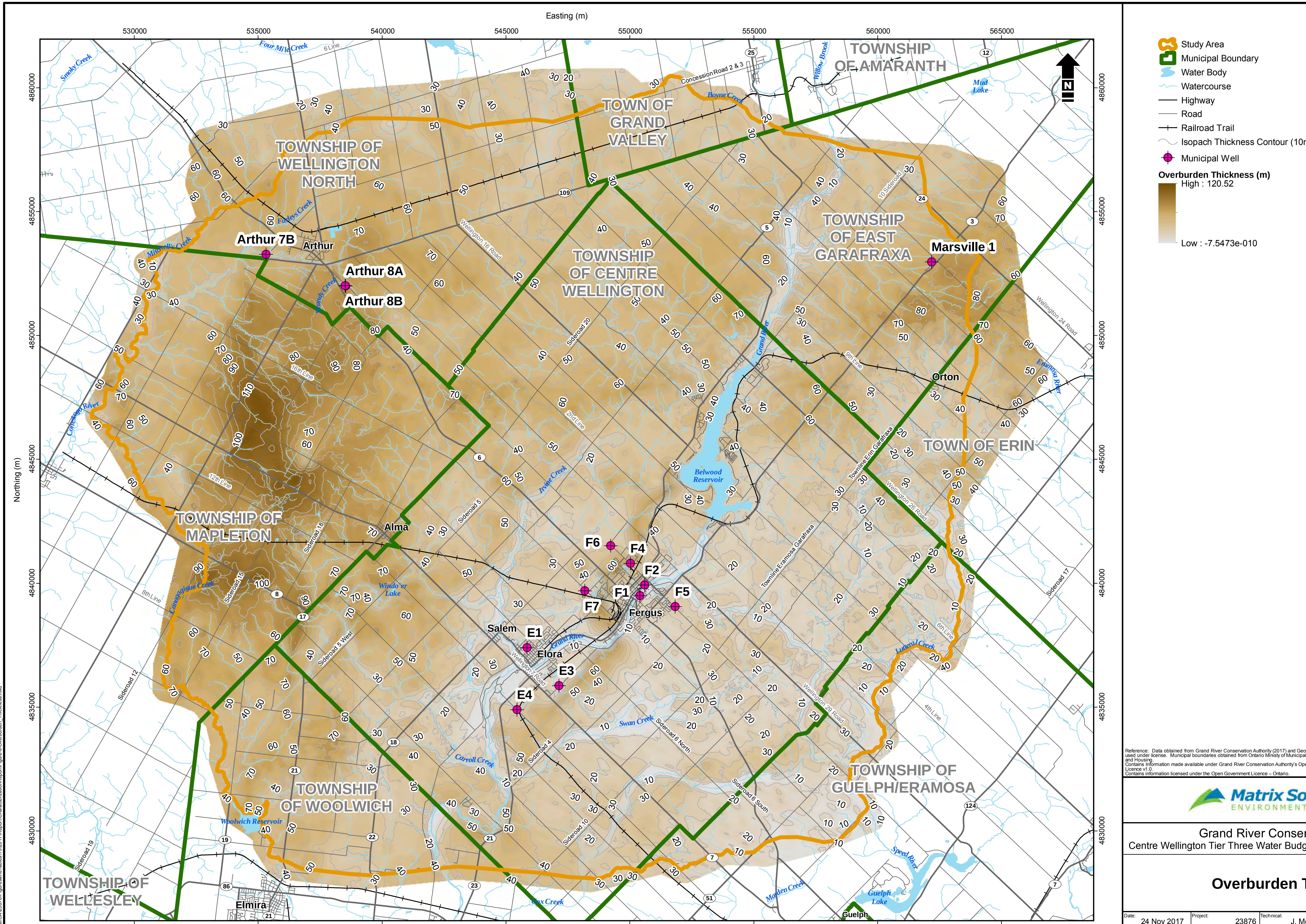
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Surficial Geology

Date:	Project:	Technical:	Reviewer:	Drawn:
24 Nov 2017	23876	J. Melchin	P. Meyer	C. Curry

Figure 8



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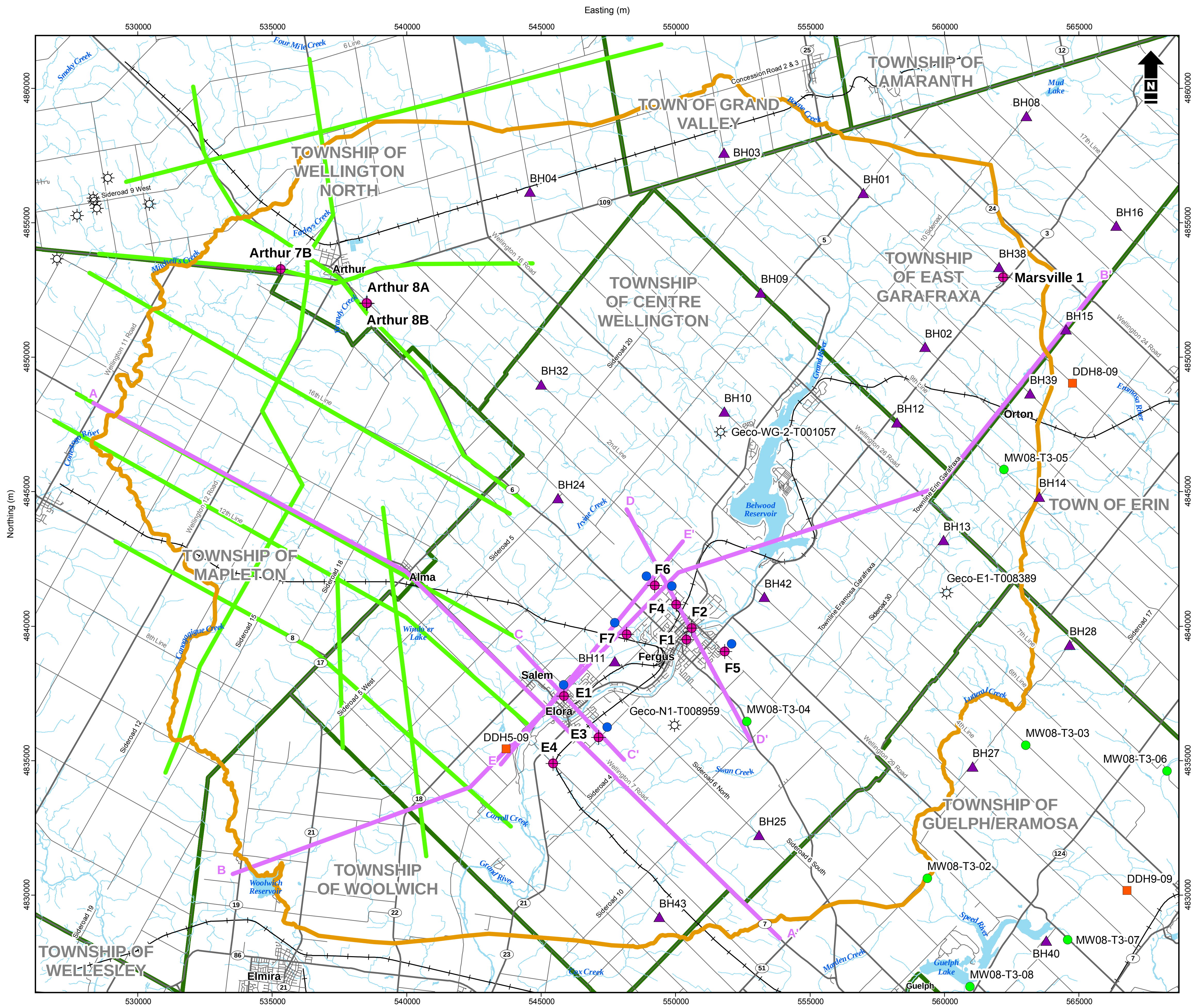
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Overburden Thickness

Date:	Project:	Technical:	Reviewer:	Drawn:
24 Nov 2017	23876	J. Melchin	P. Meyer	C. Curry

Figure 9



Study Area
Municipal Boundary
Water Body
Watercourse
Highway
Road
Railroad Trail
Conceptual Cross Section Location
Overburden Cross Section Location
Municipal Well
OGS High Quality Overburden Corehole
OGS High Quality Bedrock Corehole
Guelph Tier Three Bedrock Well
Oil and Gas Well
Multi-level Monitoring Well

1:145,000
1,400 0 1,400 2,800 m
NAD 1983 UTM Zone 17N

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Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Cross Section Locations

Date:	Project:	Technical:	Reviewer:	Drawn:
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Figure 10

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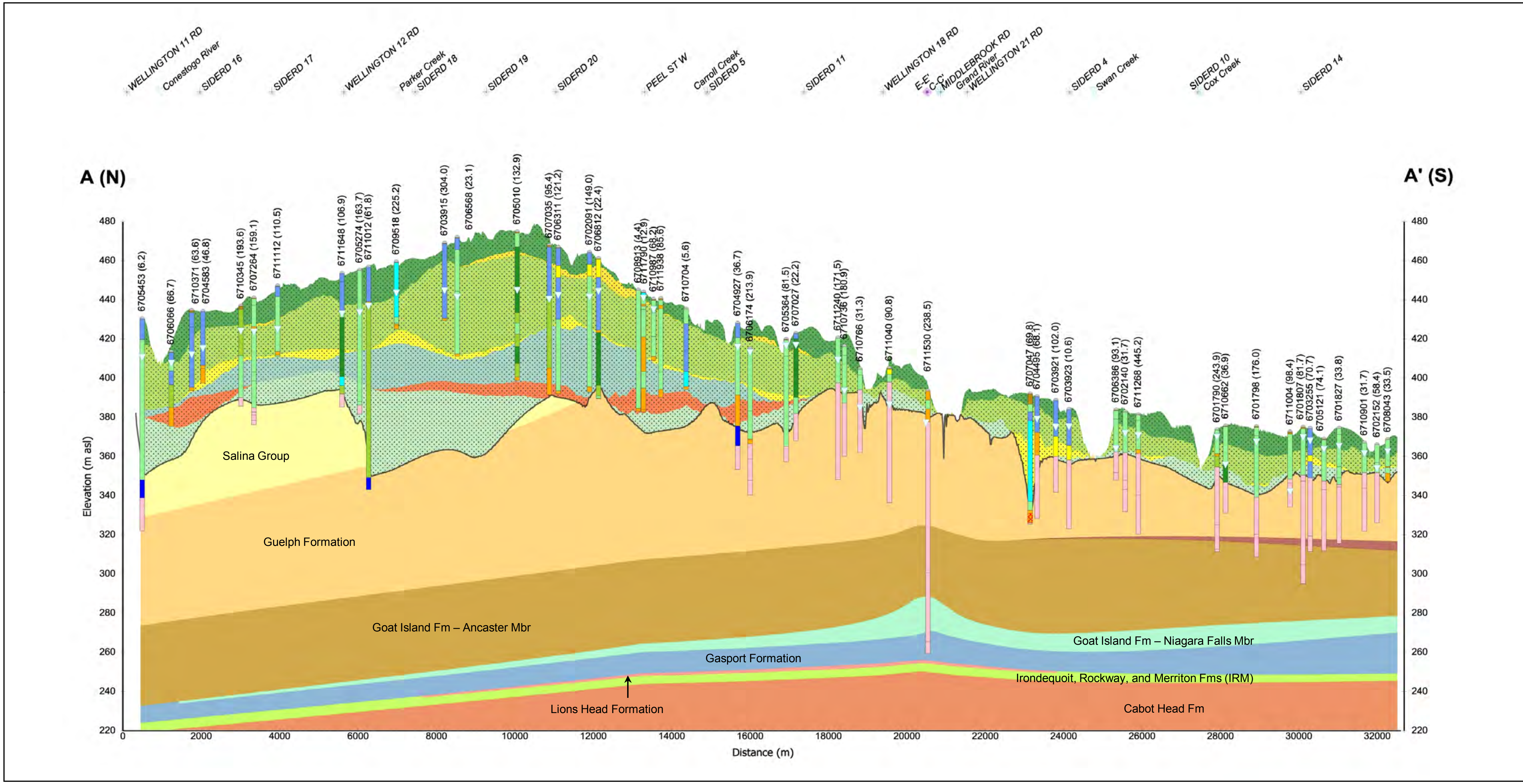

LEGEND

Road	**Borehole Lithology**	Silt to sandy silt till	**Interpreted Unit**	Pre-Catfish Aquifer (AFD1)
Drainage	Topsoil, fill	Sandy till	Grand River Outwash (AFA2)	Canning Drift Aquitard (ATE1)
Observed Water Level	Organic deposits	Sand, silty sand	Tavistock, Port Stanley Till (ATB1)	Pre-Canning Aquifer (AFF1)
Profile	Clay, silty clay	Gravelly sand, gravel	Moraine Aquifer (AFB1)	PreCanning Aquitard (ATG1)
Top of Bedrock	Silt, clayey silt, sandy silt	Limestone, Dolostone	Maryhill/ Catfish Creek Drift (ATB3, ATC1, AFC1, ATC2)	
Screened Interval	Clay to clayey silt till	Shale		

NOTE: Water levels for domestic wells are levels contained within the WWIS. Water levels for high quality wells are from recent, higher quality transient water level observations.

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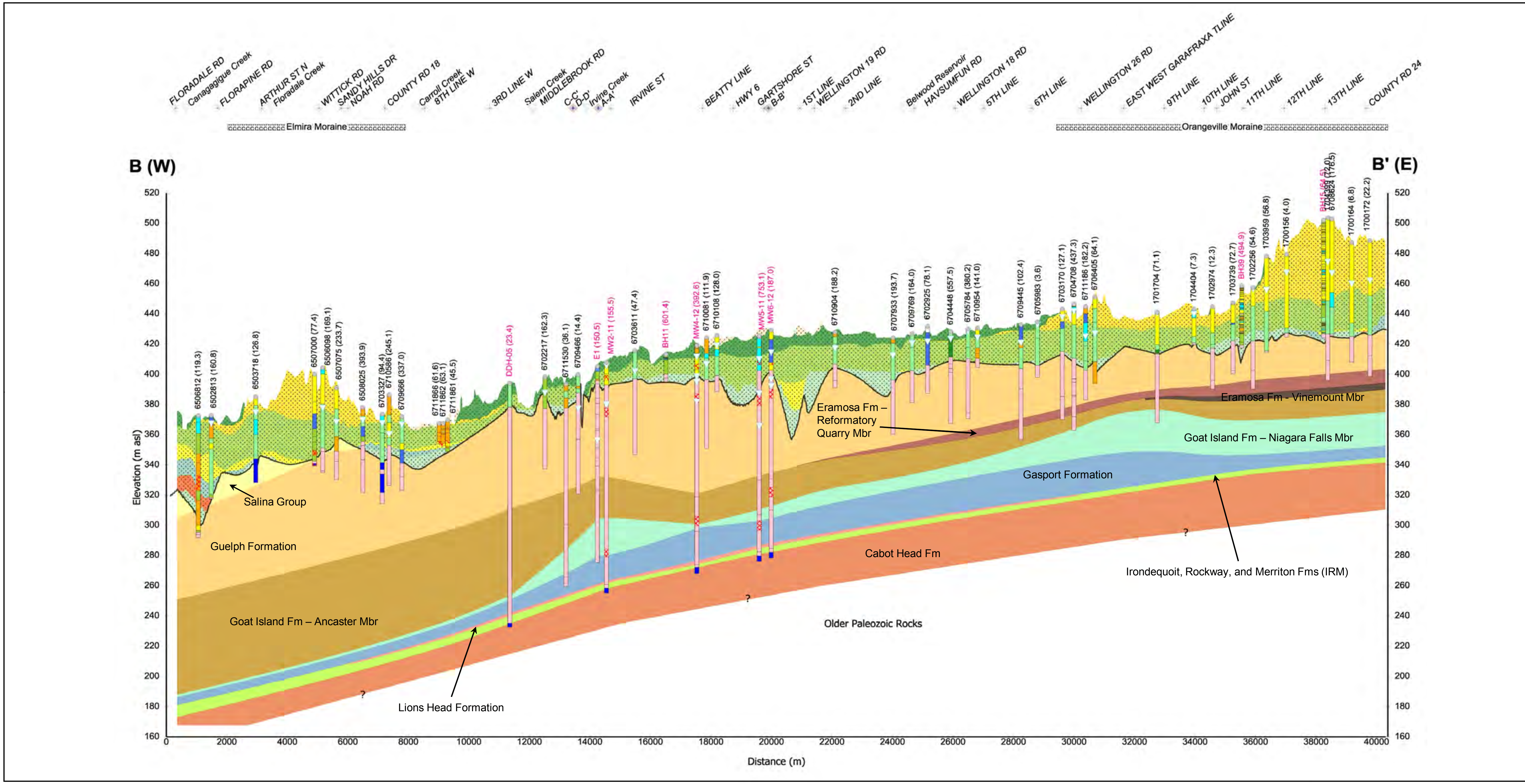
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Regional Cross Section A-A'

Date:	Project:	Technical:	Reviewer:	Drawn:
08 Nov 2017	23876	J. Melchin	P. Meyer	C.Curry

Figure 11



LEGEND

Road	**Borehole Lithology**	Silt to sandy silt till	**Interpreted Unit**	Pre-Catfish Aquifer (AFD1)
Drainage	Topsoil, fill	Sandy till	Grand River Outwash (AFA2)	Canning Drift Aquitard (ATE1)
Observed Water Level	Organic deposits	Sand, silty sand	Tavistock, Port Stanley Till (ATB1)	Pre-Canning Aquifer (AFF1)
Profile	Clay, silty clay	Gravelly sand, gravel	Moraine Aquifer (AFB1)	PreCanning Aquitard (ATG1)
Top of Bedrock	Silt, clayey silt, sandy silt	Limestone, Dolostone	Maryhill/ Catfish Creek Drift (ATB3, ATC1, AFC1, ATC2)	
Screened Interval	Clay to clayey silt till	Shale		

NOTE: Water levels for domestic wells are levels contained within the WWIS. Water levels for high quality wells are from recent, higher quality transient water level observations.

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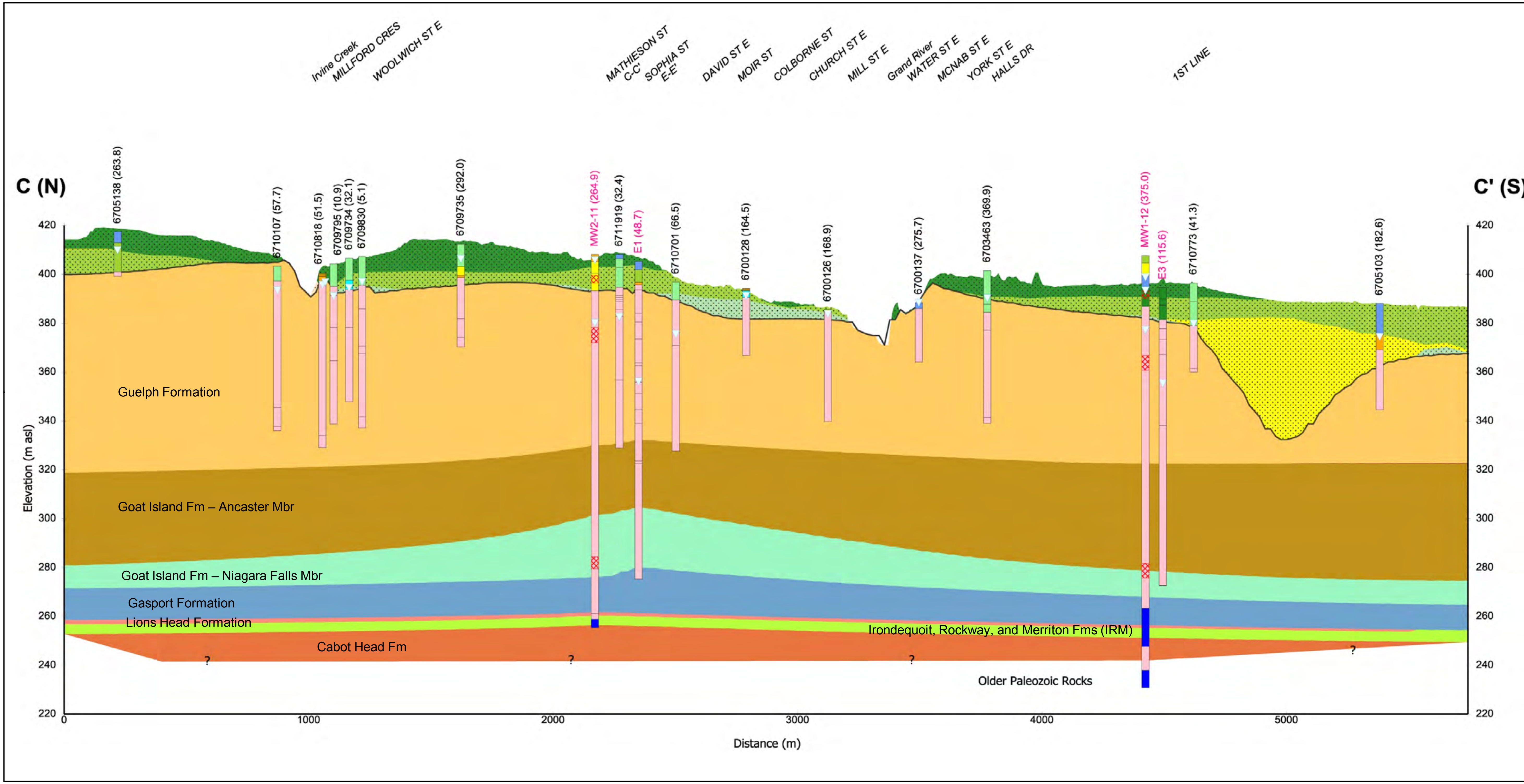
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Regional Cross Section B-B'

Date:	Project:	Technical:	Reviewer:	Drawn:
08 Nov 2017	23876	J. Melchin	P. Meyer	C.Curry

Figure 12



LEGEND

Road	**Borehole Lithology**	Silt to sandy silt till	**Interpreted Unit**	Pre-Catfish Aquifer (AFD1)
Drainage	Topsoil, fill	Sandy till	Grand River Outwash (AFA2)	Canning Drift Aquitard (ATE1)
Observed Water Level	Organic deposits	Sand, silty sand	Tavistock, Port Stanley Till (ATB1)	Pre-Canning Aquifer (AFF1)
Profile	Clay, silty clay	Gravelly sand, gravel	Moraine Aquifer (AFB1)	PreCanning Aquitard (ATG1)
Top of Bedrock	Silt, clayey silt, sandy silt	Limestone, Dolostone	Maryhill/ Catfish Creek Drift	
Screened Interval	Clay to clayey silt till	Shale	(ATB3, ATC1, AFC1, ATC2)	

NOTE: Water levels for domestic wells are levels contained within the WWIS. Water levels for high quality wells are from recent, higher quality transient water level observations.

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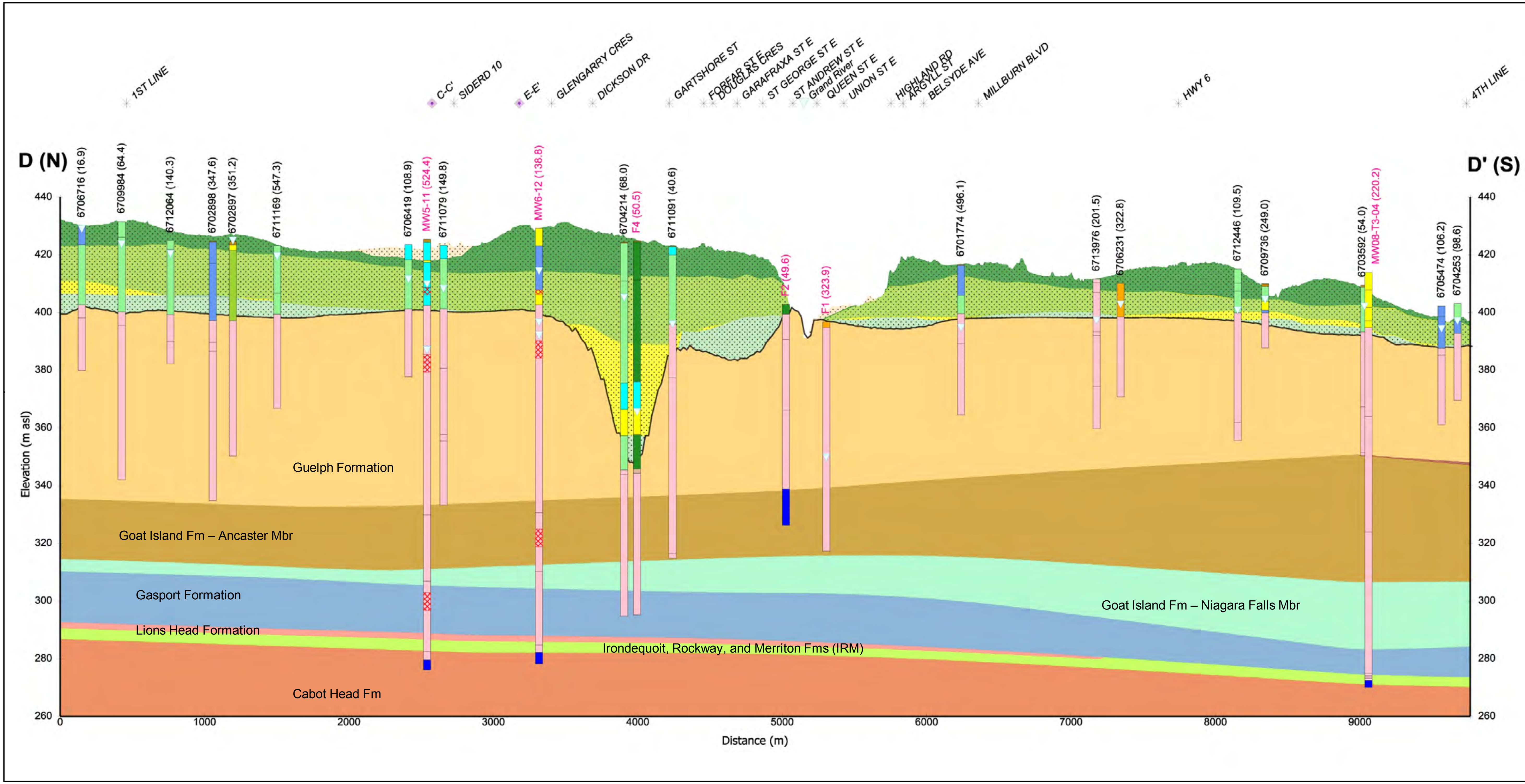
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Local Elora Cross Section C-C'

Date:	Project:	Technical:	Reviewer:	Drawn:
08 Nov 2017	23876	J. Melchin	P. Meyer	C.Curry

Figure 13



LEGEND

Road	**Borehole Lithology**	Silt to sandy silt till	**Interpreted Unit**	Pre-Catfish Aquifer (AFD1)
Drainage	Topsoil, fill	Sandy till	Grand River Outwash (AFA2)	Canning Drift Aquitard (ATE1)
Observed Water Level	Organic deposits	Sand, silty sand	Tavistock, Port Stanley Till (ATB1)	Pre-Canning Aquifer (AFF1)
Profile	Clay, silty clay	Gravelly sand, gravel	Moraine Aquifer (AFB1)	PreCanning Aquitard (ATG1)
Top of Bedrock	Silt, clayey silt, sandy silt	Limestone, Dolostone	Maryhill/ Catfish Creek Drift	
Screened Interval	Clay to clayey silt till	Shale	(ATB3, ATC1, AFC1, ATC2)	

NOTE: Water levels for domestic wells are levels contained within the WWIS. Water levels for high quality wells are from recent, higher quality transient water level observations.

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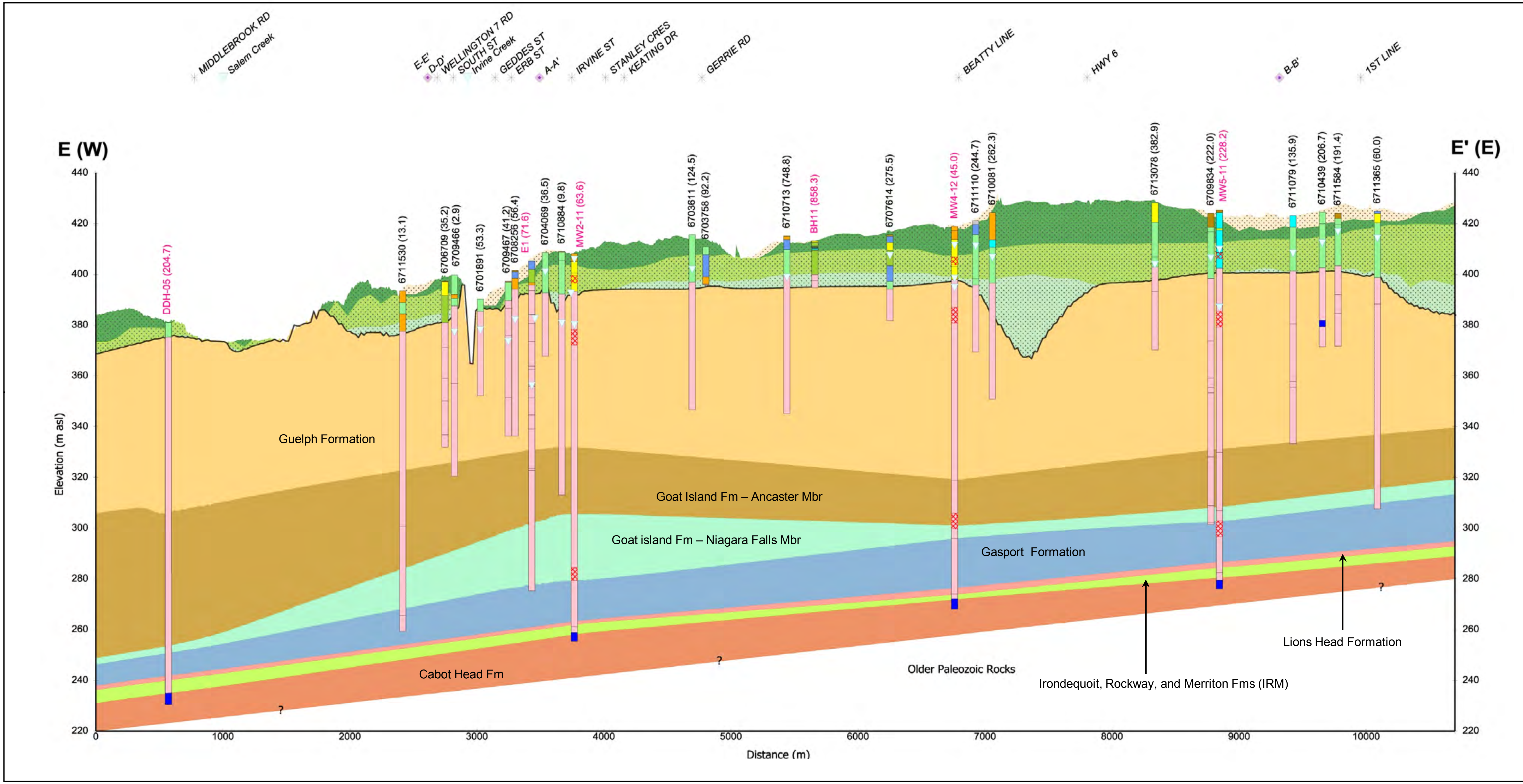
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Local Fergus Cross Section D-D'

Date:	Project:	Technical:	Reviewer:	Drawn:
08 Nov 2017	23876	J. Melchin	P. Meyer	C.Curry

Figure 14



LEGEND

Road	**Borehole Lithology**	Silt to sandy silt till	**Interpreted Unit**	Pre-Catfish Aquifer (AFD1)
Drainage	Topsoil, fill	Sandy till	Grand River Outwash (AFA2)	Canning Drift Aquitard (ATE1)
Observed Water Level	Organic deposits	Sand, silty sand	Tavistock, Port Stanley Till (ATB1)	Pre-Canning Aquifer (AFF1)
Profile	Clay, silty clay	Gravelly sand, gravel	Moraine Aquifer (AFB1)	PreCanning Aquitard (ATG1)
Top of Bedrock	Silt, clayey silt, sandy silt	Limestone, Dolostone	Maryhill/ Catfish Creek Drift	
Screened Interval	Clay to clayey silt till	Shale	(ATB3, ATC1, AFC1, ATC2)	

NOTE: Water levels for domestic wells are levels contained within the WWIS. Water levels for high quality wells are from recent, higher quality transient water level observations.

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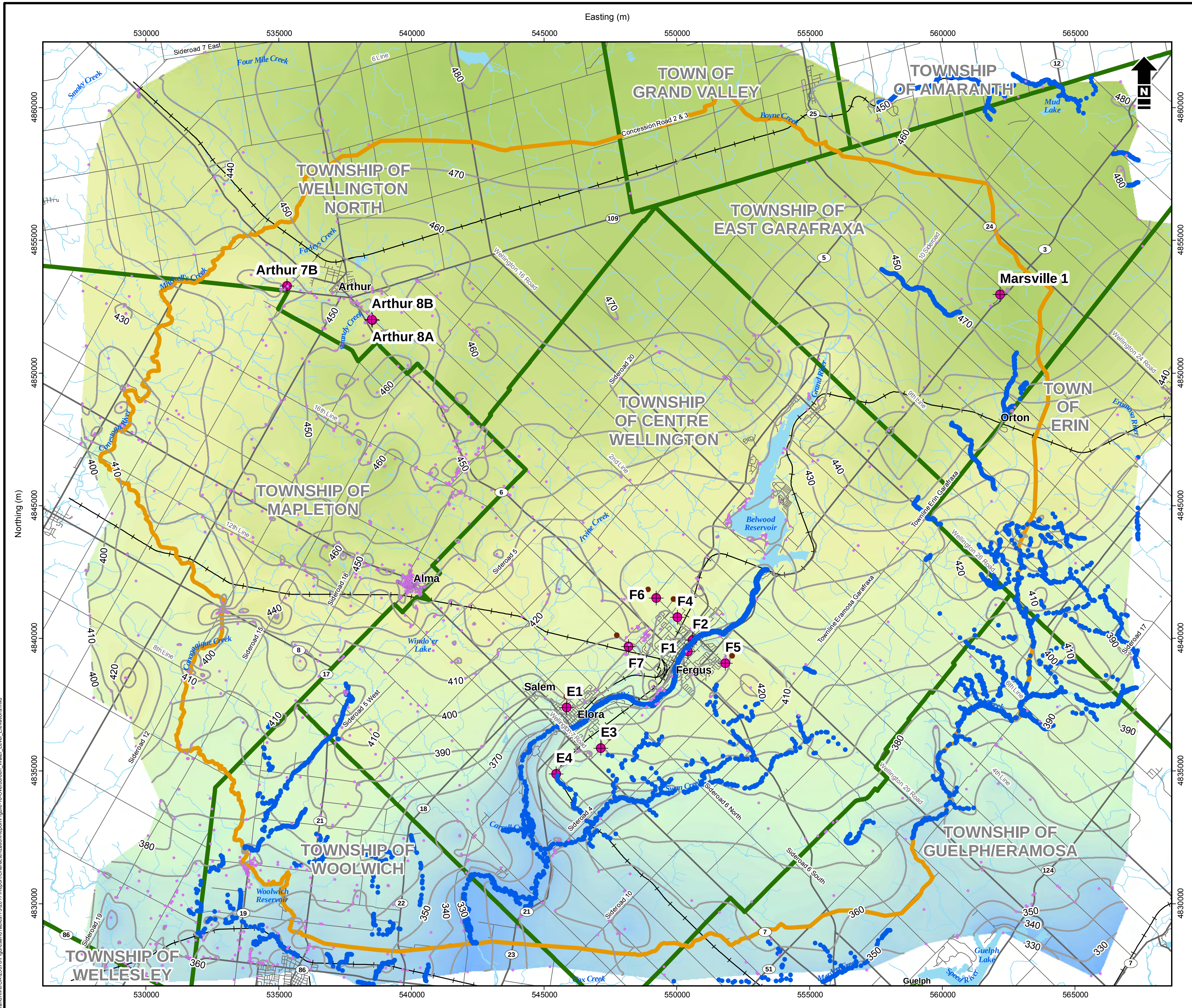
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Local Elora to Fergus Cross Section E-E'

Date:	Project:	Technical:	Reviewer:	Drawn:
08 Nov 2017	23876	J. Melchin	P. Meyer	C.Curry

Figure 15

I:\GrandRiverCA\23876\Figures and Tables\T3\2017\Report\Characterization Report\Figure-15-Local_Elora_to_Fergus_Cross_Section_E-E.mxd



Study Area
Municipal Boundary
Water Body
Watercourse
Highway
Road
Railroad Trail
Overburden Water Level Elevation Contour (10m)
Municipal Well

Overburden Water Level Well Location

Overburden Well - MOE WWIS
Surface Water Control Point
Municipal Monitoring Well

Overburden Water Level Elevation (masl)

High : 485

Low : 320

Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministy of Municipal Affairs and Housing.
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1:145,000

1,400 0 1,400 2,800 m

NAD 1983 UTM Zone 17N

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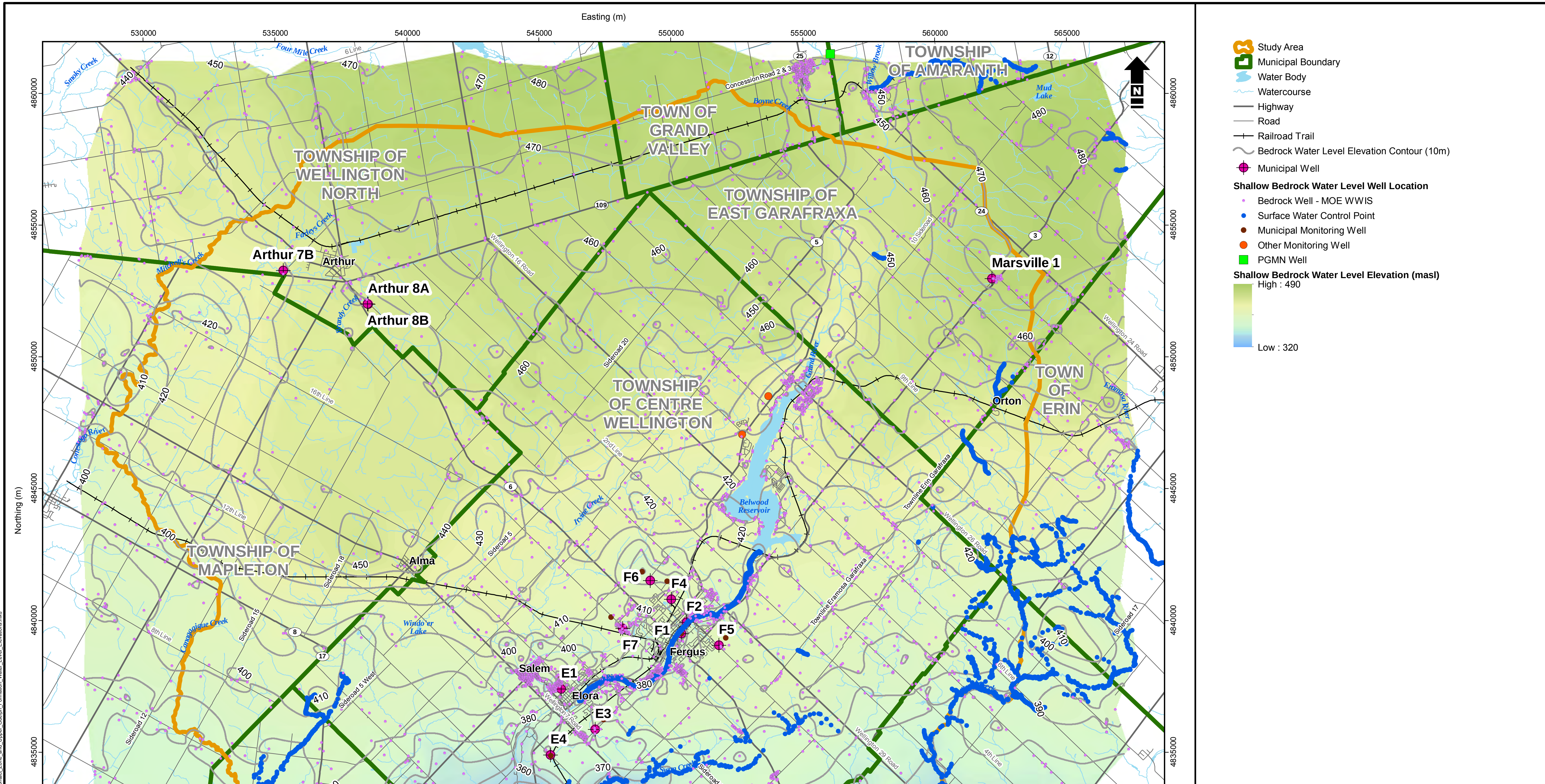
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Overburden Water Level Elevations

Date:	Project:	Technical:	Reviewer:	Drawn:
24 Nov 2017	23876	J. Melchin	P. Meyer	C. Curry

Figure 16



Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministy of Municipal Affairs and Housing.
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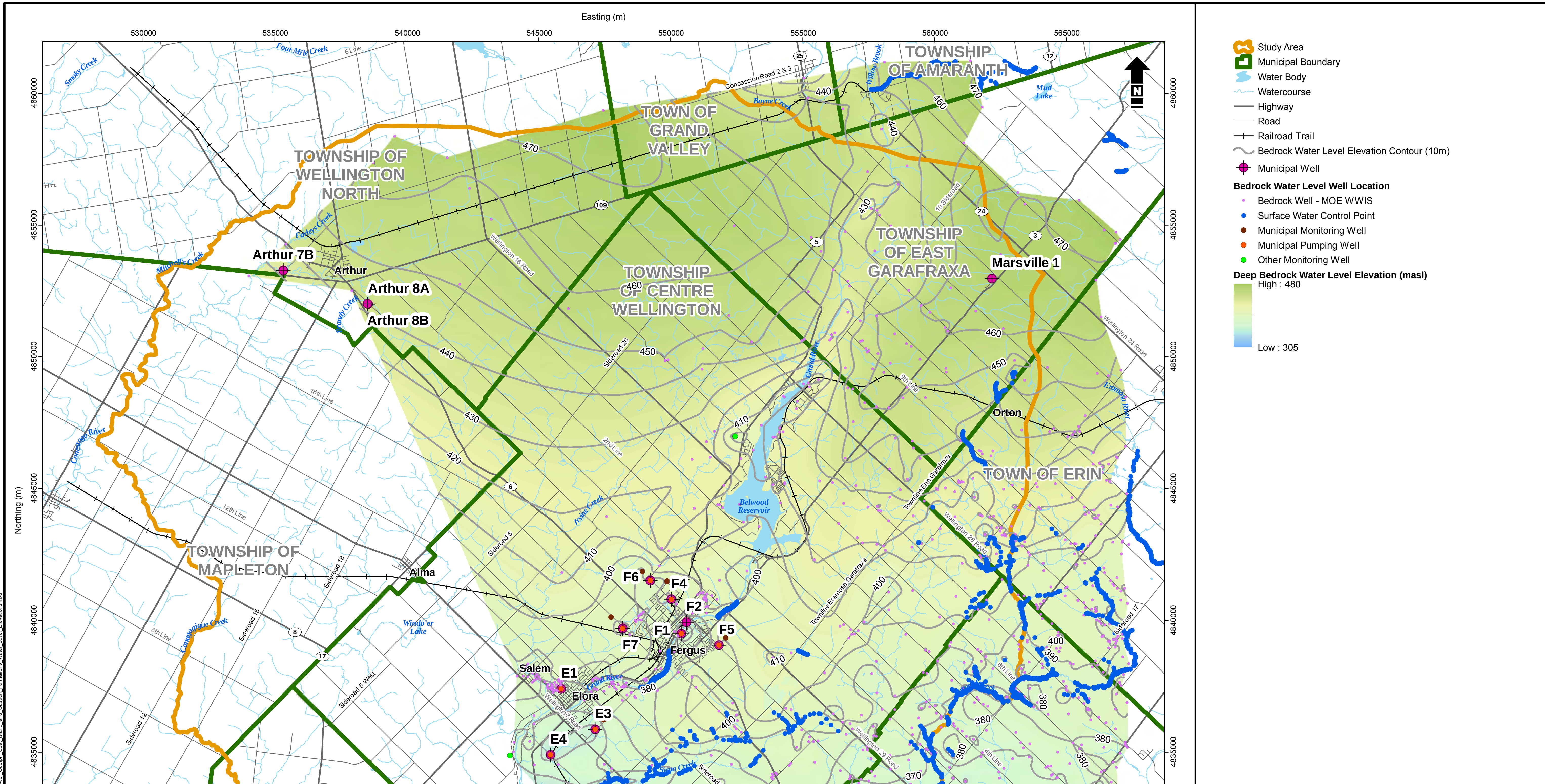
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Contact Zone and Upper Guelph Formation Water Level Elevations

Date:	Project:	Technical:	Reviewer:	Drawn:
24 Nov 2017	23876	J. Melchin	P. Meyer	C. Curry

Figure 17



Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministy of Municipal Affairs and Housing.
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1:145,000

NAD 1983 UTM Zone 17N

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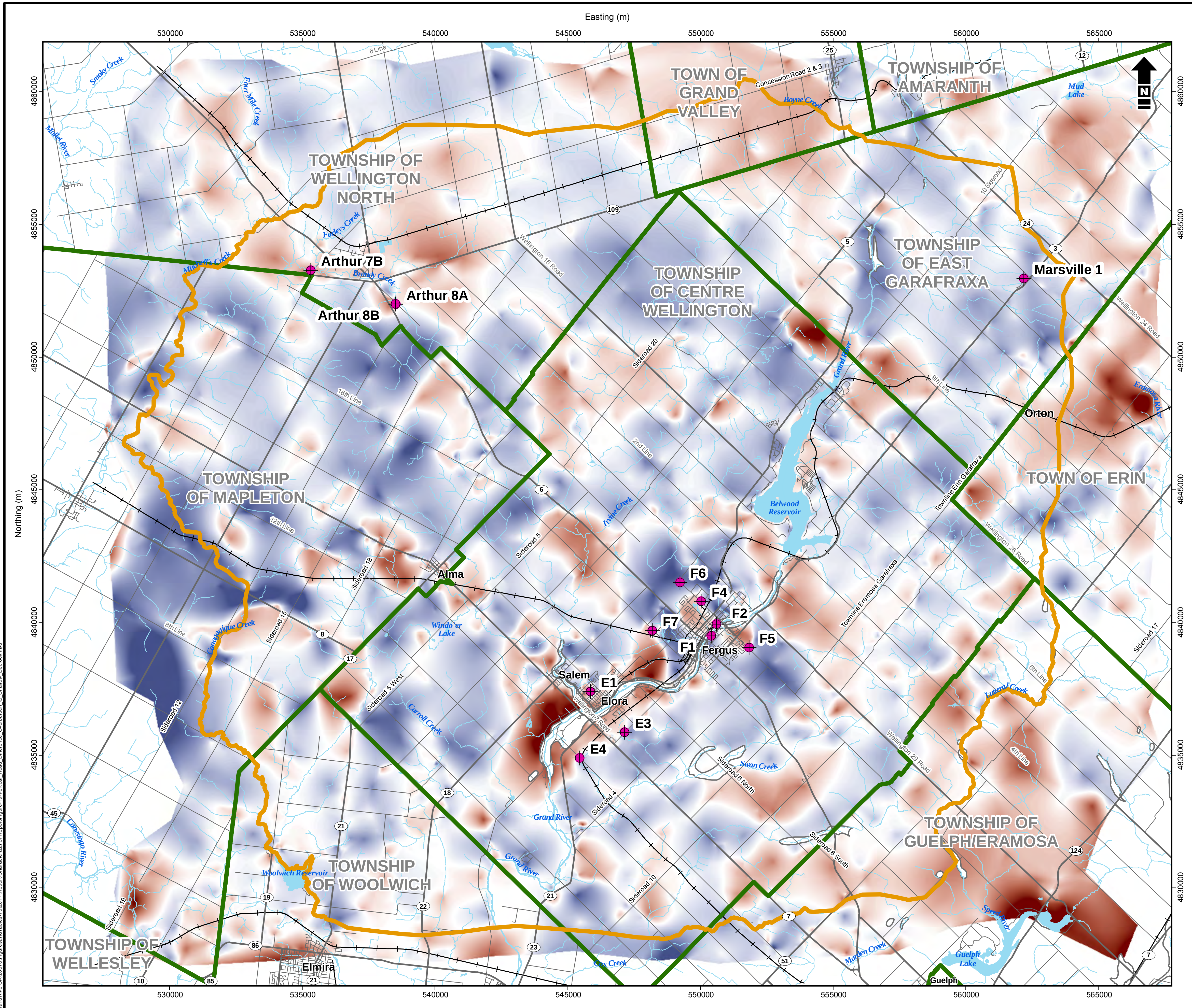
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Lower Guelph, Goat Island and Gasport Formations Water Level Elevations

Date:	Project:	Technical:	Reviewer:	Drawn:
24 Nov 2017	23876	J. Melchin	P. Meyer	C. Curry

Figure 18



Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministy of Municipal Affairs and Housing. Contains information licensed under the Open Government Licence – Ontario.

1:145,000
1,400 0 1,400 2,800 m
NAD 1983 UTM Zone 17N

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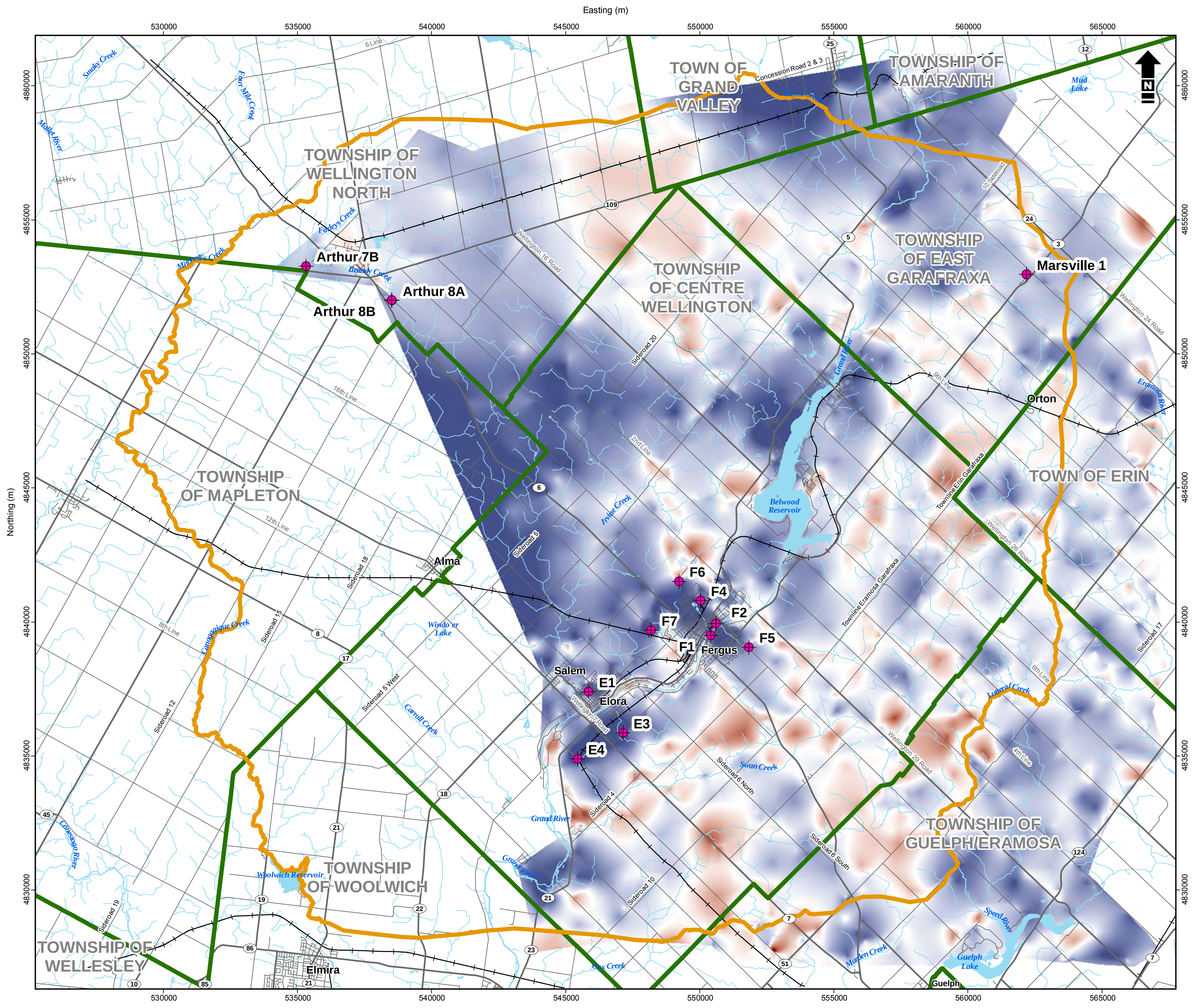
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Vertical Head Difference: Overburden to Shallow Bedrock

Date:	Project:	Technical:	Reviewer:	Drawn:
24 Nov 2017	23876	J. Melchin	P. Meyer	C. Curry

Figure 19



Study Area
Municipal Boundary
Water Body
Watercourse
Highway
Road
Railroad Trail
Municipal Well

Difference in Vertical Head from Shallow Bedrock to Deep Bedrock

20 m Downward

20 m Upward

NOTE: Vertical head difference mapping unavailable in the western portion of the Study Area where water levels in the deep bedrock are unavailable.

1:145,000 m

1,400 0 1,400 2,800

NAD 1983 UTM Zone 17N

Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministy of Municipal Affairs and Housing. Contains information licensed under the Open Government Licence – Ontario.

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Grand River Conservation Authority

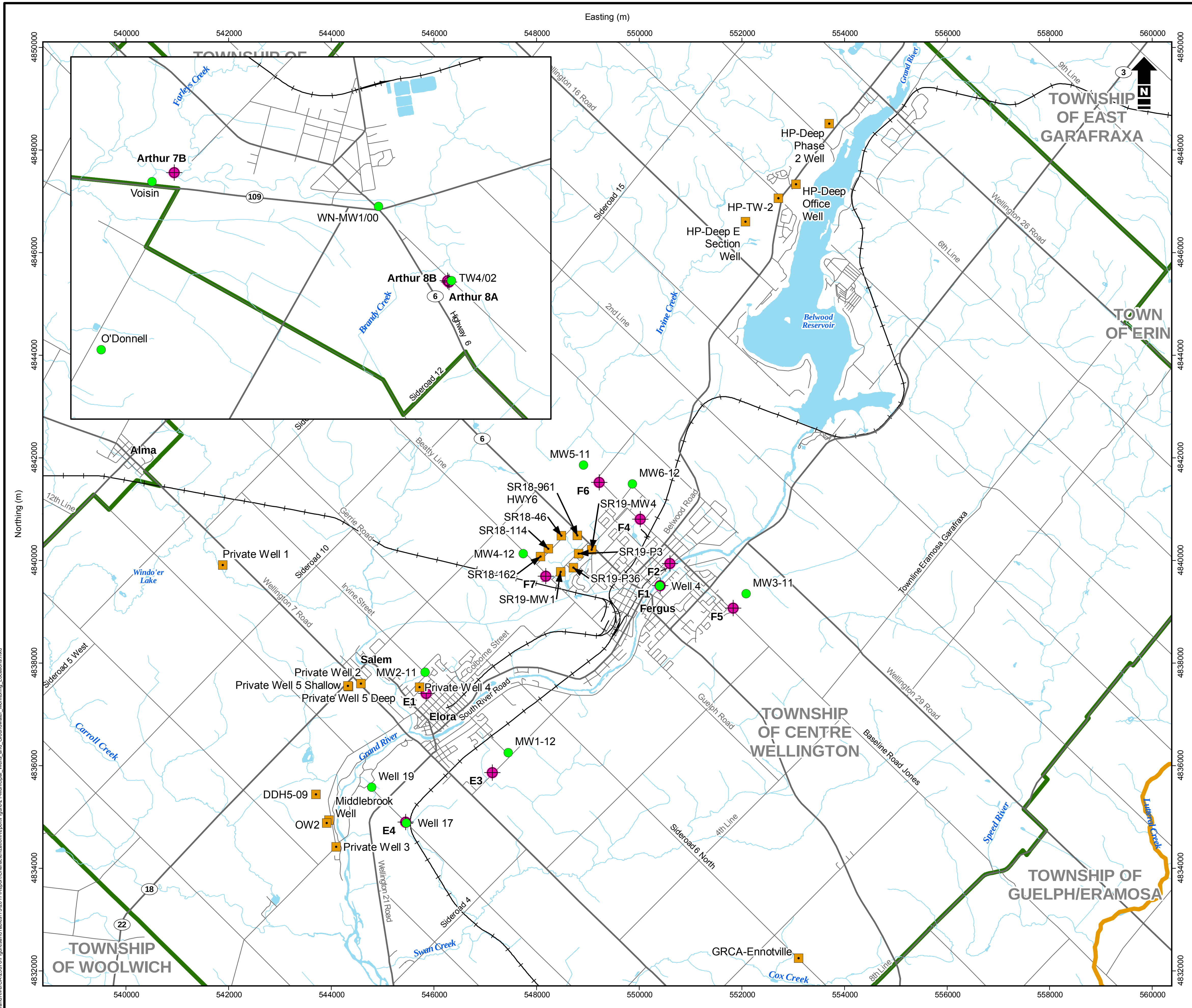
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Vertical Head Difference: Shallow Bedrock to Deep Bedrock

Date:	Project:	Technical:	Reviewer:	Drawn:
24 Nov 2017	23876	J. Melchin	P. Meyer	C. Curry

Figure 20

I:\GrandRiverCA\23876\Figures\andTables\T3\2017\Report\Characterization\Report\Figure-20-Vertical_Head_Difference_Shallow_Bedrock_to_Deep_Bedrock.mxd



Study Area
Municipal Boundary
Water Body
Watercourse
Highway
Road
Railroad Trail
Municipal Well
Municipal Monitoring Well
Non Municipal Monitoring Well

NOTE:
HP: Highland Pines Campground
PGMN: Provincial Groundwater Monitoring Network
SR18: Side Road 18
SR19: Side Road 19
GRCA: Grand River Conservation Authority

Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministry of Municipal Affairs and Housing. Contains information licensed under the Open Government Licence – Ontario.

1:75,000
750 0 750 1,500 m
NAD 1983 UTM Zone 17N

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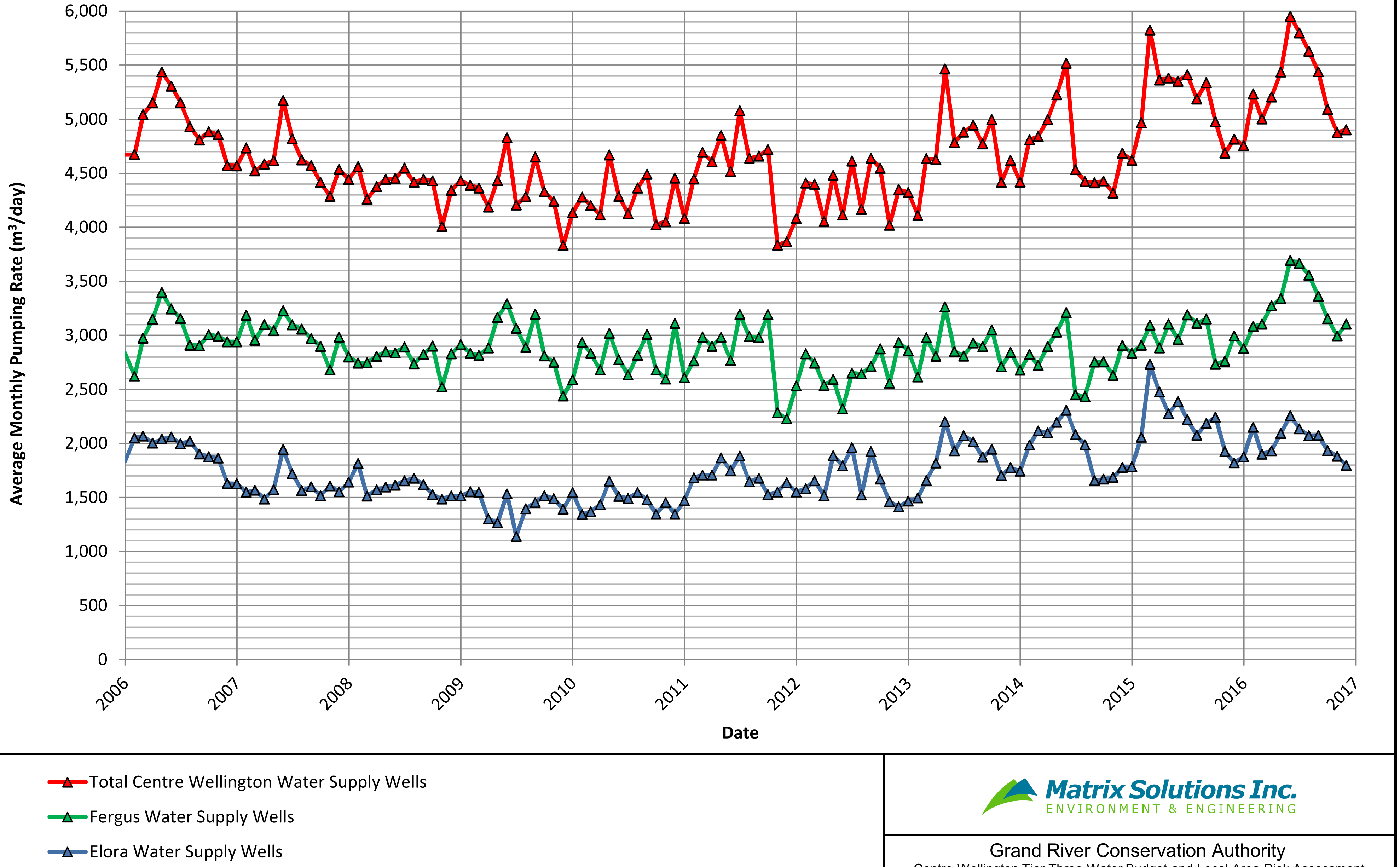
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Municipal Wells and Groundwater Monitoring Locations

Date:	Project:	Technical:	Reviewer:	Drawn:
24 Nov 2017	23876	J. Melchin	P. Meyer	C. Curry

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

Figure 21



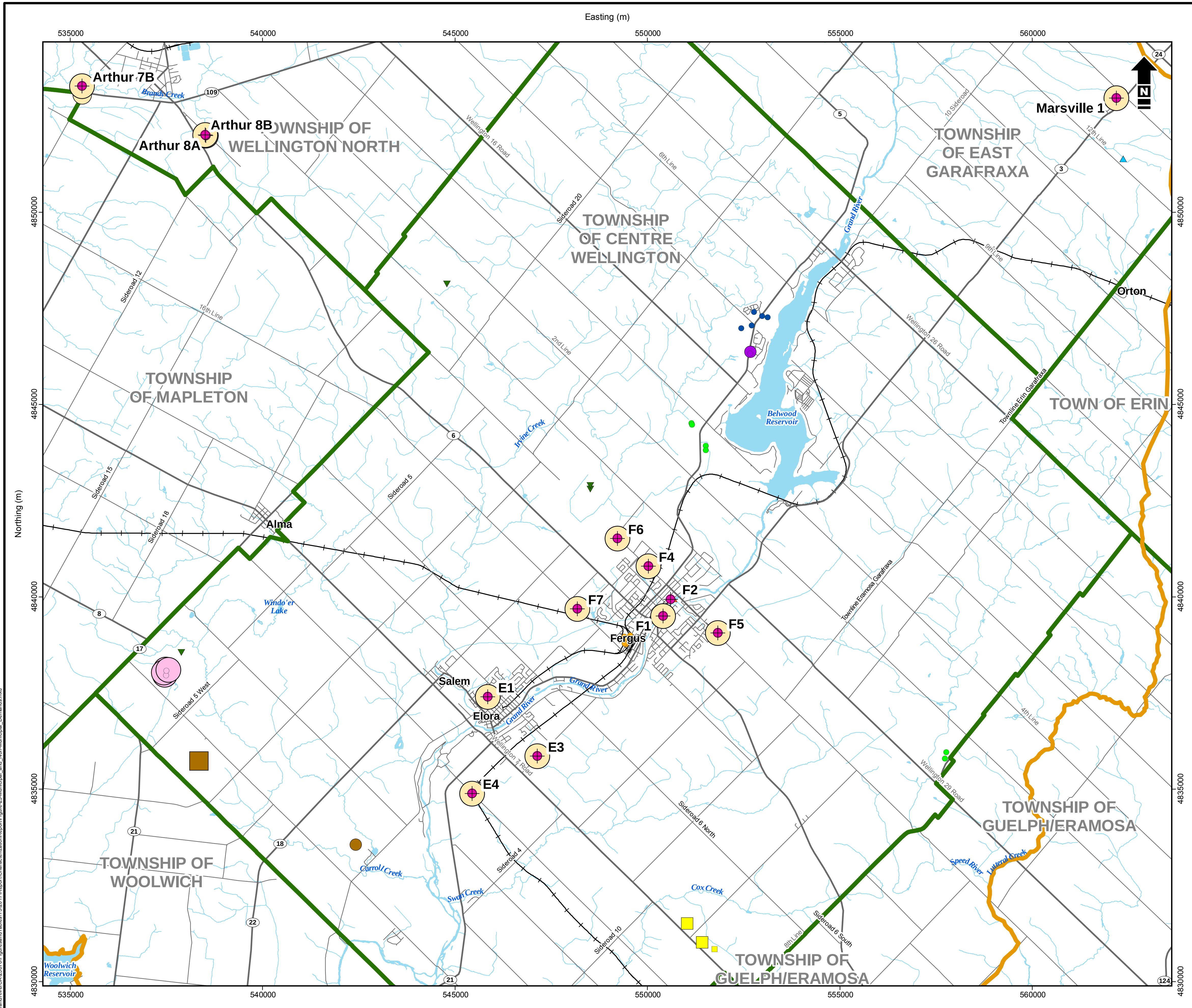
Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Centre Wellington Municipal Wells – Average Monthly Pumping Rate

Date:	Project:	Technical:	Reviewer:	Drawn:
25 Oct 2017	23876	J. Melchin	P. Meyer	J. Melchin

Figure 22



Study Area
Municipal Boundary
Water Body
Watercourse
Highway
Road
Railroad Trail
Municipal Well

Specific Purpose

- Aggregate Washing
- Aquaculture
- Communal
- Golf Course Irrigation
- Industrial
- Livestock Watering
- Municipal
- Remediation
- Water Supply
- Wetland
- Wildlife Conservation

Taking Type

- Groundwater Permit – Estimated
- Groundwater Permit – Reported
- Surface Water Permit – Estimated
- Surface Water Permit – Reported

Consumptive Use (m³/day)

- < 100
- 100 - 300
- 300 - 500
- > 500

Reference: Data obtained from Grand River Conservation Authority (2017) and GeoBase® used under license. Municipal boundaries obtained from Ontario Ministry of Municipal Affairs and Housing.
Contains information made available under Grand River Conservation Authority's Open Data Licence v1.0.
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1:100,000
1,000 0 1,000 2,000 m
NAD 1983 UTM Zone 17N

Matrix Solutions Inc.
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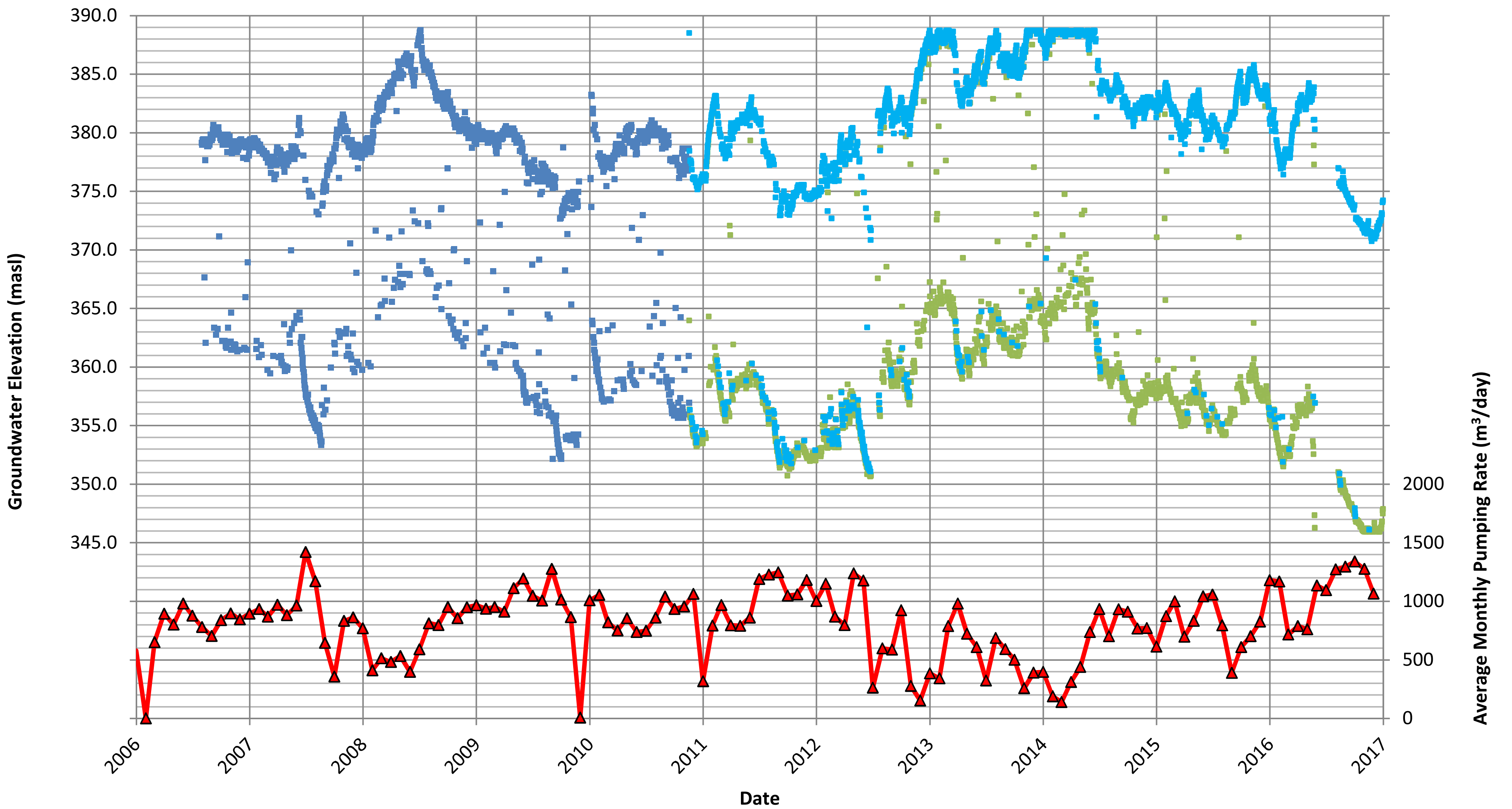
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Municipal and Non-Municipal Demands

Date:	Project:	Technical:	Reviewer:	Drawn:
24 Nov 2017	23876	J. Melchin	P. Meyer	C. Curry

Figure 23

I:\GrandRiver\CA23876\FiguresandTables\T3\2017\Report\CharacterizationReport\Figure-23-Municipal_and_Non-Municipal_Demands.mxd



Matrix Solutions Inc.
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Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Municipal Well F1 – Pumping and Water Levels

Date:	Project:	Technical:	Reviewer:	Drawn:
25 Oct 2017	23876	J. Melchin	P. Meyer	J. Melchin

Figure 24

APPENDIX A
List of Additional Reference Materials

APPENDIX A

LIST OF ADDITIONAL REFERENCE MATERIALS

Anderson GeoLogic Ltd. 2001. *2000 Monitoring Report, Village of Elora Wells, Township of Centre Wellington.* Report prepared for Township of Centre Wellington Works Department. February 2001.

Aquafor Beech Ltd. 2007. *Nichol Drain Subwatershed Study, Phase 1 Existing Conditions, Draft.* Prepared for Township of Centre Wellington. Elora, Ontario. September 2007.

Brintnell F.R., and C. Brunton. 2010. Update of Early Silurian sequence stratigraphy, sedimentology and bedrock aquifer mapping of Niagara Escarpment cuesta; in Summary of Field Work and Other Activities 2010, Open File Report 6260, p.33-1 to 33-7.

Burt, A.K. (2012) Project Unit 12-005. The Mount Forest-Elmira Study: A New Three-Dimensional Quaternary Mapping Project. From Summary of Field Work and Other Activities 2012; Ontario Geological Survey, Open File Report 6280, 33-1 to 33-6 p.

Chung and Vander Doelen Engineering Ltd. 2015. *Hydrogeological Assessment, Proposed Youngblood Subdivision, South River Rd., Elora, Ontario*. Prepared for Mr. Bruce Youngblood. March 2015.

Golder Associates Ltd. 2010. Technical Memorandum from R. McLaughlin, G. Padusenko and J. Petrie to K. Elder, Township of Centre Wellington re: Scope of Work, Wellfield Capacity Assessment to Address Condition 4.3 of Permit To Take Water 2823-7QEH3C. January 27, 2010.

Golder Associates Ltd. 2011. *Reconstruction of Sideroad 19, Burnett Court and Victoria Crescent, Hydrogeological Assessment for Permit To Take Water Number 4406-8FXJX7*. October 2011.

Golder Associates Ltd. 2010. Technical Memorandum from R. McLaughlin, G. Padusenko and J. Petrie to K. Elder, Township of Centre Wellington re: Monitoring Program to Address Condition 4.2 of Permit To Take Water 2823-7QEH3C. January 27, 2010.

Golder Associates. 2015. *Drinking Water Issue (Chloride) Review for the Township of Centre Wellington Municipal Water Supply Wells*. August 2014.

Golder Associates Ltd. 2016. *Township of Centre Wellington, 2014/2015 Annual Monitoring Report*. April 2016.

Golder Associates Ltd. (Golder). 2015b. *Category 3 Application for Permit to Take Water, Middlebrook Well, 7734 Middlebrook Road, Centre Wellington, Ontario.* Prepared for Nestle Waters Canada. Guelph, Ontario. July 2015.

Hunter and Associates. 2016. Re: Comments on Nestle Waters Canada Temporary Permit to Take Water (Category 3 Application) as prepared by Golder Associates dated July 20, 2015 and Environmental Monitoring Program Addendum as proposed November 10, 2015.

Lee V.L., Priebe E.H., Brunton F.R. et al. 2011. Bedrock aquifer mapping of Niagara Escarpment cuesta: installation and sampling of multi-level monitoring wells; in Summary of Field Work and Other Activities 2011, Open File Report 6270, p.31-1 to 31-6.

Mass, C. and Porter-Bopp, S. 2011. A Soft Path Strategy for Fergus-Elora, Ontario, A Soft Path for Water Case Study. Polis Discussion Series Paper 11-01. Accessible at: http://poliswaterproject.org/sites/default/files/Fergus-Elora%20Water%20Soft%20Path%20Strategy.pdf.

Terraqua Investigations Ltd. 1994. *1993 Well Testing Program, Fergus P.U.C.* Prepared for Fergus Public Utilities Commission. March 1994.

Terraqua Investigations Ltd. 1995. *Water Management Plan for the Village of Elora*. Prepared for Village of Elora. May 1995.

Terraqua Investigations Ltd. 1995. *Water Level Monitoring Program for the Village of Eloar*. Prepared for Village of Elora. December 1995.

Township of Centre Wellington. 2008. *Comprehensive Study Report, Upgrading of the Elora Well System*. Prepared for Industry Canada. Toronto, Ontario. February 2008.

Triton Engineering Services Ltd. 2005. *The Corporation of the Township of Centre Wellington, Elora Water System Municipal Well E4 Design Brief*. January 2005.

APPENDIX B
Municipal Production Well Records

-29-05 10:40am From-TRITON ENG (FERGUS) +15198431943 T-000 P.02/02 F-237

Ontario Ministry of the Environment

Well Tag Number: A 003395

A 003396

Well Record
Regulation 903 Ontario Water Resources Act

A285005 - R12 page ___ of ___

Instructions for Completing Form

- For use in the Province of Ontario only. This document is a permanent legal document. Please retain for future reference.
- All Sections must be completed in full to avoid delays in processing. Further instructions and explanations are available on the back of this form.
- Questions regarding completing this application can be directed to the Water Well Management Coordinator at 416-235-6203.
- All metre measurements shall be reported to 1/10th of a metre.
- Please print clearly in blue or black ink only.

Ministry Use Only: MUN | CON | LOT

Well Owner's Information and Location of Well Information

First Name	Centre Wellington
Last Name	
Mailing Address (Street Number/Name, RR, Lot, Concession)	1 MacDonald Square
County/District/Municipality	
Township/City/Town/Village	Elora
Province	Ontario
Postal Code	N0B 1S0
Telephone Number (include area code)	519 846 9801
Address of Well Location (County/District/Municipality)	Centre Wellington
Township	
Lot	
Concession	
RR#/Street Number/Name	295 Queen St. East
City/Town/Village	Fergus
Site/Compartment/Block/Tract etc.	
GPS Reading: NAD 83, Zone 17	Easting 550358(?) Northing 4839514(?)
Unit Make/Model	Garmin
Mode of Operation	Undifferentiated / Averaged / Differentiated, specify TRAK 12

Log of Overburden and Bedrock Materials (see instructions)

General Colour	Most common material	Other Materials	General Description	Depth Metres From	Depth Metres To
	Previously Drilled				
brown	Sand & gravel	silt	silty sand & gravel	0	2
cream, grey	dolostone		vuggy light brown to grey dolostone some fossiliferous	2	79.5
	Previously drilled				

Hole Diameter

Depth Metres From	Depth Metres To	Diameter Centimetres
Previously drilled		
4.15	79.5	30.5

Construction Record

Inside diam centimetres	Material	Wall thickness centimetres	Depth Metres From	Depth Metres To
Casing				
35.5	X Steel		0	unknown / previously installed
26		.64	.3	4.15
20.9	X Steel	0.68		19.9
Screen				
	Outside diam; Steel / Fibreglass / Plastic / Concrete / Galvanized; Slot No.			
No Casing or Screen				
	X Open hole		19.9	79.5

Water Record

Water found at Metres / Kind of Water: Fresh / Sulphur / Salty / Minerals / Gas / Other

After test of well yield, water was: Clear and sediment free; Other, specify

Chlorinated: X Yes / No

Test of Well Yield

Pumping test method	by others
Pump intake set at (metres)	
Pumping rate (litres/min)	
Duration of pumping ___ hrs + ___ min	
Final water level end of pumping (metres)	
Recommended pump type	Shallow / Deep
Recommended pump depth (metres)	
Recommended pump rate (litres/min)	
If flowing give rate (litres/min)	
If pumping discontinued, give reason	

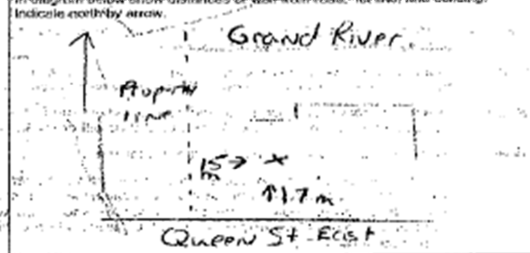
Draw Down Time min	Water Level Metres	Recovery Time min	Water Level Metres
Static Level	12.6		
1		1	
2		2	
3		3	
4		4	
5		5	
10		10	
15		15	
20		20	
25		25	
30		30	
40		40	
50		50	
60		60	

Plugging and Sealing Record — Annular space / Abandonment

Depth set at Metres From	To	Material and type (bentonite slurry, neat cement slurry) etc.	Volume Placed (cubic metres)
19.9	0		
19.9	19.5	bentonite	
19.5	0	neat cement slurry	

Location of Well

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



Method of Construction

Cable Tool / Rotary (air) / Diamond / Digging / Rotary (conventional) / Air percussion / Jetting / Other / Rotary (reverse) / Boring / Driving

Water Use

Domestic / Industrial / Public Supply / Other / Stock / Commercial / Not used / Irrigation / X Municipal / Cooling & air conditioning

Final Status of Well

X Water Supply / Recharge well / Unfinished / Abandoned, (Other) / Observation well / Abandoned, insufficient supply / Dewatering / Test Hole / Abandoned, poor quality / Replacement well

Audit No. Z 25759

Date Well Completed: 03 06 24

Was the well owner's information package delivered? Yes / X No

Date Delivered: 05 03 09

Well Contractor/Technician Information

Name of Well Contractor	Ontario Water Well Services
Well Contractor's Licence No.	4011
Business Address (street name, number, city etc.)	RR1 Orangeville Ont.
Name of Well Technician (last name, first name)	Jim Wilson
Well Technician's Licence No.	T 164
Signature of Technician/Contractor	
Date Submitted	05 03 27

Ministry Use Only: Data Source / Contractor / Date Received / Date of Inspection / Remarks / Well Record Number

0506E (09/03) Contractor's Copy / Ministry's Copy / Well Owner's Copy

Cette formule est disponible en français

FIGURE B1 Well Record for Municipal Well F1

2.

Ont. [illegible] | 9 | R | [illegible]

| 9 | R | [illegible]

Elev. | 9 | R |

Basin | 23 |

67 No. 836

mw2

ONTARIO

The Well Drillers Act

Department of Mines, Province of Ontario

Water Well Record

County or District .... Tp. .... Con. .... Lot .... Pt. Lot ....

Owner .. PUC.., Fergus .... Address .. Fergus, Ont. .... Acres ....

Date Completed ... June 29/45 ... Cost of Well (not including pump) ... [illegible]

Pipe and Casing Record	Pumping Test
Casing diameter(s) ..... 12"	Date .... June 29/45
Length(s) of casing(s) .... 11'-8"	[illegible]
Length of screen ...... none	Duration of Test .... 8 hrs
Type of screen .... none	Pumping Rate ...... 394 I.G.M.
Type of pump ... Layne deep well turbine	Pumping Level – ... 87'-6"
Capacity of pump ...... 300 I.G.M.	Static level of completed well ... 15'-8"
Depth of pump setting 120' 8P to m.B.	Is well a gravel-wall type? ... No – it is rock well

Water Record

Kind (fresh or mineral) .... [illegible] / ..?

Quality (hard, soft, contains iron, sulphur etc.) .... Fairly hard

Appearance (clear, cloudy, coloured) .... clear

For what purpose(s) is the water to be used? ... City supply

How far is well from possible source of contamination? .... ?

What is source of contamination? .... ?

Enclose a copy of any mineral analysis that has been made of water ....

Depth(s) to Water Horizon(s)	Kind of Water	No. of Feet Water Rise
210 to 251'		

Well Log

Drift and Bedrock Record	From	To
	0 ft.	... ft.
Clay, boulders & broken stone	0	11
Gray Limestone	11	40
Brownish Limestone	40	120
White Limestone	120	210
Broken shale & Limestone	210	251

Location of Well

In diagram below show distances of well from road and lot line

See PUC. at Fergus.

Situation: Is well on upland, in valley, or on hillside? ....

Drilling Firm ... International Water Supply Ltd. ....

Address ...... 12 Hartland St. ... London, Ont. ....

Recorded by ... F. [signature] ... driller - S.C. Abbott ... Address .... I.W.S.

Date ...... July 10/46 .... Licence Number ....

FIGURE B2 Well Record for Municipal Well F2

Ontario Water Resources Commission Act — WATER WELL RECORD

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

11 | 6704214 | 62009 | 114

County or District	Township, Borough, City, Town, Village	Con., Block, Tract, Survey, etc.	Lot
Wellington / Waterloo	Fergus / Nichol	XVI	20

Owner (Surname first)	Address	Date Completed
P.U.C.	Fergus	day 08 mo. 03 yr. 72

21 | 17 | 549950 | 4840650 | 4 | 1390 | 5 | 23

LOG OF OVERBURDEN AND BEDROCK MATERIALS (SEE INSTRUCTIONS)

General Colour	Most Common Material	Other Materials	General Description	Depth – Feet From	To
			Topsoil	0	1
Brown	Clay	Sand & Gravel	Packed	1	44
Grey	Clay	Sand & Gravel	Packed	44	160
Brown	Silt	Sand		160	190
Brown	Sand		Packed	190	220
Brown	Clay	Sand & Gravel	Cemented	220	259
Brown	Sandstone		Hard	259	264
White	Limestone	Brown & Grey Limestone		264	425

APL

31 | 0001 | 0244 | 00446 | 0160 | 0190 | 0220 | 0259
32 | 0264 | 0425

41 WATER RECORD

Water found at – feet	Kind of water
0265	☒ Fresh
0290	☒ Fresh
0295	☒ Fresh
0380	☒ Fresh
0385	☒ Fresh

51 CASING & OPEN HOLE RECORD

Inside diam. inches	Material	Wall thickness inches	Depth – Feet From	To
12"	☒ Steel		0	0264
12"	☒ Open hole		264	0316
10"	☒ Open hole		316	0425

SCREEN

Slot No.: | Material and type: | Diameter: | Length: | Depth to top of screen:

61 PLUGGING & SEALING RECORD

Depth set at – feet From	To	Material and type (cement grout, lead packer, etc.)

71 PUMPING TEST

Pumping test method: ☒ Pump ☐ Bailer — Pumping rate: 0300 GPM — Duration of pumping: 24 hours 00 mins

Static level: 063 feet — Water level end of pumping: 169 feet

Water levels during: ☒ Pumping ☐ Recovery

15 minutes	30 minutes	45 minutes	60 minutes
132	135	136	137 feet

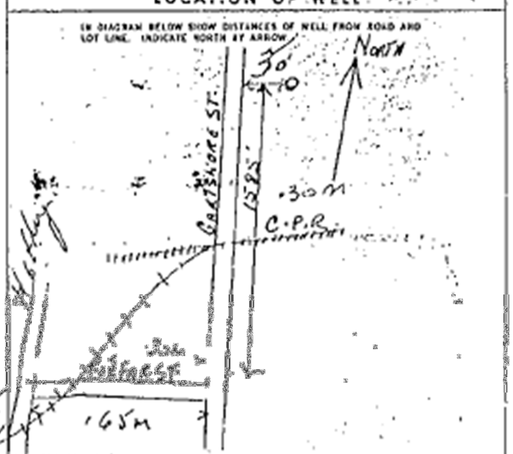
If flowing, give rate: GPM — Pump intake set at: feet — Water at end of test: ☒ Clear ☐ Cloudy

Recommended pump type: ☐ Shallow ☒ Deep — Recommended pump setting: 250 feet — Recommended pumping rate: 300 GPM

002.8 GPM/FT. SPECIFIC CAPACITY

LOCATION OF WELL

IN DIAGRAM BELOW SHOW DISTANCES OF WELL FROM ROAD AND LOT LINE. INDICATE NORTH BY ARROW.



FINAL STATUS OF WELL

☒ 1 Water supply ☐ 2 Observation well ☐ 3 Test hole ☐ 4 Recharge well ☐ 5 Abandoned, insufficient supply ☐ 6 Abandoned, poor quality ☐ 7 Unfinished

WATER USE

06

METHOD OF DRILLING

☒ 1 Cable tool ☐ 2 Rotary (conventional) ☐ 3 Rotary (reverse) ☐ 4 Rotary (air) ☐ 5 Air percussion ☐ 6 Boring ☐ 7 Diamond ☐ 8 Jetting ☐ 9 Driving

Drillers remarks:

CONTRACTOR

Name of well contractor: International Water Supply Ltd — Licence number: 2801

Address: P. Barnhardt Box 310 Barrie Ont.

Name of driller or borer: — Licence number:

Signature of contractor: — Submission date:

OFFICE USE ONLY

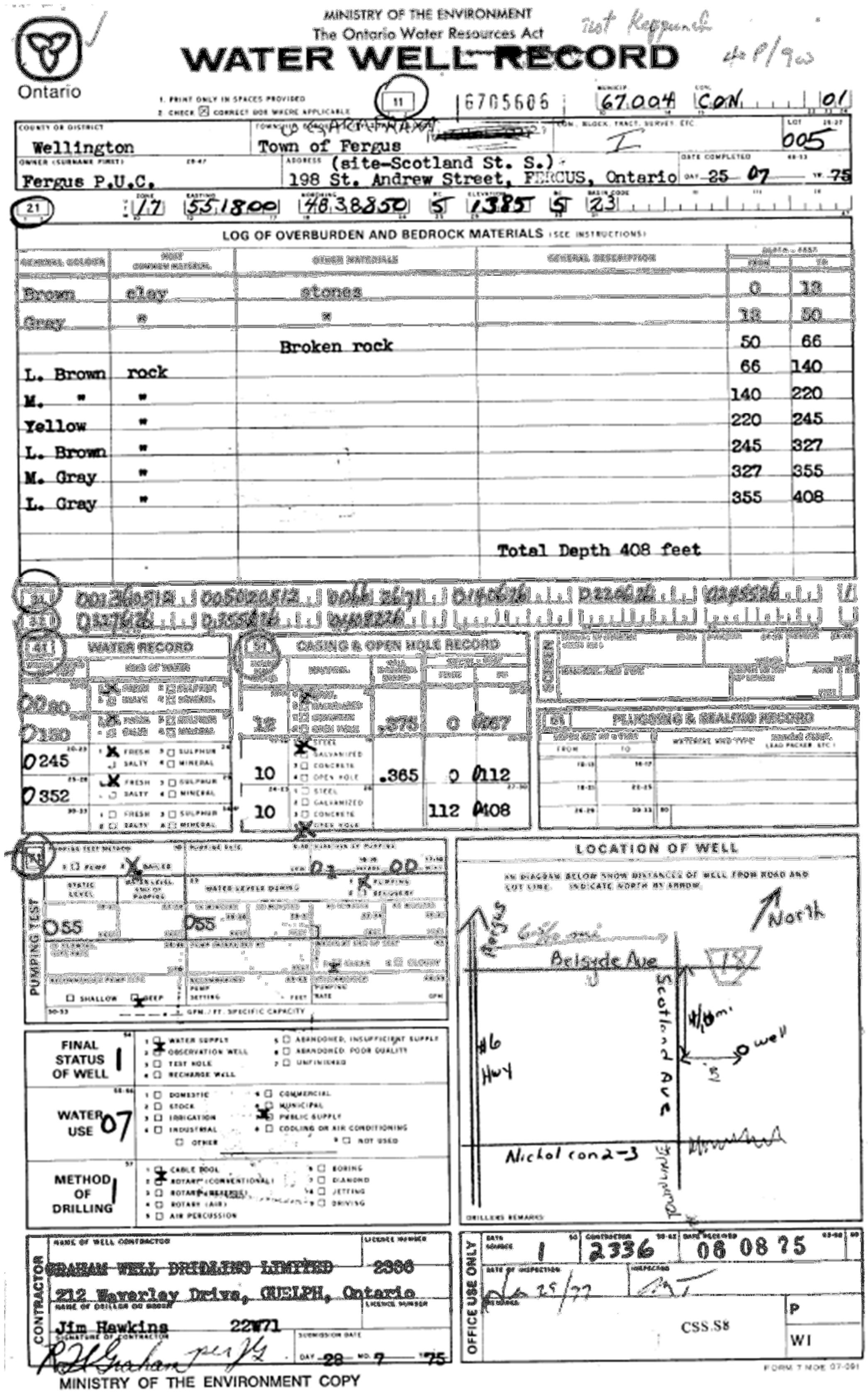
Data source: 1 — Contractor: 2801 — Date received: 060472

Date of inspection: — Inspector: — Remarks:

APL

OWRC COPY

FIGURE B3 Well Record for Municipal Well F4



MINISTRY OF THE ENVIRONMENT
The Ontario Water Resources Act
WATER WELL RECORD

Ontario

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

11 | 6705606 | 67004 | CON. | 01

COUNTY OR DISTRICT	TOWNSHIP, BOROUGH, CITY, TOWN, VILLAGE	CON., BLOCK, TRACT, SURVEY, ETC.	LOT
Wellington	Town of Fergus	I	005

OWNER (SURNAME FIRST)	ADDRESS	DATE COMPLETED
Fergus P.U.C.	(site-Scotland St. S.) 198 St. Andrew Street, FERGUS, Ontario	DAY 25 MO. 07 YR. 75

21 | ZONE 17 | EASTING 551800 | NORTHING 4838850 | RC 5 | ELEVATION 1385 | RC 5 | BASIN CODE 23

LOG OF OVERBURDEN AND BEDROCK MATERIALS (SEE INSTRUCTIONS)

GENERAL COLOUR	MOST COMMON MATERIAL	OTHER MATERIALS	GENERAL DESCRIPTION	DEPTH - FEET FROM	TO
Brown	clay	stones		0	18
Gray	"	"		18	50
		Broken rock		50	66
L. Brown	rock			66	140
M. "	"			140	220
Yellow	"			220	245
L. Brown	"			245	327
M. Gray	"			327	355
L. Gray	"			355	408
			Total Depth 408 feet		

WATER RECORD

WATER FOUND AT - FEET	KIND OF WATER
080	Fresh
150	Fresh
245	Fresh
352	Fresh

CASING & OPEN HOLE RECORD

INSIDE DIAM INCHES	MATERIAL	WALL THICKNESS INCHES	DEPTH - FEET FROM	TO
12	Steel	.375	0	067
10	Steel	.365	0	112
10	Open hole		112	408

PLUGGING & SEALING RECORD

PUMPING TEST

Pumping test method: Bailer; Duration of pumping: 02 HRS 00 MINS; Pumping / Recovery

Static level: 055; Water level end of pumping: 055

Water: Clear

Recommended pump type: Deep

FINAL STATUS OF WELL: 1 (Water supply)

WATER USE: 07 (Municipal / Public supply)

METHOD OF DRILLING: 1

LOCATION OF WELL

IN DIAGRAM BELOW SHOW DISTANCES OF WELL FROM ROAD AND LOT LINE. INDICATE NORTH BY ARROW.

DRILLERS REMARKS

CONTRACTOR	
NAME OF WELL CONTRACTOR	GRAHAM WELL DRILLING LIMITED
LICENCE NUMBER	2336
ADDRESS	212 Waverley Drive, GUELPH, Ontario
NAME OF DRILLER OR BORER	Jim Hawkins
LICENCE NUMBER	22W71
SUBMISSION DATE	DAY 28 MO. 7 YR. 75

OFFICE USE ONLY: DATA SOURCE 1 | CONTRACTOR 2336 | DATE RECEIVED 08 08 75 | CSS.S8 | P | WI

FORM 7 MOE 07-091

MINISTRY OF THE ENVIRONMENT COPY

FIGURE B4 Well Record for Municipal Well F5

Ministry of the Environment
Ontario

The Ontario Water Resources Act

WATER WELL RECORD

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

County or District	Township, Borough, City, Town, Village	Con., Block, Tract, Survey, etc.	Lot
Wellington	Nichol	XVI	17

Owner (Surname First)	Address	Date Completed
Fergus PUC	P.O. Box 10, Fergus, Ont.	Day 15 Mo 5 Yr 89

LOG OF OVERBURDEN AND BEDROCK MATERIALS (SEE INSTRUCTIONS)

General Colour	Most Common Material	Other Materials	General Description	Depth - Feet From	To
Brown	Clay	Fill, Gravel Silt		0	18
Brown	Clay	Gravel		18	24
Grey	Clay	Gravel		24	84
Grey	Limestone			84	169
Brown	Limestone			169	213
Grey	Limestone			213	225
Brown	Limestone			225	232
Lt.Grey	Limestone			232	315
Brown	Limestone			315	378
Grey	Limestone			378	400
[illegible]	Limestone			400	402

WATER RECORD

Water Found at - Feet	Kind of Water
128' - 402'	☒ Fresh ☐ Salty ☐ Sulphur ☐ Minerals ☐ Gas

CASING & OPEN HOLE RECORD

Inside Diam Inches	Material	Wall Thickness Inches	Depth - Feet From	To
12	Steel	.375	+1.5	109.5
11	Open Hole		109.5	402

SCREEN

Slot No.: – Diameter: – inches Length: – feet
Material and Type: – Depth to Top of Screen: – feet

PLUGGING & SEALING RECORD

Depth Set at - Feet From	To	Material and Type (Cement Grout, Lead Packer, etc.)
0	109.5	12" casing cemented in 28" dia. open hole

PUMPING TEST

Pumping Test Method	Pumping Rate	Duration of Pumping
☒ Pump ☐ Bailer	350 GPM	24 hours – mins

Static Level	Water Level End of Pumping	15 minutes	30 minutes	45 minutes	60 minutes
57.51 feet	153.29 feet	109.52 feet	112.41 feet	– feet	115.75 feet

Water levels during: ☐ Pumping ☐ Recovery

Water at end of test: ☒ Clear ☐ Cloudy

Recommended pump type: ☐ Shallow ☒ Deep
Recommended pump setting: 250 feet
Recommended pumping rate: 300 GPM

LOCATION OF WELL 6

IN DIAGRAM BELOW SHOW DISTANCES OF WELL FROM ROAD AND LOT LINE. INDICATE NORTH BY ARROW.

31325

FINAL STATUS OF WELL

☒ Water Supply ☐ Observation Well ☐ Test Hole ☐ Recharge Well ☐ Abandoned, insufficient supply ☐ Abandoned, poor quality ☐ Unfinished ☐ Dewatering

WATER USE

☐ Domestic ☐ Stock ☐ Irrigation ☐ Industrial ☐ Other ☐ Commercial ☒ Municipal ☐ Public Supply ☐ Cooling or air conditioning ☐ Not used

METHOD OF CONSTRUCTION

☐ Cable tool ☒ Rotary (conventional) ☐ Rotary (reverse) ☒ Rotary (air) ☐ Air percussion ☐ Boring ☐ Diamond ☐ Jetting ☐ Driving ☐ Digging ☐ Other

CONTRACTOR

Name of Well Contractor: International Water Supply,Ltd. — Licence Number: 2801
Address: 342 Bayview Dr., Barrie, Ont. L4M 4T5
Name of Well Technician: R.C. Magee — Well Technician's Licence Number: T0117
Signature of Technician/Contractor: [signature] — Submission Date: Day 14 Mo 07 Yr 89

OFFICE USE ONLY

CONTRACTOR'S COPY

FORM NO. 0506 (11/86) FORM 9

FIGURE B5 Well Record for Municipal Well F6

Ontario | Ministry of the Environment

A 011668

A011668

Well Record
Regulation 903 Ontario Water Resources Act

page ___ of ___

Instructions for Completing Form

- For use in the Province of Ontario only. This document is a permanent **legal** document. Please retain for future reference.
- All Sections **must** be completed in full to avoid delays in processing. Further instructions and explanations are available on the back of this form.
- Questions regarding completing this application can be directed to the Water Well Management Coordinator at 416-235-6203.
- **All metre measurements shall be reported to 1/10th of a metre.**
- Please print clearly in blue or black ink only.

Ministry Use Only — MUN | CON | LOT

Well Owner's Information and Location of Well Information

[redacted]

Wellington | Nichol Twp. | 19 | 14

RR#/Street Number/Name | City/Town/Village | Site/Compartment/Block/Tract etc.

GPS Reading: NAD 83 | Zone 17 | Easting 548185 | Northing 4839691 | Unit Make/Model: Garmin eTREX Venture | Mode of Operation: ☒ Undifferentiated ☐ Averaged ☐ Differentiated, specify

Log of Overburden and Bedrock Materials (see instructions)

General Colour	Most common material	Other Materials	General Description	Depth From	Ft To
Black	Topsoil		Soft	0	1'
Brown	Clay	Sand, silt	Soft	1	11
Brown	Clay	Silt, Cobbles	Hard	11	23
Grey	Till	Cobbles	Hard	23	68
Brown	Limestone	Shale	Hard	68	333
Dk.Brn.	Limestone		Hard	333	372
Grey	Limestone		Hard	372	455

Hole Diameter

Depth Ft From	To	Diameter
0	20'	14"
0	155'	10"
18'	455'	8"

Water Record

Water found at Ft	Kind of Water
88'	☒ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other
173'	☒ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other
362' 378'	☒ Fresh ☐ Sulphur ☐ Salty ☐ Minerals ☐ Other

After test of well yield, water was: ☒ Clear and sediment free ☐ Other, specify

Chlorinated ☒ Yes ☐ No

Construction Record

Inside diam	Material	Wall thickness	Depth From	To
Casing				
10"	☒ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	.250	0	72-4'
8"	☒ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	.250	+2'	155'
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
Screen (Outside diam)	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	Slot No.		
No Casing or Screen				
8"	☒ Open hole		155'	455'

Test of Well Yield

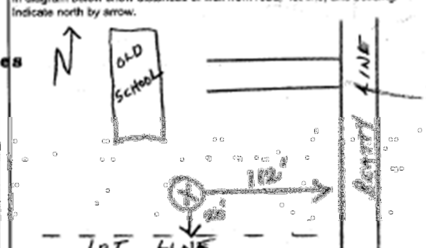
Pumping test method	Draw Down Time min	Water Level Metres	Recovery Time min	Water Level Metres
Pump intake set at - (metres)	Static Level			
Pumping rate - (litres/min)	1		1	
Duration of pumping ___ hrs + ___ min	2	DONE	2	BY
Final water level end of pumping ___ metres	3	OTHERS	3	
Recommended pump type ☐ Shallow ☐ Deep	4		4	
Recommended pump depth. ___ metres	5		5	
Recommended pump rate. (litres/min)	10		10	
If flowing give rate - (litres/min)	15		15	
If pumping discontinued, give reason.	20		20	
	25		25	
	30		30	
	40		40	
	50		50	
	60		60	

Plugging and Sealing Record ☒ Annular space ☐ Abandonment

Depth set at - Ft From	To	Material and type (bentonite slurry, neat cement slurry) etc.	Volume Placed (cubic metres)
0	155'	Neat Cement	1 cu.metre
0	20	Neat Cement	0.3cu.metres

Location of Well

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



Method of Construction

☐ Cable Tool ☐ Rotary (conventional) ☐ Rotary (reverse) ☒ Rotary (air) ☐ Air percussion ☐ Boring ☐ Diamond ☐ Jetting ☐ Driving ☐ Digging ☐ Other

Water Use

☐ Domestic ☐ Stock ☐ Irrigation ☐ Industrial ☐ Commercial ☒ Municipal ☐ Public Supply ☐ Not used ☐ Cooling & air conditioning ☐ Other

Final Status of Well

☒ Water Supply ☐ Observation well ☐ Test Hole ☐ Recharge well ☐ Abandoned, insufficient supply ☐ Abandoned, poor quality ☐ Unfinished ☐ Dewatering ☐ Replacement well ☐ Abandoned, (Other)

Audit No. Z 24385 | Date Well Completed 2005 03 09 | Date Delivered 2005 03 09

Was the well owner's information package delivered? ☐ Yes ☐ No

Well Contractor/Technician Information

Name of Well Contractor: Davidson Well Drilling Limited | Well Contractor's Licence No.: 1737

Business Address (street name, number, city etc.): 147 North St.W. Wingham, Ontario N0G 2W0

Name of Well Technician (last name, first name): Reavie Gary | Well Technician's Licence No.: T0156

Signature of Technician/Contractor: x G. C. Davidson | Date Submitted 2005 03 31

Ministry Use Only

Data Source | Contractor 1737

Date Received MAY 2 0 2005 | Date of Inspection

Remarks | Well Record Number

0506E (09/03) Contractor's Copy ☐ Ministry's Copy ☒ Well Owner's Copy ☐ *Cette formule est disponible en français*

FIGURE B6 Updated Well Record for Municipal Well F7

3A

WELL 1

WATER WELL RECORD

county or district. Well[illegible].......tp. Nichol....con.......lot.[illegible]..pt lot.......

owner Corp. Village of Elora........address. David St.....acres [illegible]

date completed June 1948...cost of well(not including pump) [illegible]

Pipe & casing record	pump test
casing diameter... 8" [illegible].........	.....date. Jan. 1948..........
lngth.of.casing... 31 ft......	developed..........................
lngth of screen....................	duration of test.. 9 hrs...........
type of screen..........................	pumping rate.. [illegible] G.P.M........
type of pump............................	drawdown.... 8 ft..................
capacity of pump........................	static level of well.. [illegible] ft.........
depth of pump setting...............	is well a gravel wall type. [illegible]...

WATER RECORD

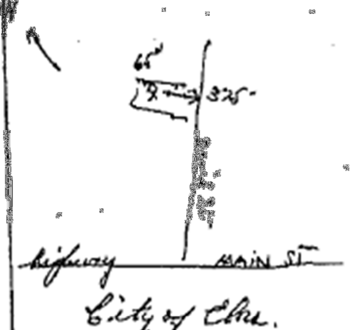
	Depth to water horizon	kind of water	no. of ft water rises
kind(fresh or mineral)... fresh.............			
quality(hard,soft,contains iron,sulphur) soft			
appearance(clear,cloudy,coloured. clear.....			
for what purpose is water to be used. Town.	45-426	Good.	385 ft.
how far is well from possible source of contamination..............................			
what is source of contamination.............			
enclose a copy of any mineral analysis that has been made of water....................			

WELL LOG

drift & bedrock record	from	to
yellow clay	0 ft	11 ft
hard pan	11	28
gravel & large boulders	28	31
limestone	31	38
blue limestone	38	69
brown "	69	81
light brown & white streaks	81	104
white limestone	104	138
dark brown	138	140
light "	140	162
blue & white streaks	162	177
white lime	177	199
blue & white course flaky 1" piece	199	217
white lime cource & fine streaks	217	268
blue & some grey	268	271
white lime	271	278

over

Location of well in diagram show distance of well from road & lot line



situation : is well on upland .in valley, or on hillside? - hillside

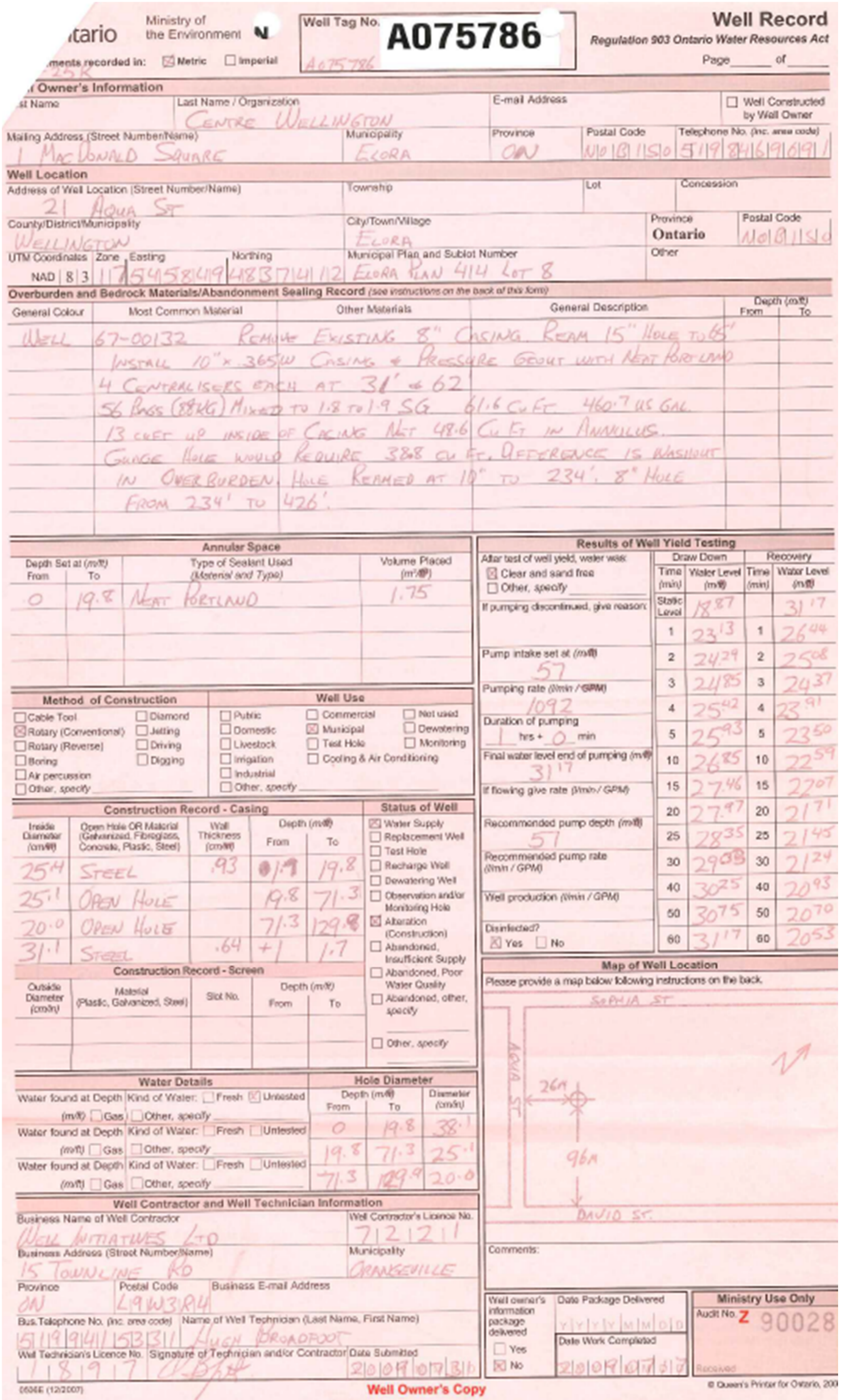
Drilling firm - D. L. Grudinski - Address - [illegible]

Recorded by - R. W. Collingridge - Address - R. R. 1 [illegible]

Date - Jan. 1948 - Licence number - 243

blue & light brown	278	to 290
brown & some blue	290	332
find sand & stone	332	350
white lime	350	369
blue white lime	369	390
blue grey	390	412
blue & some white	412	416
blue grey & white	416	426

FIGURE B7 **Original Well Record for Municipal Well E1**



Ontario Ministry of the Environment

Well Tag No. A075786

Well Record

Regulation 903 Ontario Water Resources Act

Page ___ of ___

Measurements recorded in: ☒ Metric ☐ Imperial

Well Owner's Information

Last Name / Organization: CENTRE WELLINGTON

Mailing Address (Street Number/Name): 1 MACDONALD SQUARE

Municipality: ELORA

Province: ON

Postal Code: N0B 1S0

Telephone No. (inc. area code): 519 846 9691

Well Location

Address of Well Location (Street Number/Name): 21 AQUA ST

County/District/Municipality: WELLINGTON

City/Town/Village: ELORA

Province: Ontario

Postal Code: N0B 1S0

UTM Coordinates: NAD 83, Zone 17, Easting 545849, Northing 4837412

Municipal Plan and Sublot Number: ELORA PLAN 414 LOT 8

Overburden and Bedrock Materials/Abandonment Sealing Record

WELL 67-00132 REMOVE EXISTING 8" CASING. REAM 15" HOLE TO 65'
INSTALL 10" x .365W CASING + PRESSURE GROUT WITH NEAT PORTLAND
4 CENTRALISERS EACH AT 31' + 62'
56 BAGS (88KG) MIXED TO 1.8 TO 1.9 SG 61.6 CU FT 460.7 US GAL
13 CU FT UP INSIDE OF CASING NET 48.6 CU FT IN ANNULUS.
GAUGE HOLE WOULD REQUIRE 38.8 CU FT. DIFFERENCE IS WASHOUT
IN OVERBURDEN. HOLE REAMED AT 10" TO 234'. 8" HOLE
FROM 234' TO 426'.

Annular Space

Depth Set at (m/ft) From	To	Type of Sealant Used (Material and Type)	Volume Placed (m³/ft³)
0	19.8	NEAT PORTLAND	1.75

Method of Construction: ☒ Rotary (Conventional)

Well Use: ☒ Municipal

Construction Record - Casing

Inside Diameter (cm/in)	Open Hole OR Material	Wall Thickness (cm/in)	Depth From	Depth To
25.4	STEEL	.93	+0.1	19.8
25.1	OPEN HOLE		19.8	71.3
20.0	OPEN HOLE		71.3	129.8
31.1	STEEL	.64	+1	1.7

Status of Well: ☒ Water Supply; ☒ Alteration (Construction)

Water Details: Water found at Depth — Kind of Water: ☒ Untested

Hole Diameter

Depth From (m/ft)	To	Diameter (cm/in)
0	19.8	38.1
19.8	71.3	25.1
71.3	129.9	20.0

Results of Well Yield Testing

After test of well yield, water was: ☒ Clear and sand free

Pump intake set at (m/ft): 57

Pumping rate (l/min / GPM): 1092

Duration of pumping: 1 hrs + 0 min

Final water level end of pumping (m/ft): 31.17

Recommended pump depth (m/ft): 57

Disinfected? ☒ Yes

Draw Down Time (min)	Water Level (m/ft)	Recovery Time (min)	Water Level (m/ft)
Static Level	18.87		31.17
1	23.13	1	26.44
2	24.29	2	25.08
3	24.85	3	24.37
4	25.42	4	23.91
5	25.93	5	23.50
10	26.85	10	22.59
15	27.46	15	22.07
20	27.97	20	21.71
25	28.35	25	21.45
30	29.08	30	21.24
40	30.25	40	20.93
50	30.75	50	20.70
60	31.17	60	20.53

Map of Well Location

Well Contractor and Well Technician Information

Business Name of Well Contractor: WELL INITIATIVES LTD

Well Contractor's Licence No.: 7121

Business Address: 15 TOWNLINE RD

Municipality: ORANGEVILLE

Province: ON

Postal Code: L9W 3R4

Bus. Telephone No.: 519 941 1533

Name of Well Technician: HUGH BROADFOOT

Well Technician's Licence No.: 1897

Date Submitted: 2009 07 31

Well owner's information package delivered: ☒ No

Date Work Completed: 2009 07 07

Ministry Use Only — Audit No. Z 90028

0506E (12/2007)

Well Owner's Copy

© Queen's Printer for Ontario, 2007

FIGURE B8 Revised Well Record for Municipal Well E1

Ministry of the Environment
Ontario

The Ontario Water Resources Act

WATER WELL REC

12-91 — 1. PRINT ONLY IN SPACES PROVIDED 2. CHECK ☒ CORRECT BOX WHERE APPLICABLE

11 | 6710658 | 67704

COUNTY OR DISTRICT	TOWNSHIP, BOROUGH, CITY, TOWN, VILLAGE	CON., BLOCK, TRACT, SURVEY, ETC.	
WELLINGTON	VILLAGE OF ELORA	B. FRONT CON. FIRST LINE	PT PARK LOT 11

VILLAGE OF ELORA
C/O TERRAQUA INVESTIGATIONS LTD. 41 PRINCESS ST. E., WATERLOO, ON.

DATE COMPLETED: DAY 015 MO 05 YR 91

21

LOG OF OVERBURDEN AND BEDROCK MATERIALS (SEE INSTRUCTIONS)

GENERAL COLOUR	MOST COMMON MATERIAL	OTHER MATERIALS	GENERAL DESCRIPTION	DEPTH - FEET FROM	TO
BROWN	CLAY	STONES - GRAVEL		0	15
GREY	CLAY	SAND		15	23
GREY	CLAY	GRAVEL		23	24
GREY	CLAY	SAND - GRAVEL		24	43
GREY	ROCK		BROKEN	43	55
L. BROWN	ROCK			55	70
M. BROWN	ROCK			70	90
L. GREY	ROCK			90	125
D. GREY	ROCK			125	185
L. BROWN	ROCK			185	400

31

32

41 WATER RECORD

WATER FOUND AT - FEET	KIND OF WATER
60'	FRESH
80'	FRESH
125'	FRESH
235'	FRESH
285'	FRESH

51 CASING & OPEN HOLE RECORD

INSIDE DIAM INCHES	MATERIAL	WALL THICKNESS INCHES	DEPTH - FEET FROM	TO
10"	STEEL	.344	0	45
10"	OPEN HOLE		45	400

SCREEN: SIZE(S) OF OPENING (SLOT NO.) | DIAMETER INCHES | LENGTH FEET | MATERIAL AND TYPE | DEPTH TO TOP OF SCREEN FEET

61 PLUGGING & SEALING RECORD

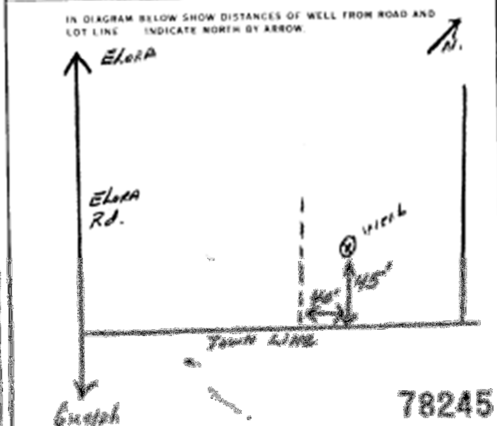
DEPTH SET AT - FEET FROM / TO | MATERIAL AND TYPE (CEMENT GROUT, LEAD PACKER, ETC.)

71 PUMPING TEST

PUMPING TEST METHOD	☒ PUMP ☐ BAILER
PUMPING RATE	450 GPM
DURATION OF PUMPING	48 HOURS
STATIC LEVEL	20.85 M.
WATER LEVEL END OF PUMPING	42.0 M.
WATER LEVELS DURING	☒ PUMPING ☐ RECOVERY
15 MINUTES	34.5 m.
30 MINUTES	34.7 m.
45 MINUTES	34.88 m.
60 MINUTES	35.8 m.
IF FLOWING GIVE RATE	— GPM
WATER AT END OF TEST	☒ CLEAR ☐ CLOUDY
RECOMMENDED PUMP TYPE	☐ SHALLOW ☒ DEEP

LOCATION OF WELL

IN DIAGRAM BELOW SHOW DISTANCES OF WELL FROM ROAD AND LOT LINE. INDICATE NORTH BY ARROW.



78245

FINAL STATUS OF WELL: ☒ WATER SUPPLY

WATER USE: ☒ MUNICIPAL

METHOD OF CONSTRUCTION: ☒ ROTARY (AIR)

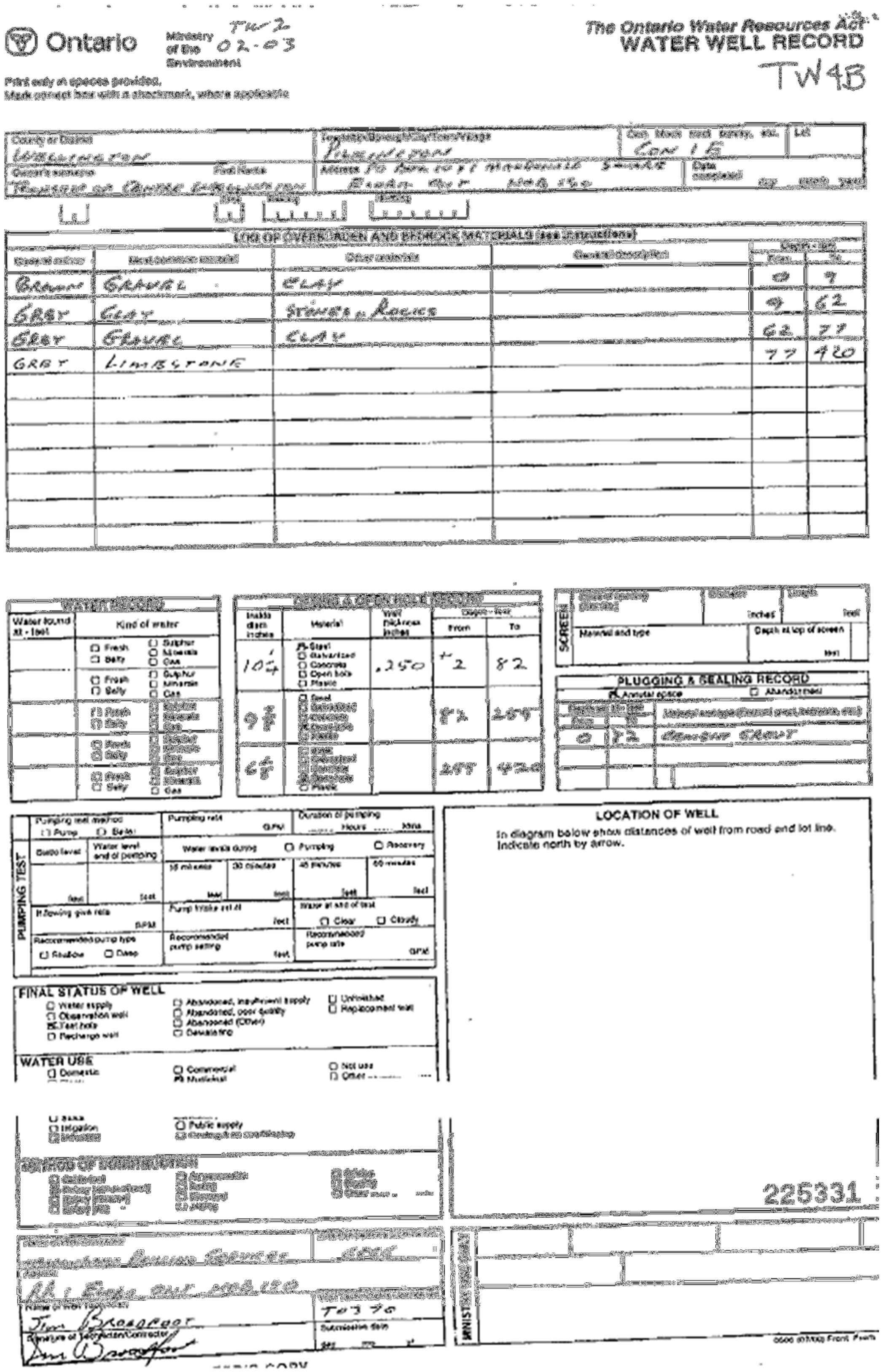
CONTRACTOR: GRAHAM WELL DRILLING LIMITED — 2336
R.R. #5, ROCKWOOD, ON. N0B 2K0
R. GRAHAM — T-0189
DATE SUBMITTED 011 05 91

OFFICE USE ONLY: 2336 JUL 16 1991

CSS.ES

MINISTRY OF THE ENVIRONMENT COPY

FIGURE B9 Original Well Record for Municipal Well E3



Ontario Ministry of the Environment TW-2 02-03

The Ontario Water Resources Act
WATER WELL RECORD
TW4B

Print only in spaces provided.
Mark correct box with a checkmark, where applicable

County or District: WELLINGTON
Township/Borough/City/Town/Village: PILKINGTON
Con: CON 1 E
Owner's surname: TOWNSHIP OF CENTRE WELLINGTON
Address: PO BOX 10 ... ELORA ONT N0B 1S0

LOG OF OVERBURDEN AND BEDROCK MATERIALS (see instructions)

General colour	Most common material	Other materials	General description	Depth - feet From	To
BROWN	GRAVEL	CLAY		0	9
GREY	CLAY	STONES & ROCKS		9	62
GREY	GRAVEL	CLAY		62	77
GREY	LIMESTONE			77	420

WATER RECORD

CASING & OPEN HOLE RECORD

Inside diam inches	Material	Wall thickness inches	Depth - feet From	To
10¾	Steel	.250	+2	82
9⅝			82	255
6⅝			255	420

PLUGGING & SEALING RECORD
Annular space

From	To	Material and type
0	82	CEMENT GROUT

PUMPING TEST

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

FINAL STATUS OF WELL
Test hole

WATER USE
Municipal

225331

Name of Well Contractor: WELLINGTON DRILLING SERVICES
Address: RR 1 ELORA ONT N0B 1S0
Name of Well Technician: JIM BRADFOOT
Signature of Technician/Contractor

FIGURE B10 Well Record for Municipal Well E4

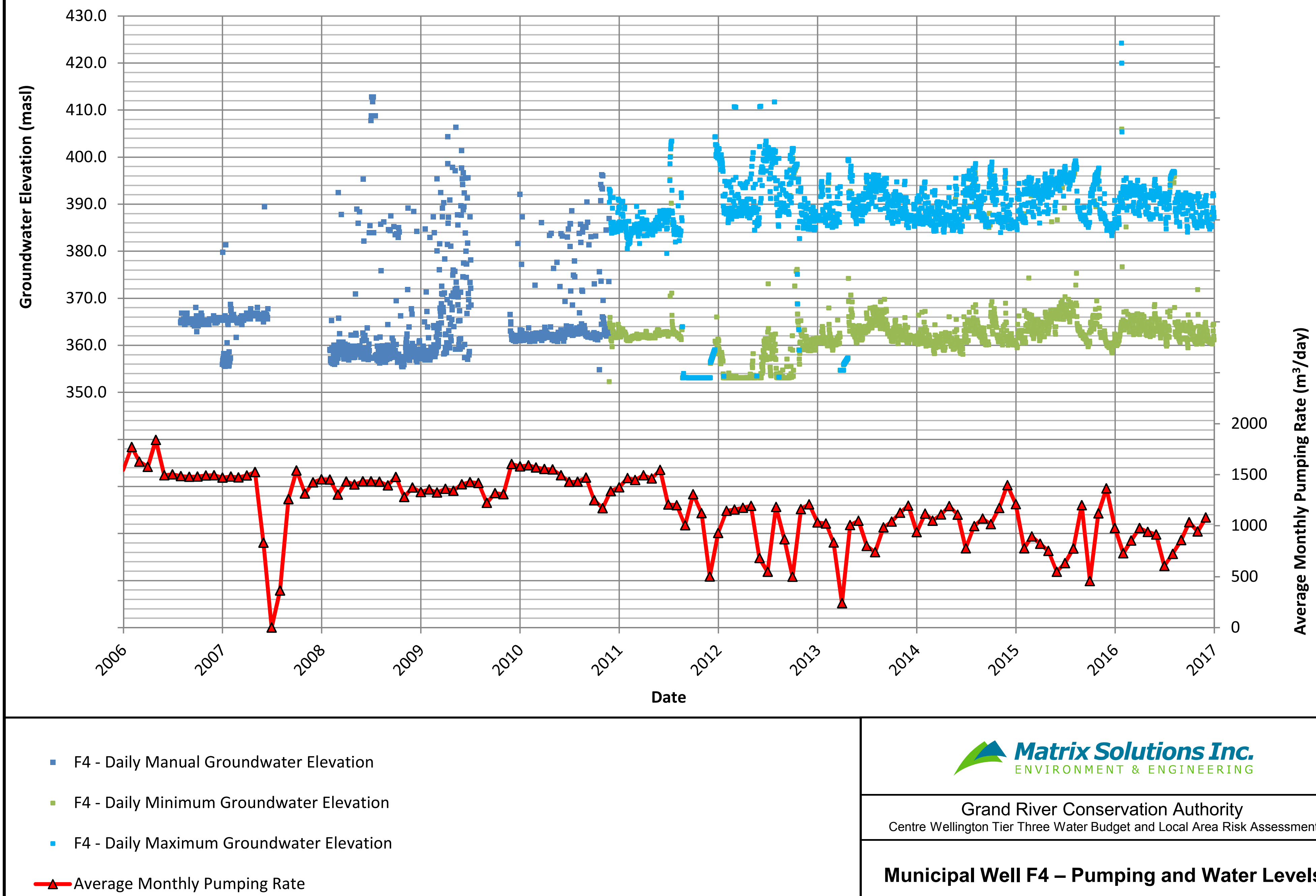
APPENDIX C
Permitted Water Takings within the Study Area

APPENDIX C Permitted Water Takers in the Study Area

Permit #	Source	General / Specific Purpose	Easting	Northing	Maximum Permitted Taking (m^3/d)	Max Permitted Taking (Days/Year)	Max Permitted Avg Annual Rate (m^3/d)	WTRS Reported Takings (Avg Annual; m^3/d)	Consumptive Use Factor	Current Consumptive Demand (m^3/d)	Data Source for Consumptive Demand
0601-88MKJ7	Groundwater or Both Groundwater and Surface Water	Water Supply - Municipal	562182	4852974	182	365	182	-	1	25	2016 Annual Summary Report
1733-8QKR4S		Commercial - Golf Course Irrigation	557767	4835969	2182	214	1279	50	0.85	42	2015 WTRS
			557733	4835803	589	214	345	0	0.85	0	2012 WTRS
2633-9XARF2		Commercial - Golf Course Irrigation	551512	4843928	82	184	41	2.7	0.85	2.3	2015 WTRS
			551512	4843819	30	184	15	2.7	0.85	2.3	2015 WTRS
3277-7RDSJW		Communal – Water Supply	552675	4846378	1178	365	1178	-	1	114	2016 pumping logs
			552662	4846325	393	365	393	-	1	3	
3347-84VQV5		Commercial - Aquaculture	537484	4838121	2399	365	2399	1791	1	1791	2015 WTRS
			537461	4837989	2399	365	2399	1800	1	1800	
			537435	4838042	982	365	982	669	1	669	
			537548	4838114	982	365	982	519	1	519	
			537491	4837967	2399	365	2399	0	1	0	
			537499	4838084	982	365	982	0	1	0	
4348-9NYNX3		Industrial – Aggregate Washing	538344	4835742	3000	244	2005	-	0.15	301	No WTRS data available: Max permitted rate and consumptive use factor applied to estimate takings
5817-8JQN3B		Commercial - Golf Course Irrigation	551146	4844524	793	214	465	2.7	0.85	2.3	2015 WTRS
			551159	4844481	197	214	115	2.7	0.85	2.3	
5874-955TM9		Other - Water Supply	552769	4847410	415	244	277	42	1	42	2015 WTRS and spreadsheets provided by Centre Wellington
			552979	4847310	415	244	277	0	1	0	
			553123	4847275	415	244	277	0	1	0	
			552437	4846991	120	244	80	8	1	8	
			552711	4847063	167	244	112	0	1	0	
8202-9DNKD3		Water Supply - Municipal	535319	4853057	1965	365	1965	-	1	335	2016 Annual Summary Report
			538499	4852043	2261	365	2261	-	1	316	
			538494	4852048	2261	365	2261	-	1	317	
8304-6XWRVZ		Remediation- Groundwater	549400	4838965	87	365	87	17	1	17	2014 WTRS
			549434	4838900	35	365	35	1	1	1	
			549436	4838776	34	365	34	1	1	1	
			549409	4838788	34	365	34	8	1	8	
			549546	4838999	34	365	34	16	1	16	
8813-9NYQXV		Industrial – Aggregate Washing	542421	4833563	3000	244	2005	902	0.15	135	2015 WTRS
N/A		Agriculture – Poultry Farm*	551028	4831518	N/A	N/A	N/A	-	1	120	Estimate
			551424	4831028	N/A	N/A	N/A	-	1	120	Estimate
			551741	4830850	N/A	N/A	N/A	-	1	40	Estimate
1160-887HN4	Surface Water	Wildlife Conservation	537890	4838561	824	365	824	0	0	0	2015 WTRS
8315-887KDV		Wildlife Conservation	548515	4842807	301	365	301	0	0	0	2015 WTRS
			548515	4842897	301	365	301	0	0	0	
5765-A2UJ9Q		Wildlife Conservation	544791	4848136	5500	365	5500	0	0	0	2015 WTRS
3125-97HQ2P		Agriculture – Field/ Pasture Crops	542113	4829038	2423	30	199	6.8	0.85	5.8	2015 WTRS
5587-9Y2QMX		Industrial - Other	550686	4839951	578888	365	578888	-	0	0	No WTRS data available. Used max permitted rate and consumptive use factor
7387-9S3KP8		Wetlands	564013	4851010	127908	365	127908	-	0	0	
6847-9S3K6Q		Wetlands	562366	4851392	87660	365	87660	-	0	0	

*Number of wells and well coordinates for the poultry farm were estimated
See Figure 23 for locations of PTTWs

APPENDIX D
Municipal Groundwater Level Monitoring



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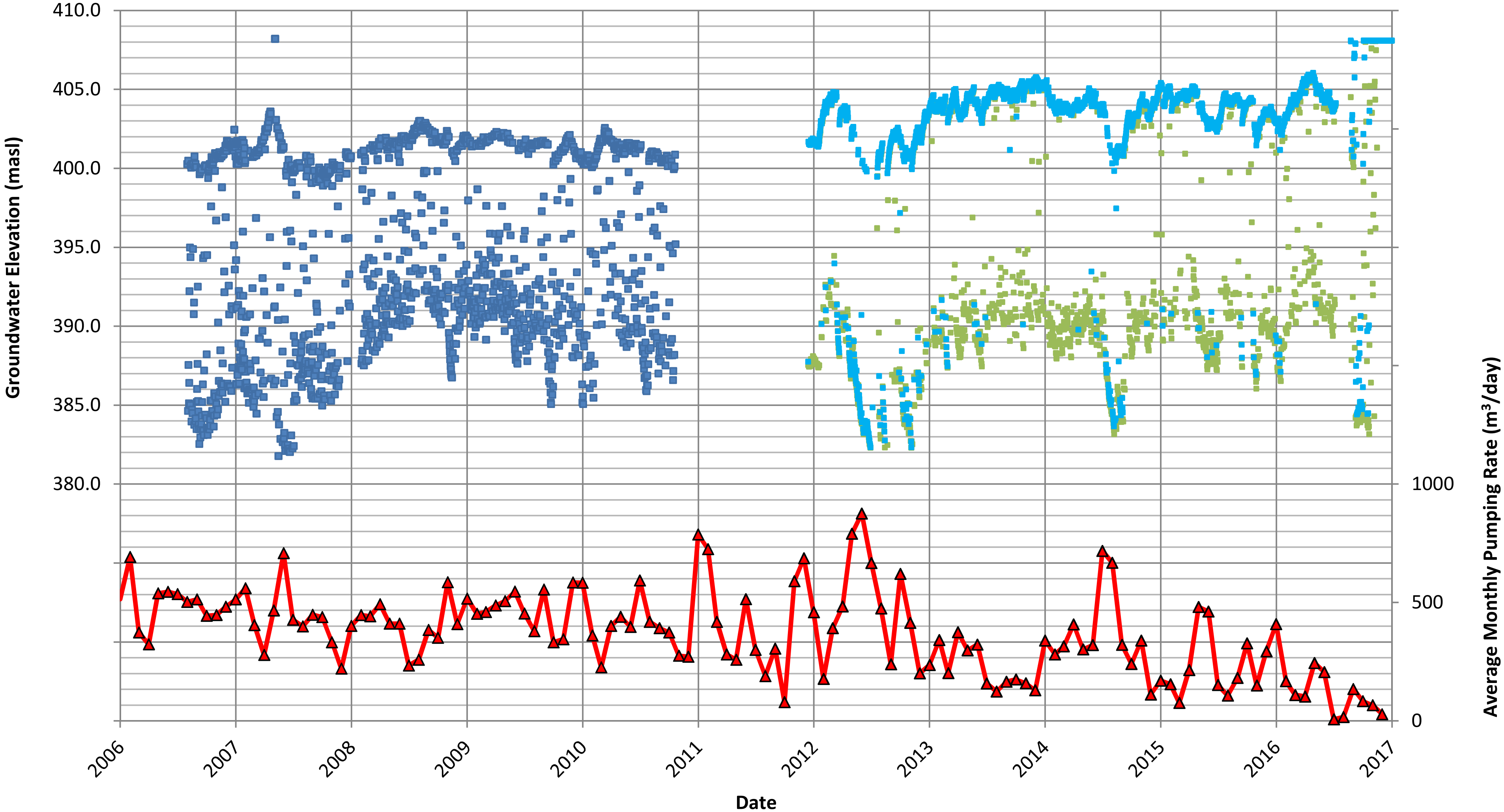
Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Municipal Well F4 – Pumping and Water Levels

Date:	Project:	Technical:	Reviewer:	Drawn:
25 Oct 2017	23876	J. Melchin	P. Meyer	J. Melchin

Figure D1



F5 - Daily Manual Groundwater Elevation

F5 - Daily Minimum Groundwater Elevation

F5 - Daily Maximum Groundwater Elevation

Average Monthly Pumping Rate

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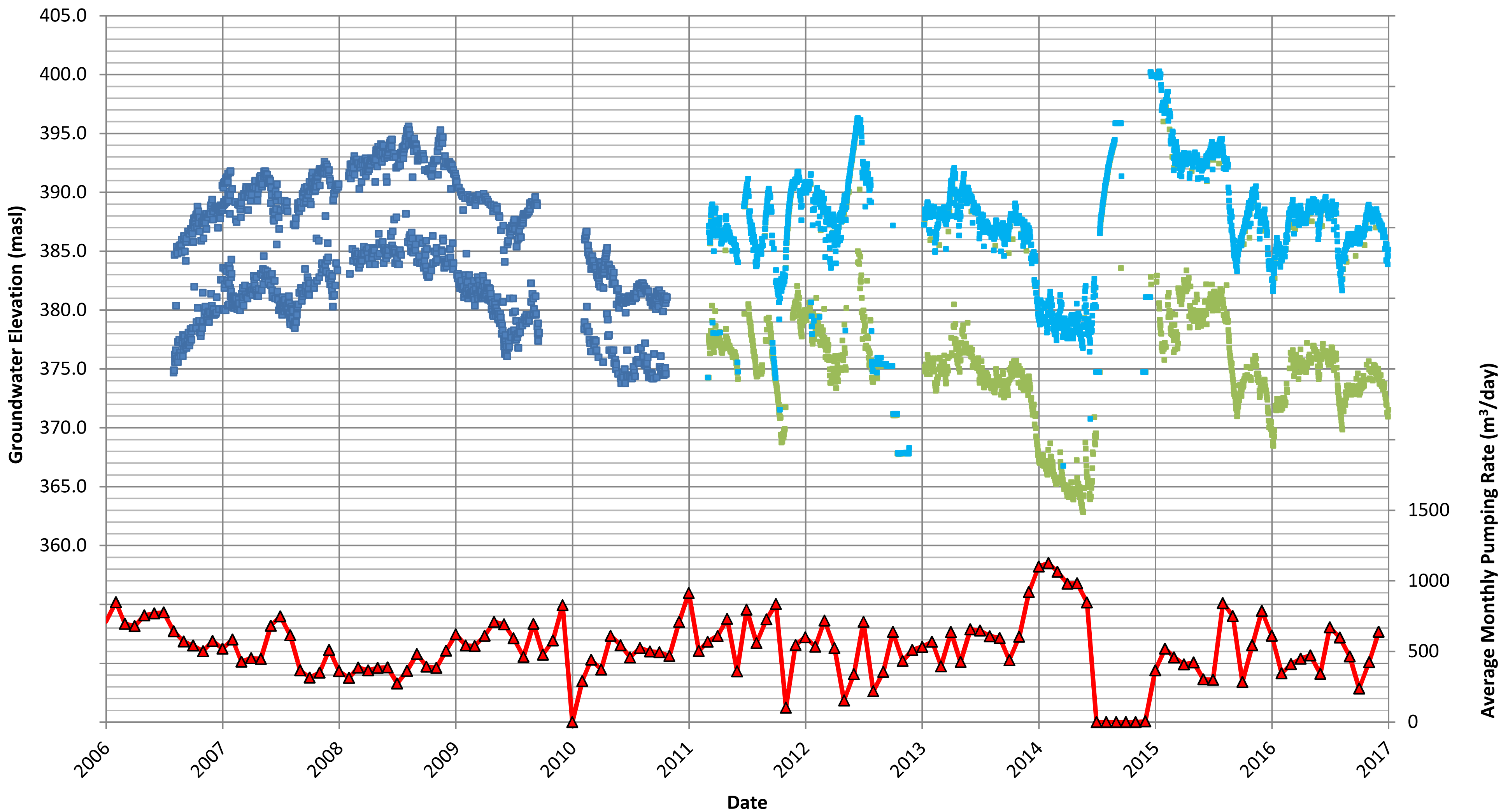
Municipal Well F5 – Pumping and Water Levels

Date:	Project:	Technical:	Reviewer:	Drawn:
25 Oct 2017	23876	J. Melchin	P. Meyer	J. Melchin

Figure **D2**



F6 - Daily Manual Groundwater Elevation

F6 - Daily Minimum Groundwater Elevation

F6 - Daily Maximum Groundwater Elevation

Average Monthly Pumping Rate

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Municipal Well F6 – Pumping and Water Levels

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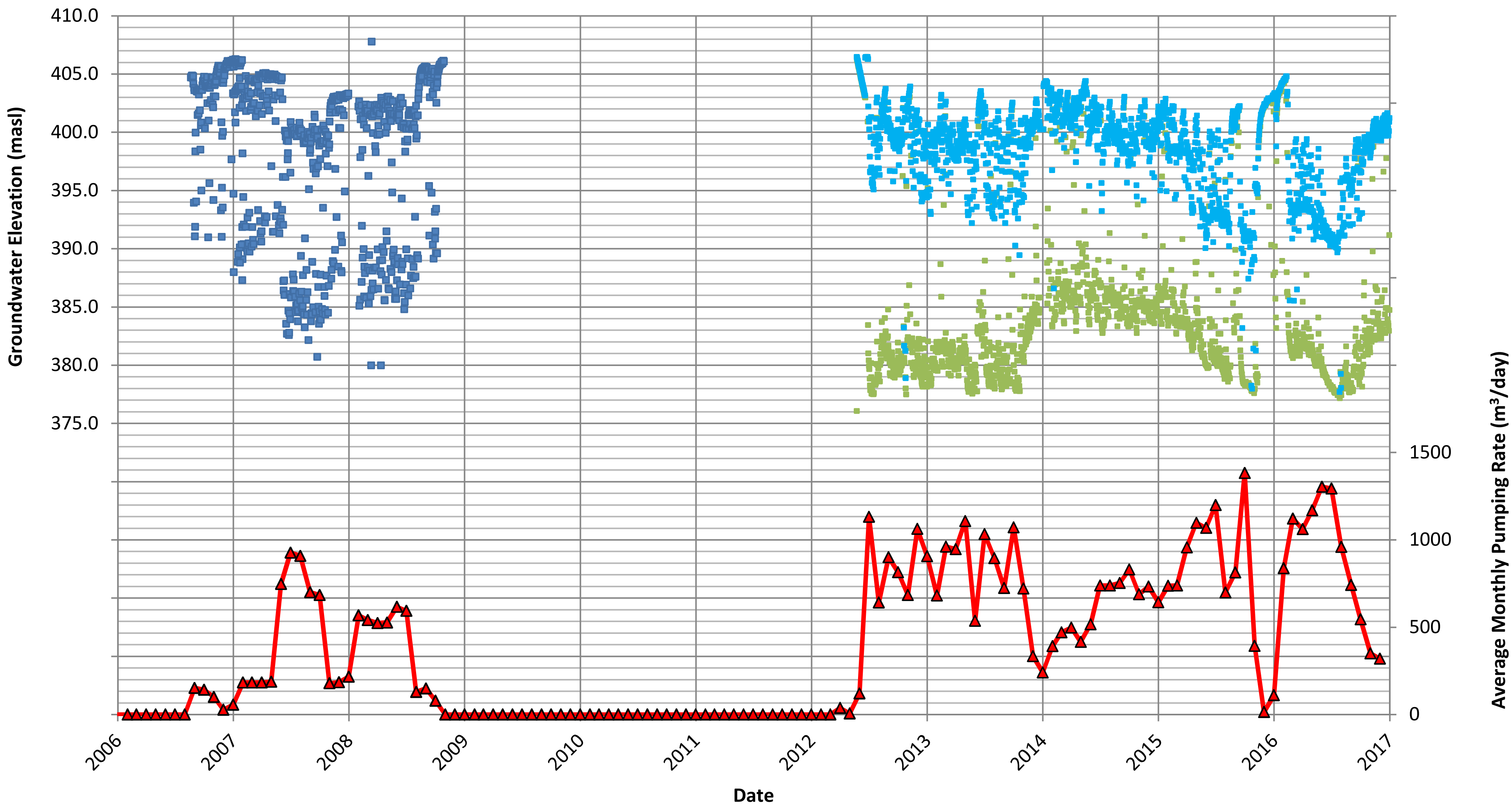
Figure
D3



F7 - Daily Manual Groundwater Elevation

F7 - Daily Minimum Groundwater Elevation

F7 - Daily Maximum Groundwater Elevation

Monthly Average Pumping Rate

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Municipal Well F7 – Pumping and Water Levels

Date:	Project:	Technical:	Reviewer:	Drawn:
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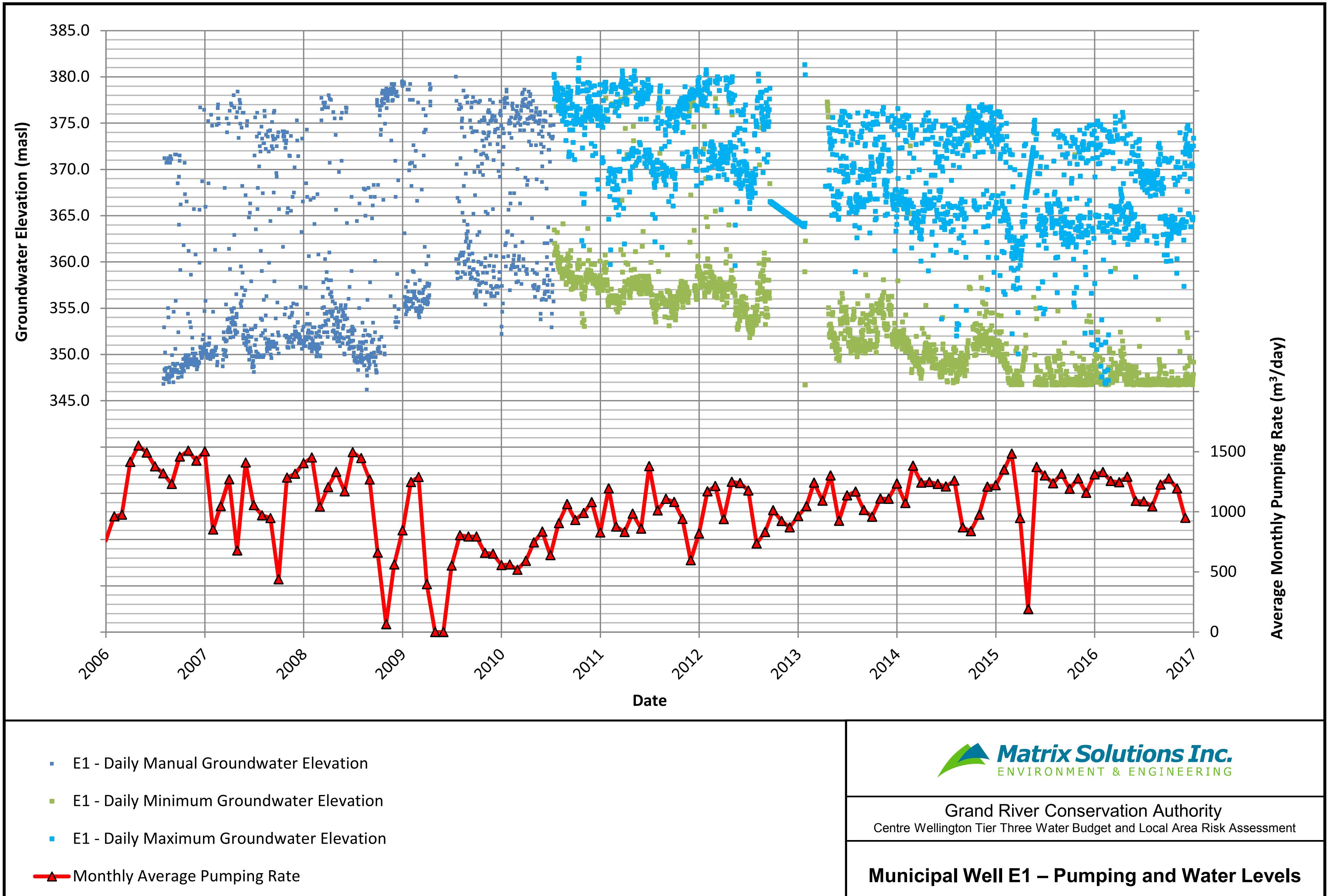
Figure
D4



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Municipal Well E1 – Pumping and Water Levels

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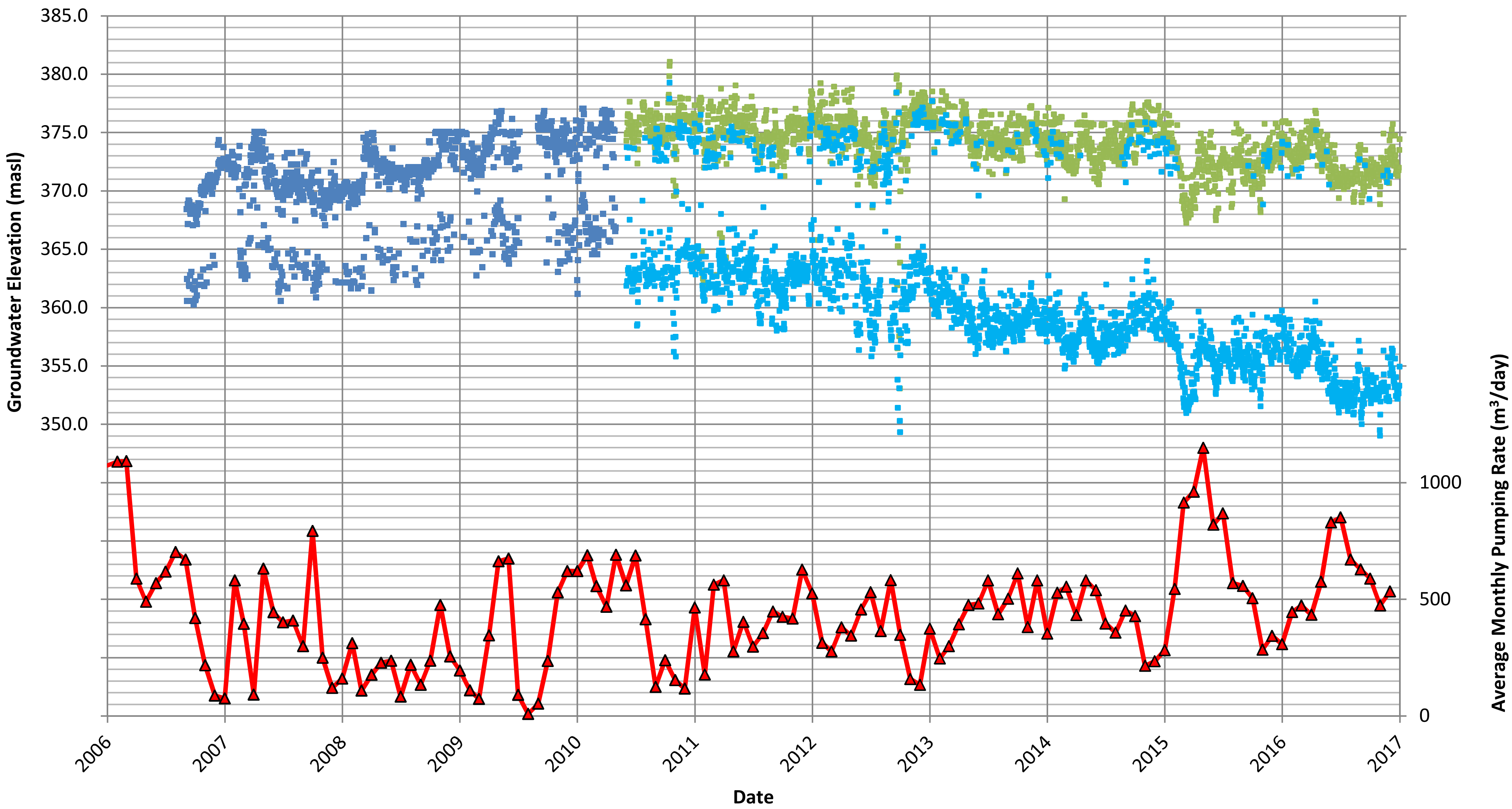
Figure
D5



E3 - Daily Manual Groundwater Elevation

E3 - Daily Maximum Groundwater Elevation

E3 - Daily Minimum Groundwater Elevation

Average Monthly Pumping Rate

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Municipal Well E3 – Pumping and Water Levels

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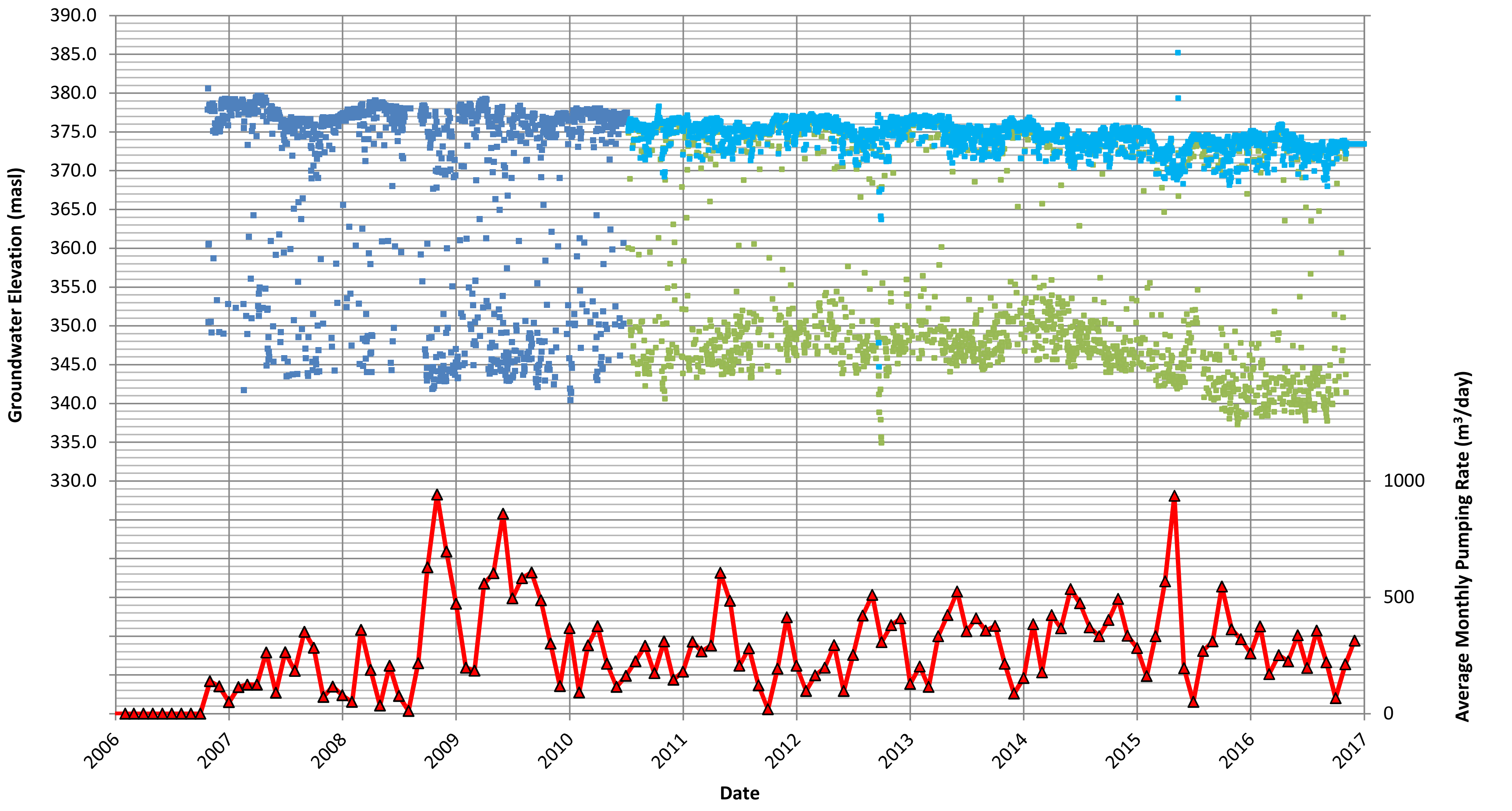
Figure D6



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Municipal Well E4 – Pumping and Water Levels

Date:	Project:	Technical:	Reviewer:	Drawn:
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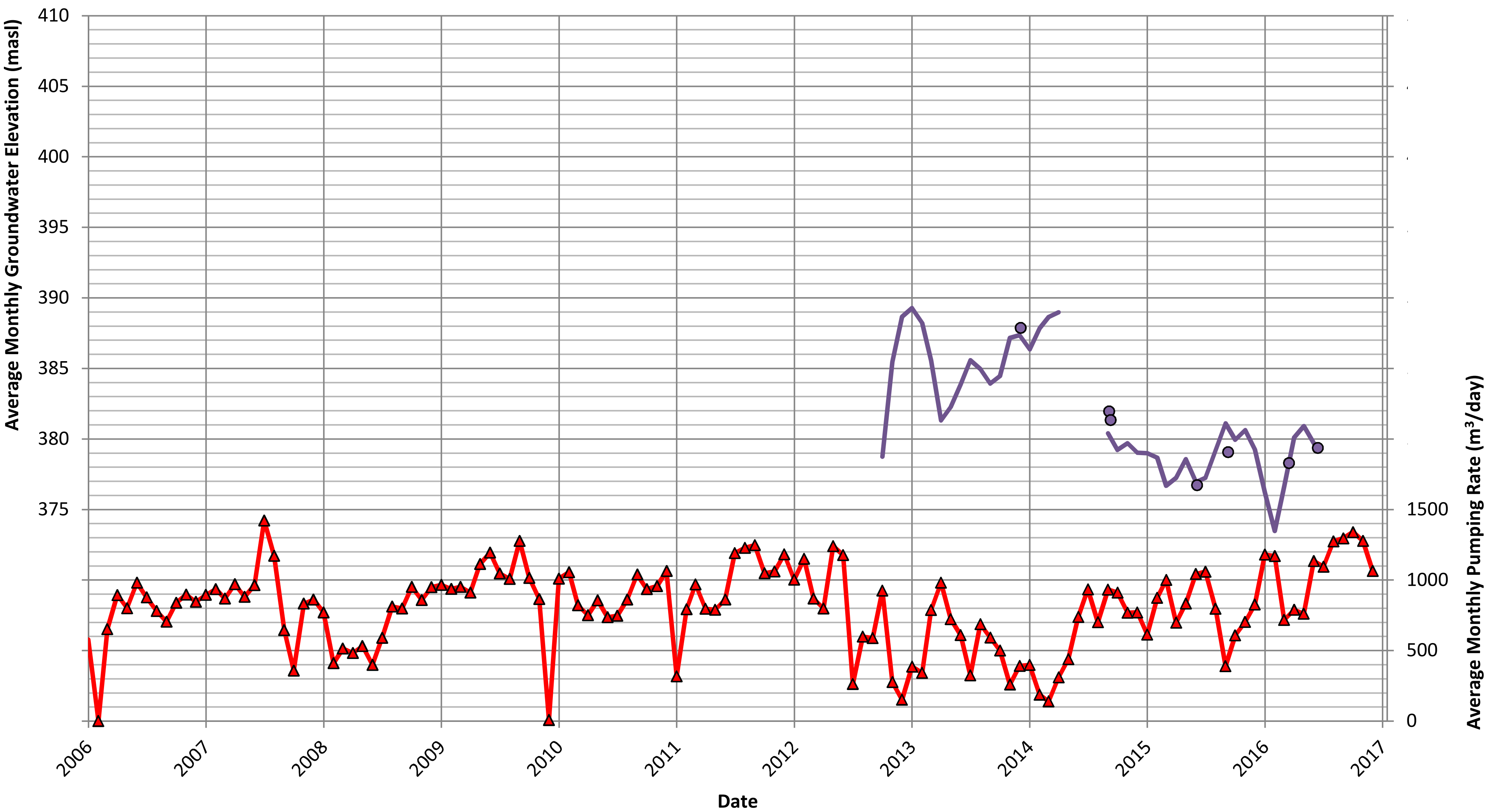
Figure
D7



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Municipal Monitoring of Well F1

Date:	Project:	Technical:	Reviewer:	Drawn:
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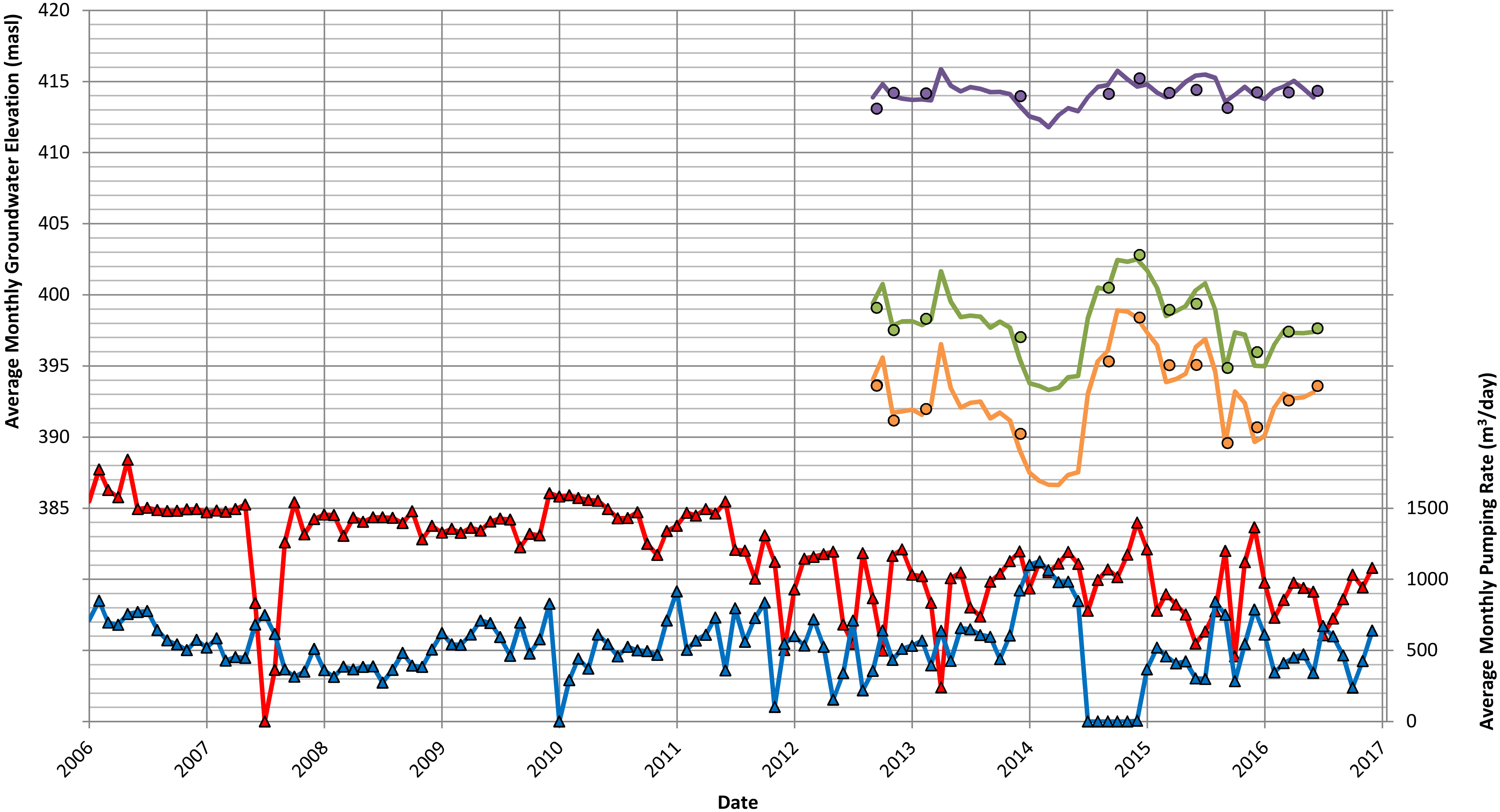
Figure
D8



MW6C-12 - Groundwater Elevation

MW6C-12 - Manual Levels

MW6B-12 - Groundwater Elevation

MW6B-12 - Manual Levels

MW6A-12 - Groundwater Elevation

MW6A-12 - Manual Levels

Average Monthly Pumping Rate - F4

Average Monthly Pumping Rate - F6

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Municipal Monitoring of Well F4 and F6

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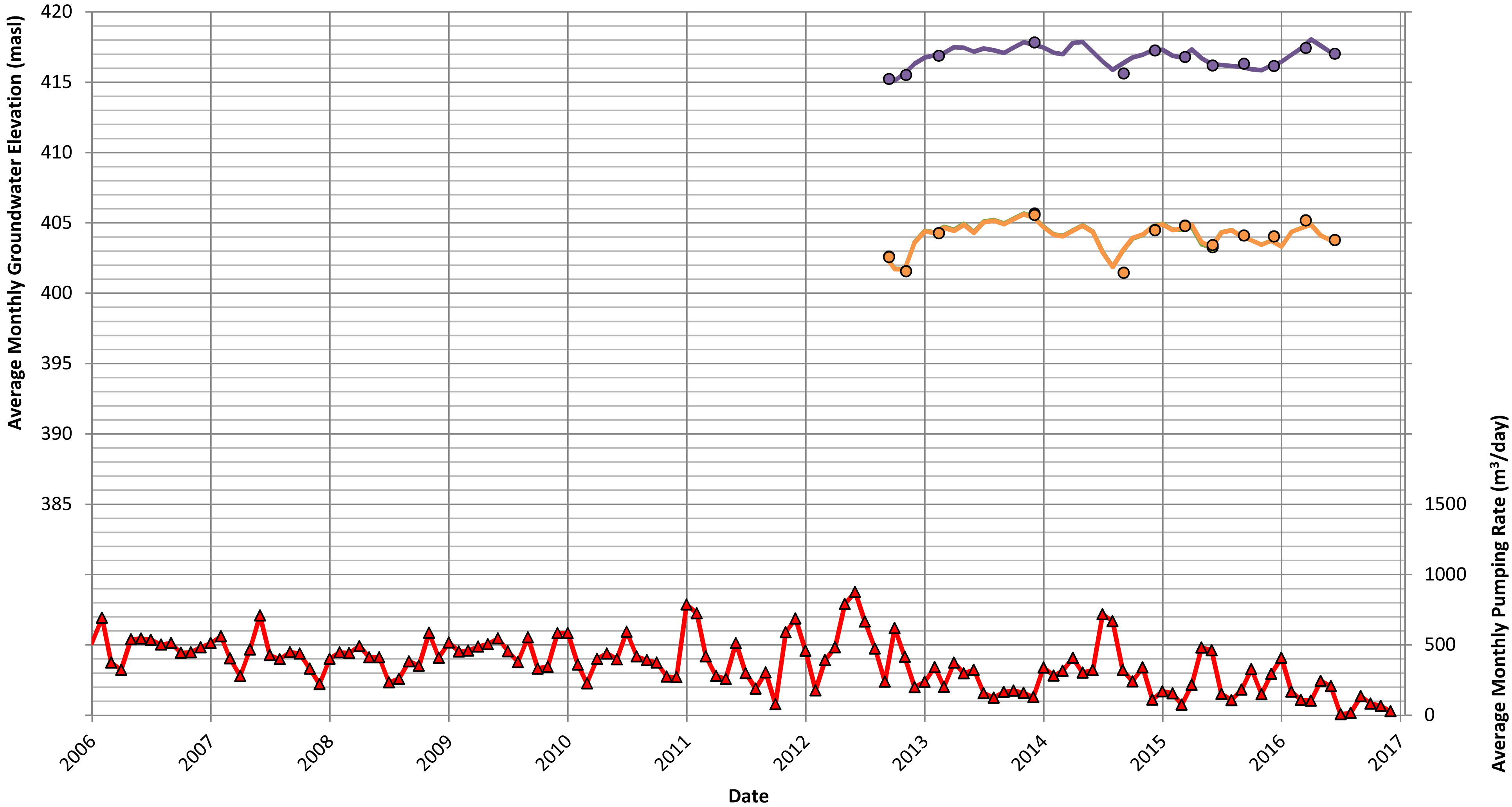
Figure
D9



MW3C-11 - Groundwater Elevation

MW3B-11 - Groundwater Elevation

MW3A-11 - Groundwater Elevation

Average Monthly Pumping Rate

MW3C-11 - Manual Levels

MW3B-11 - Manual Levels

MW3A-11 - Manual Levels

NOTE: MW3A-11 and MW3B-11 show overlapping hydraulic response

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Municipal Monitoring of Well F5

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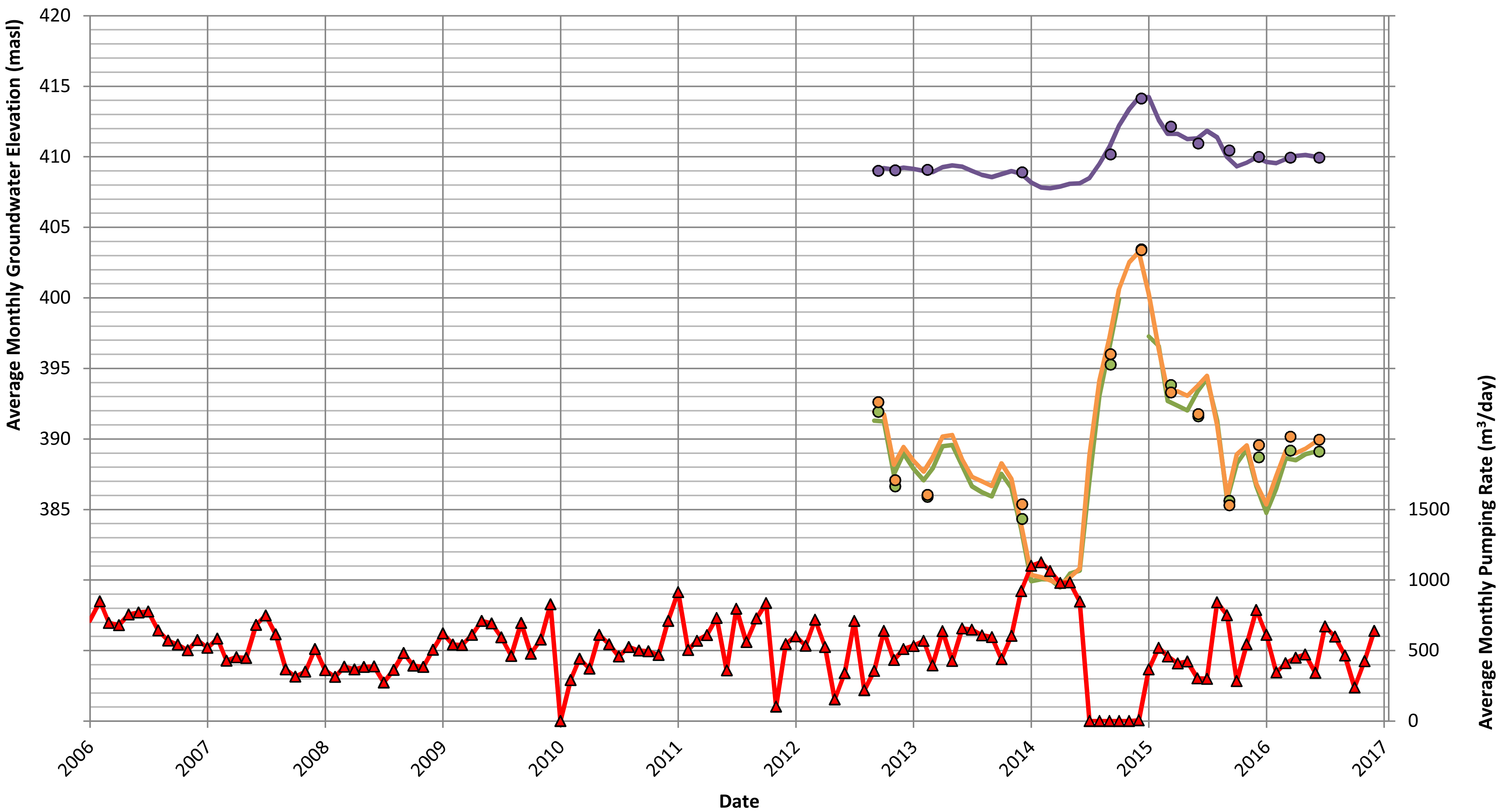
Figure **D10**



MW5C-11 - Groundwater Elevation

MW5B-11 - Groundwater Elevation

MW5A-11 - Groundwater Elevation

Average Monthly Pumping Rate

MW5C-11 - Manual Levels

MW5B-11 - Manual Levels

MW5A-11 - Manual Levels

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Municipal Monitoring of Well F6

Date:	Project:	Technical:	Reviewer:	Drawn:
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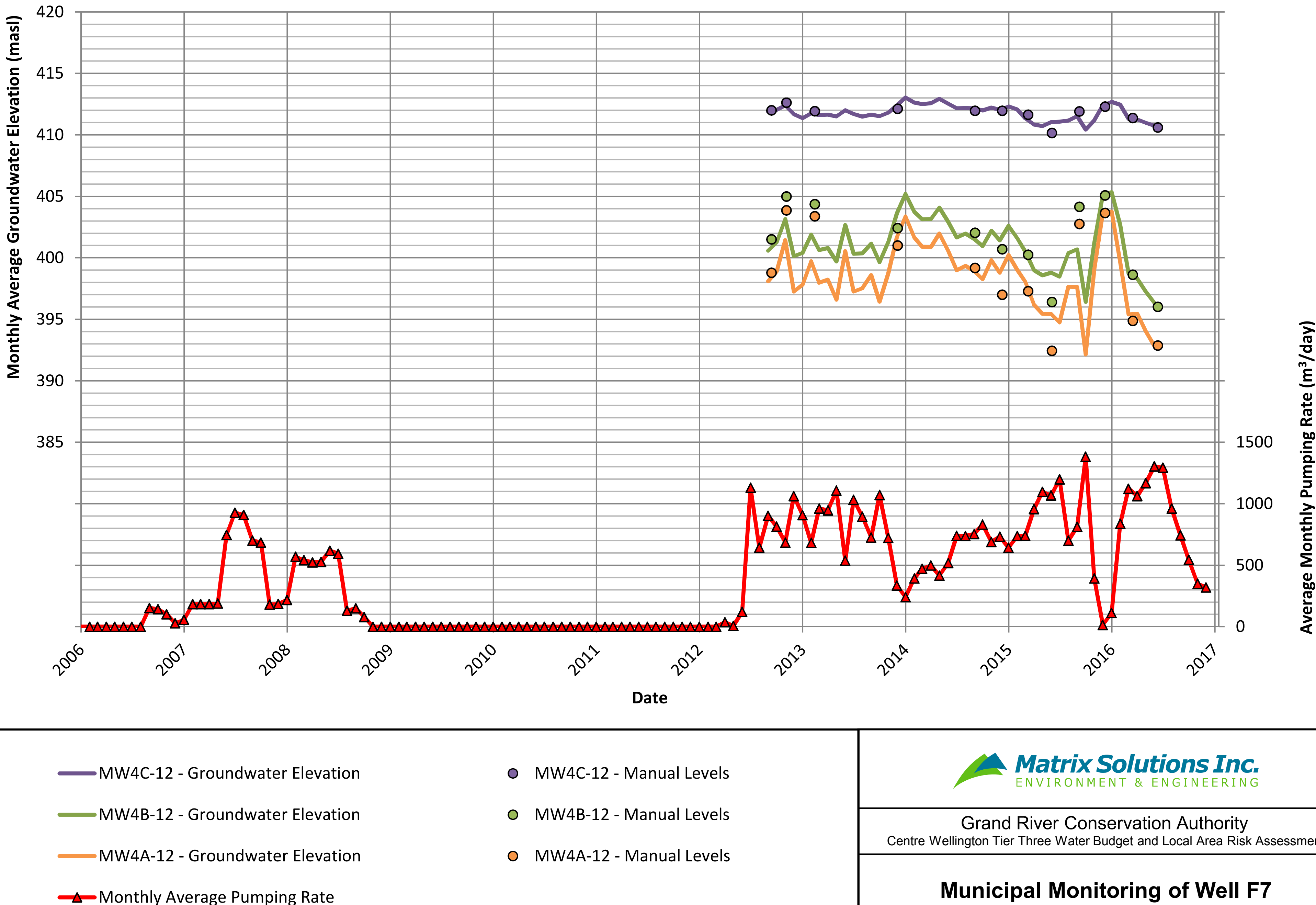
Figure
D11



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Municipal Monitoring of Well F7

Date:	Project:	Technical:	Reviewer:	Drawn:
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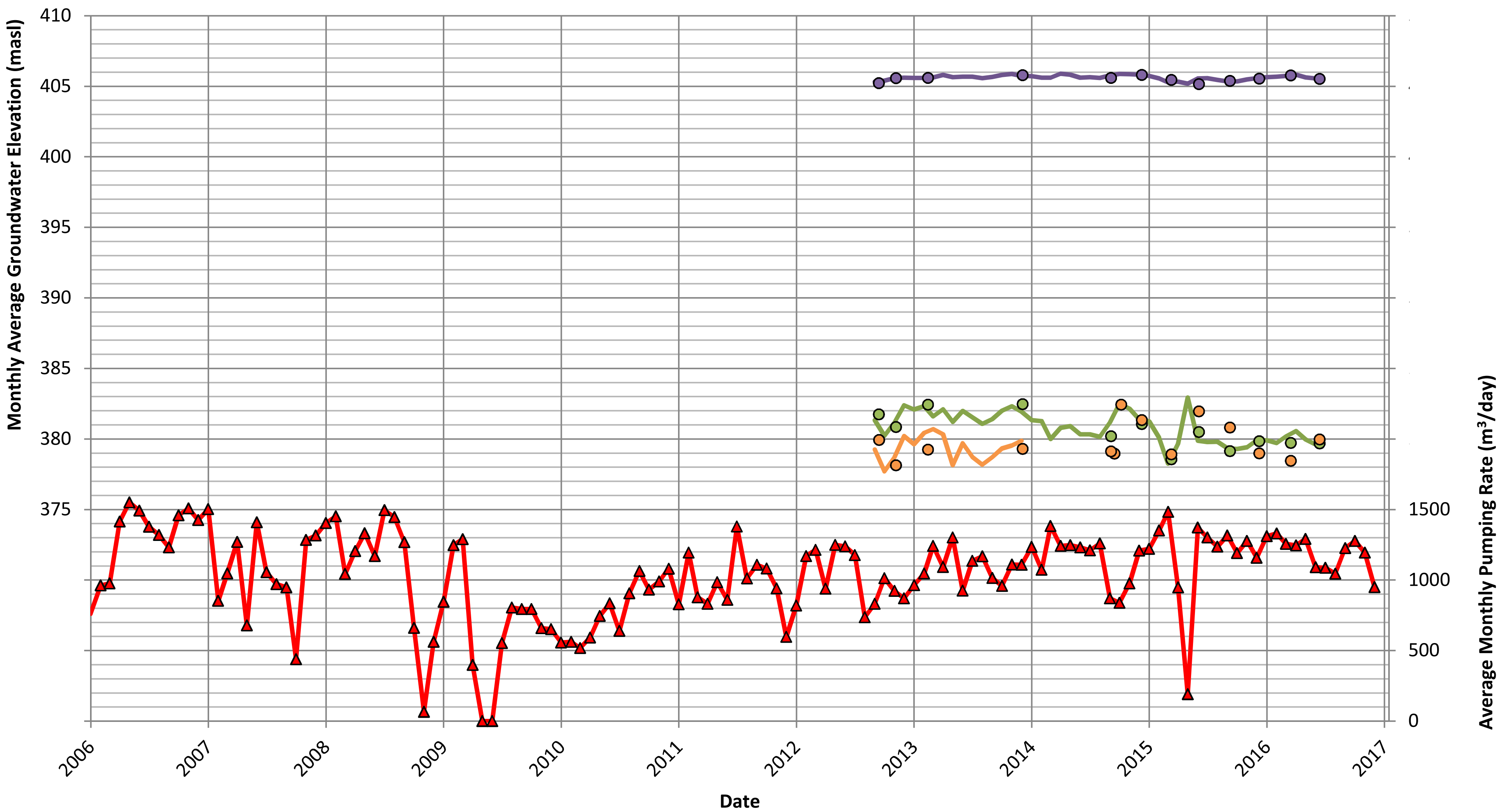
Figure
D12



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Municipal Monitoring of Well E1

Date:	Project:	Technical:	Reviewer:	Drawn:
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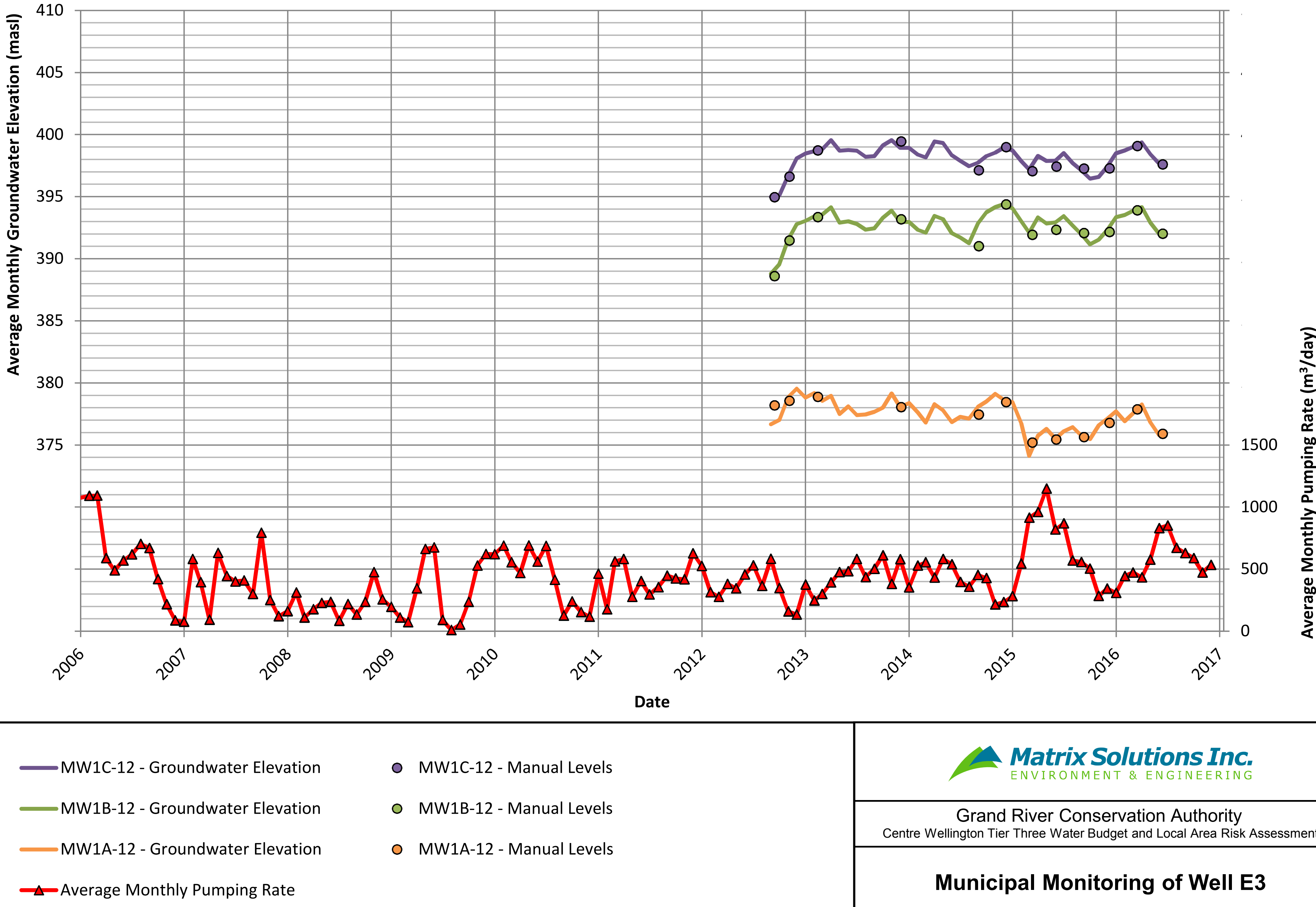
Figure
D13



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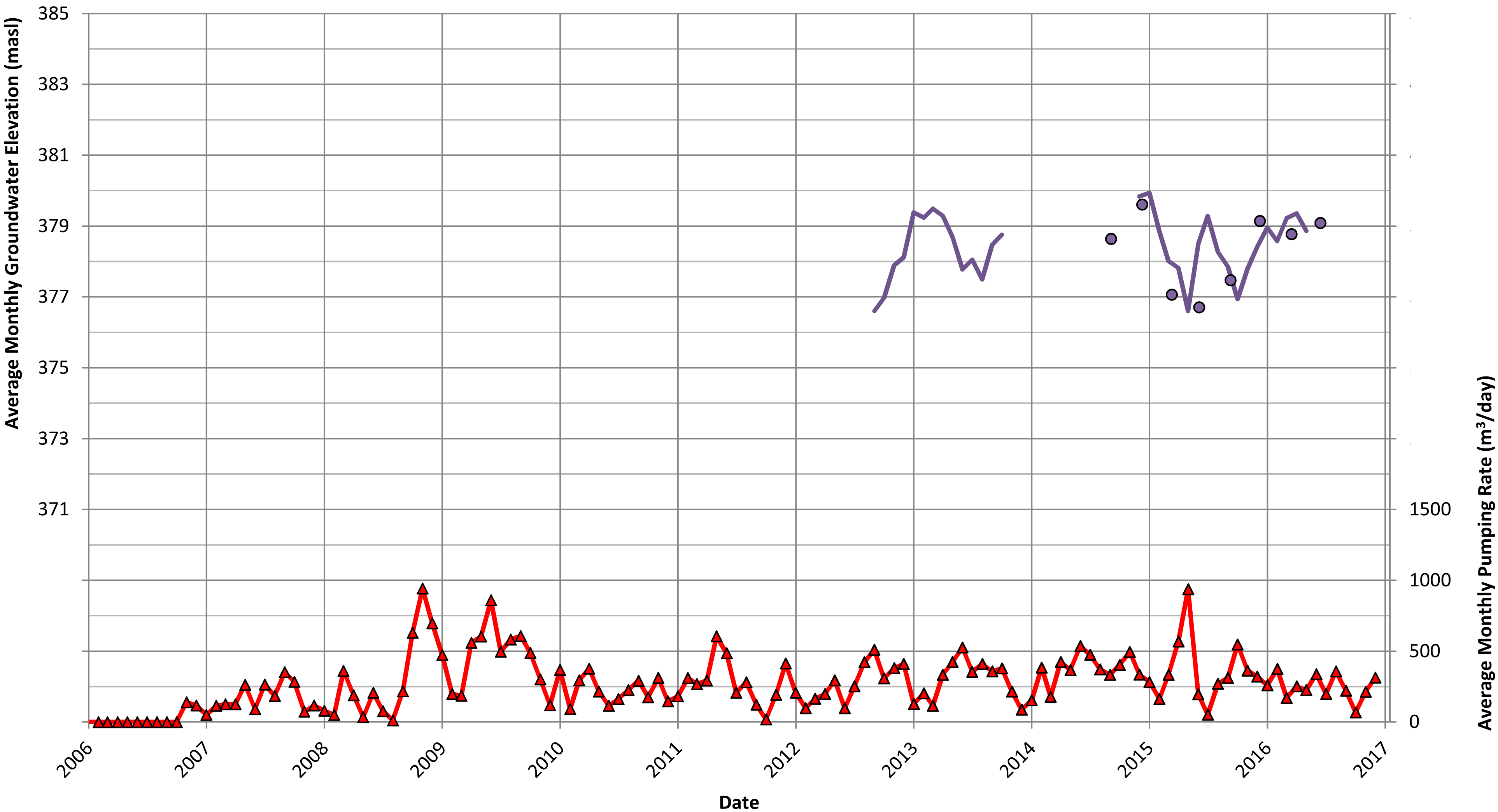
Municipal Monitoring of Well E3

Date:	Project:	Technical:	Reviewer:	Drawn:
25 Oct 2017	23876	J. Melchin	P. Meyer	J. Melchin

Figure
D14



Well 17 - Groundwater Elevation

Well 17 - Manual Levels

Average Monthly Pumping Rate

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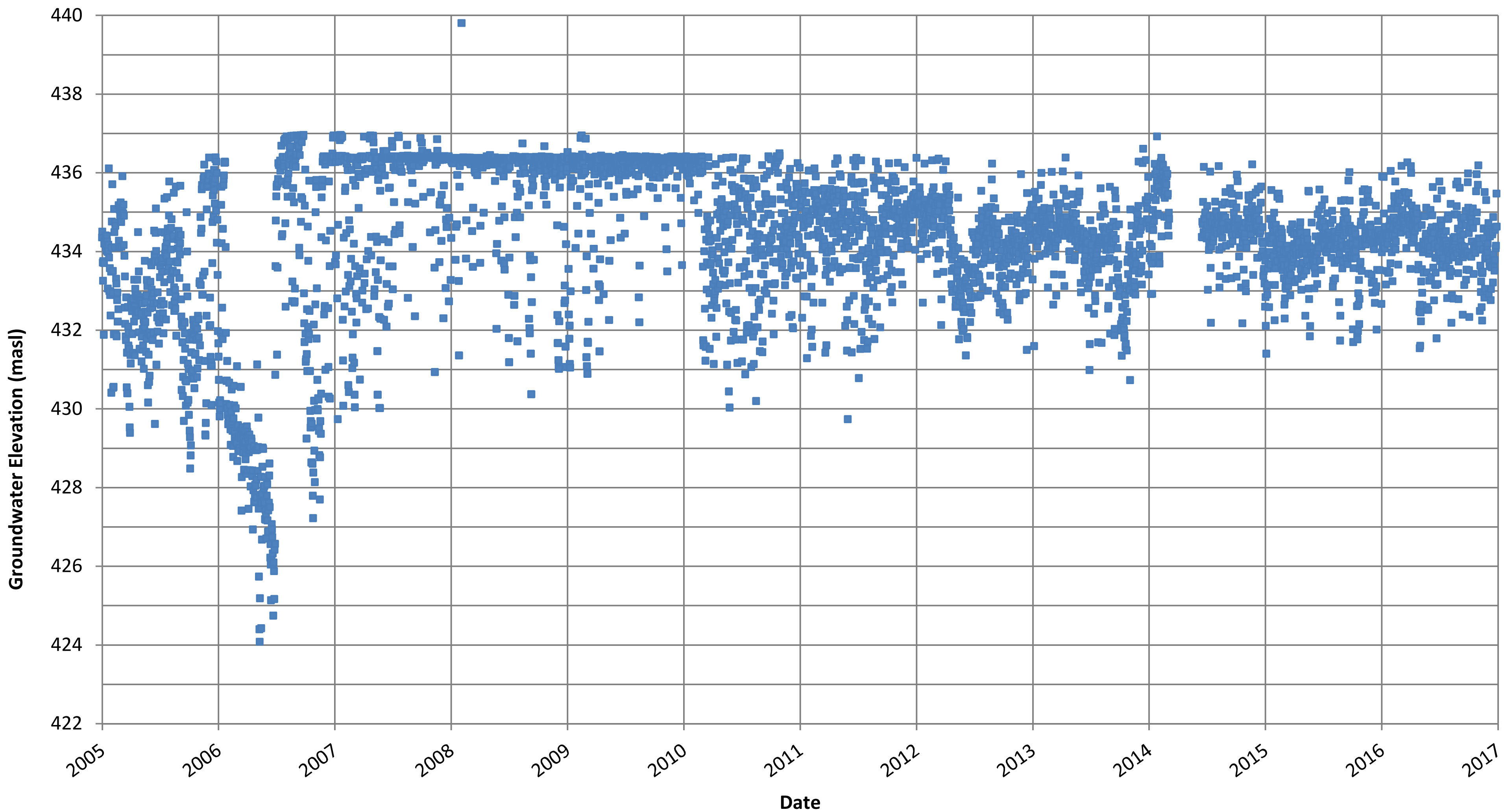
Municipal Monitoring of Well E4

Date:	Project:	Technical:	Reviewer:	Drawn:
25 Oct 2017	23876	J. Melchin	P. Meyer	J. Melchin

Figure
D15



7B - Daily Average SCADA Groundwater Elevation

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Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Arthur Municipal Well 7B Water Levels

Date:	Project:	Technical:	Reviewer:	Drawn:
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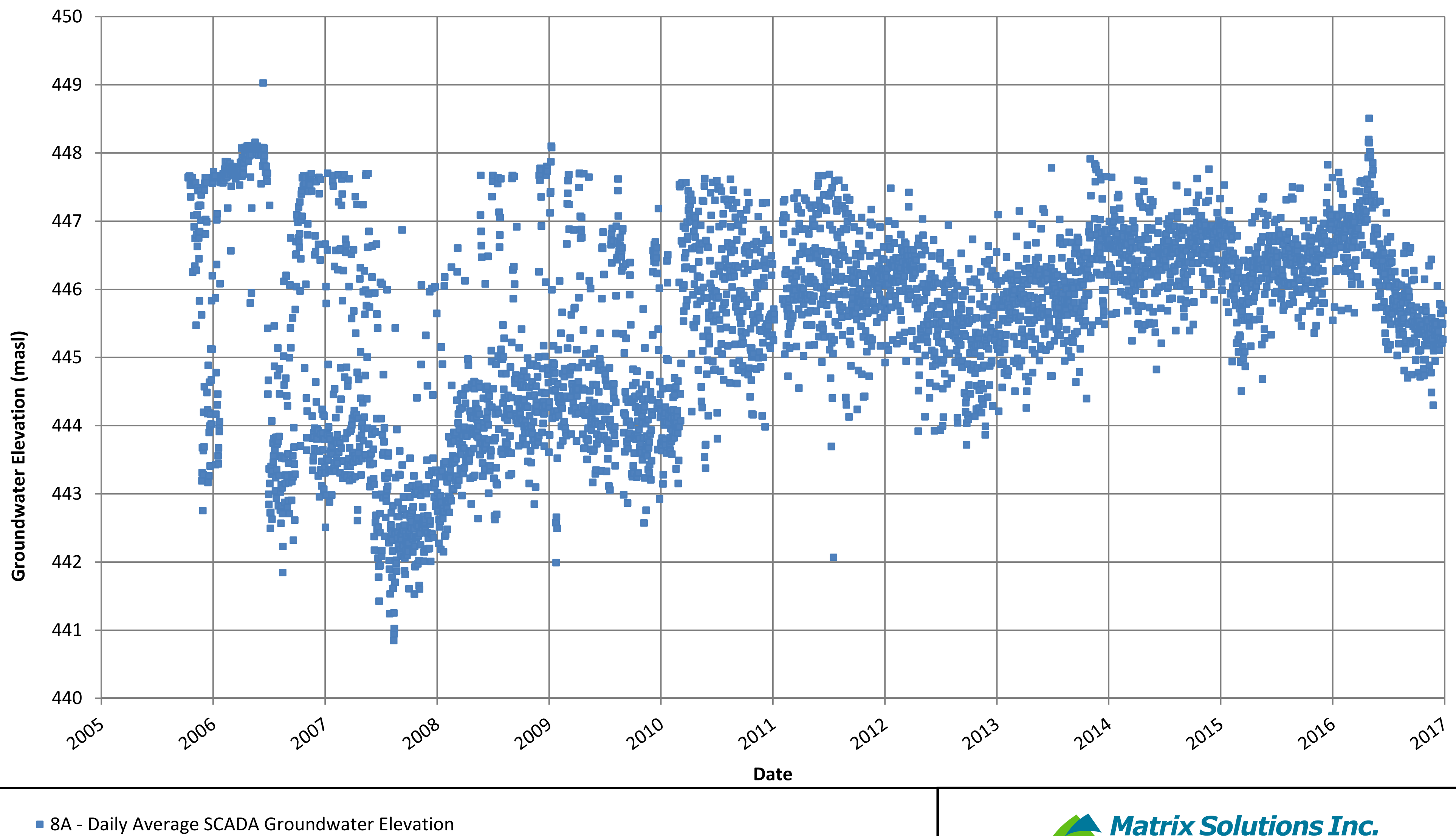
Figure
D16



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Arthur Municipal Well 8A Water Levels

Date:	Project:	Technical:	Reviewer:	Drawn:
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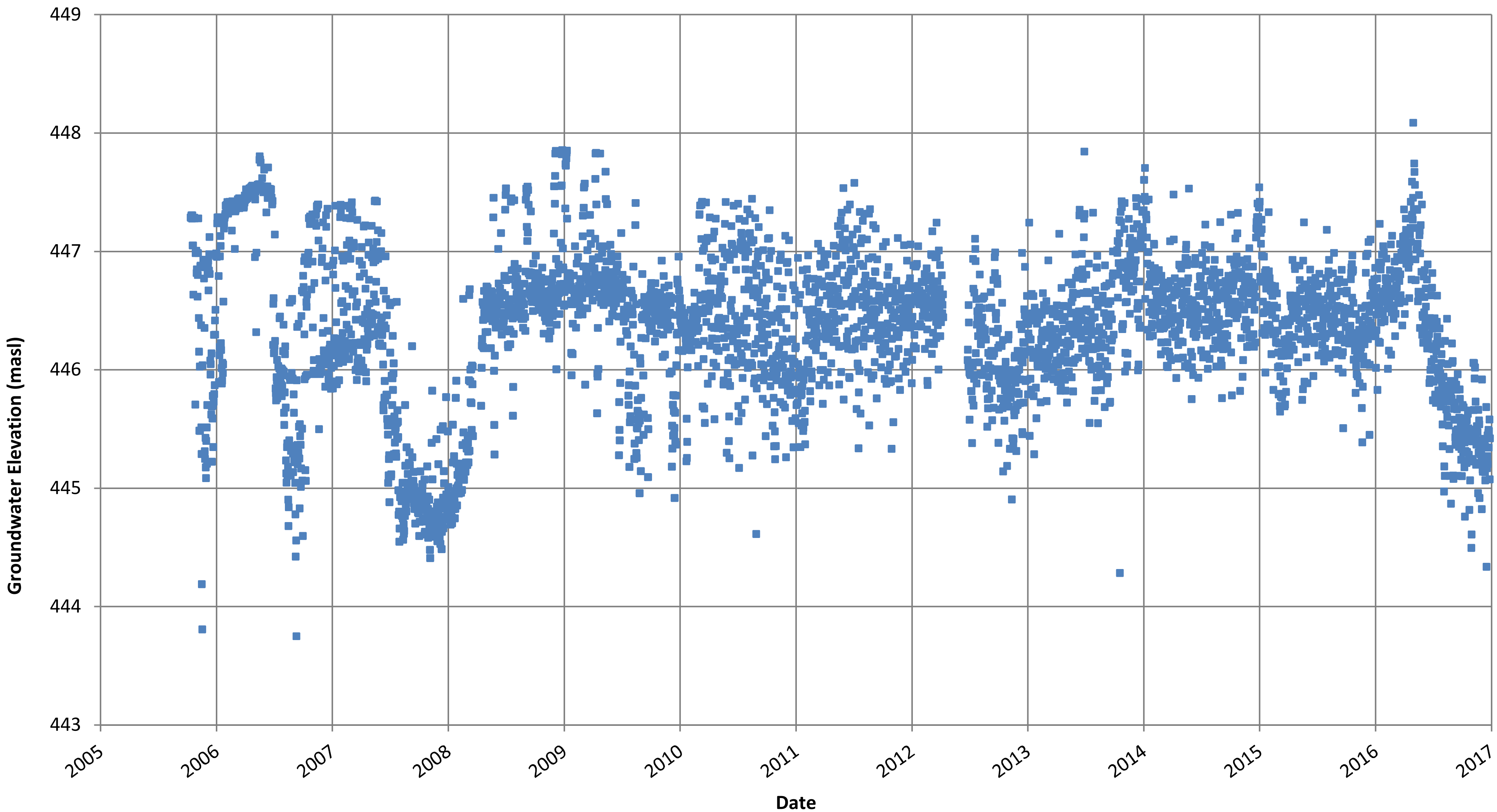
Figure
D17



■ 8B - Daily Average SCADA Groundwater Elevation

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Arthur Municipal Well 8B Water Levels

Date:	Project:	Technical:	Reviewer:	Drawn:
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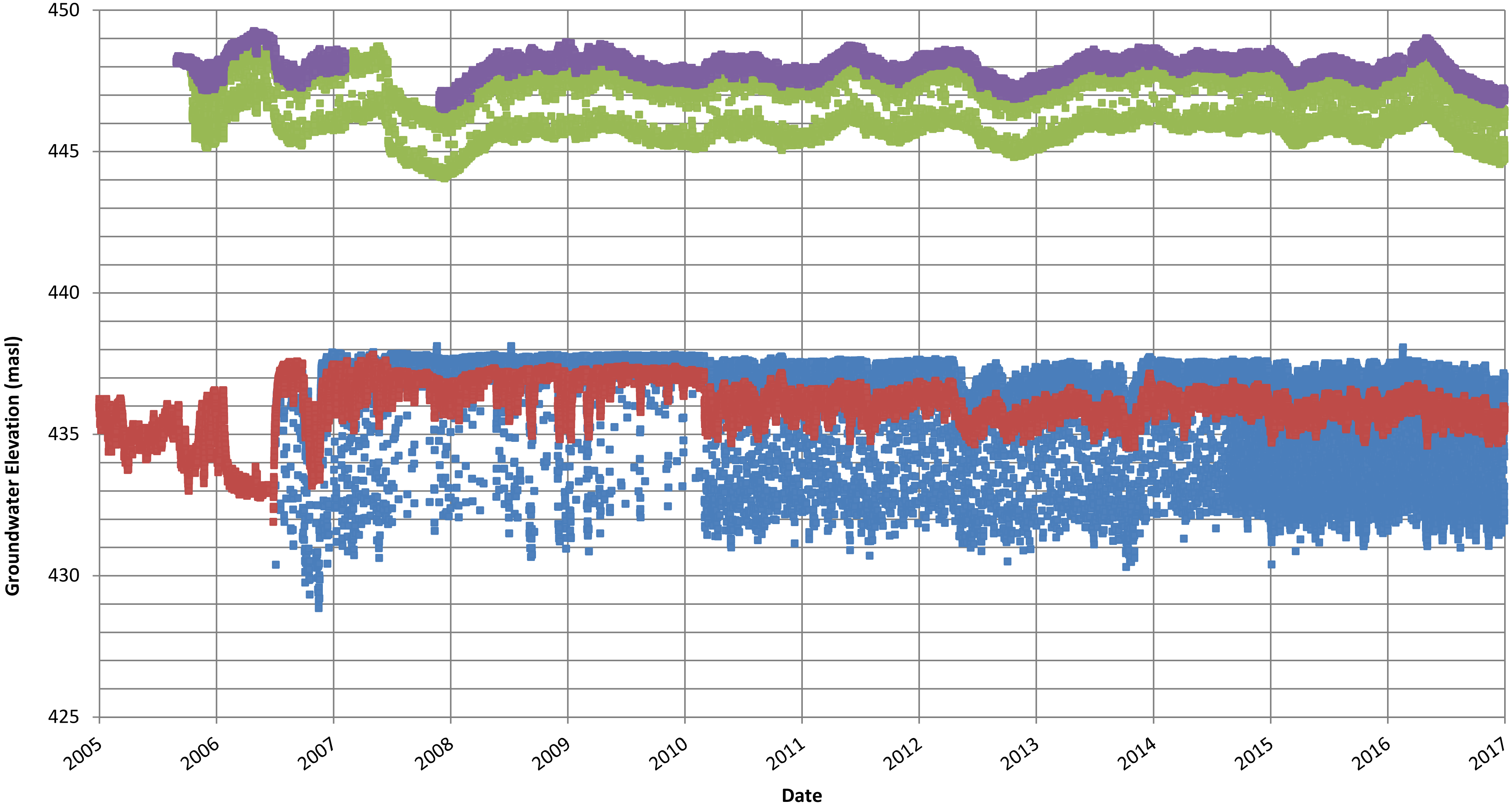
Figure
D18



TW4/02 - Transducer Groundwater Elevation
Voisin - Transducer Groundwater Elevation
O`Donnell - Transducer Groundwater Elevation
WN-MW1/00 - Transducer Groundwater Elevation

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Municipal Monitoring in Arthur

Date:	Project:	Technical:	Reviewer:	Drawn:
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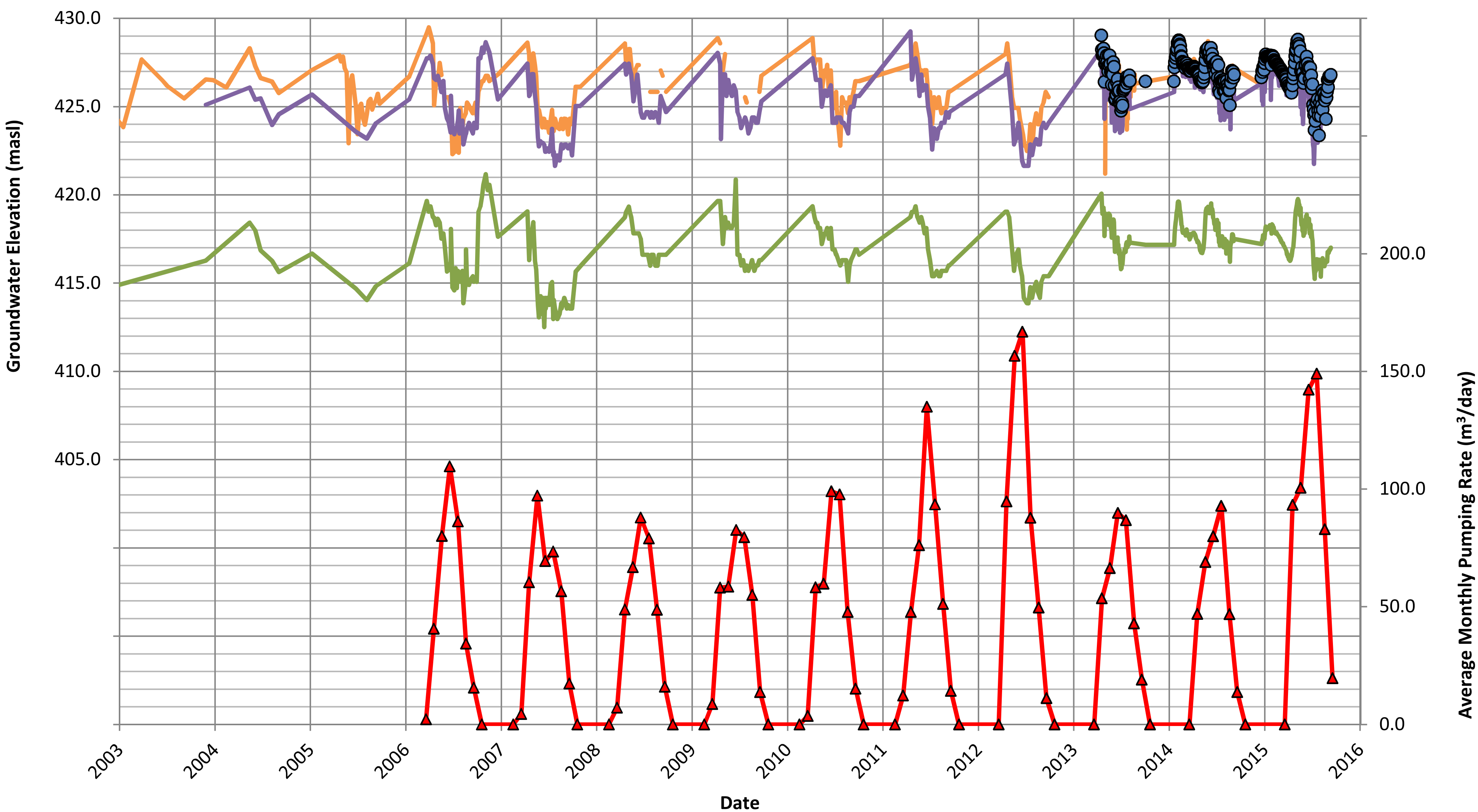
Figure
D19

APPENDIX E
Non-municipal Groundwater Level Monitoring



Deep Phase 2 Well - Groundwater Elevation

Deep Office Well - Groundwater Elevation

Deep E Section Well - Groundwater Elevation

TW-2 - Groundwater Elevation

TW1/TW2 Combined Monthly Pumping Rate

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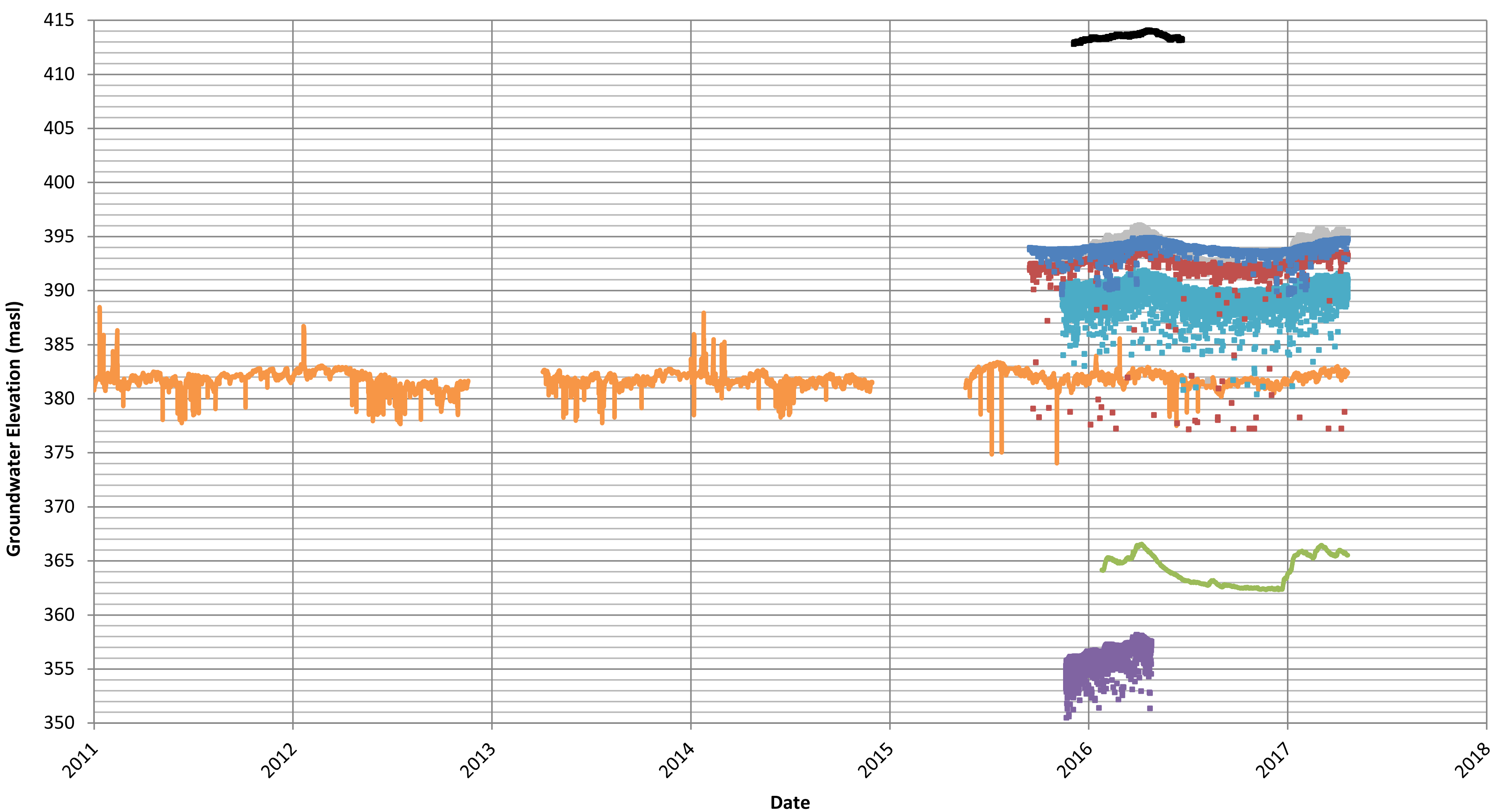
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Water Level Monitoring and Pumping at Highland Pines Campground

Date:	Project:	Technical:	Reviewer:	Drawn:
25 Oct 2017	23876	J. Melchin	P. Meyer	J. Melchin

Figure **E1**



Middlebrook Well
OW2
Private Well 1 - Wellington Rd 7
Private Well 4 - Sophia St
Private Well 2 - Wellington Rd 7
Private Well 5 Deep - Wellington Rd 18
Private Well 3 - Middlebrook Rd
Private Well 5 Shallow - Wellington Rd 18

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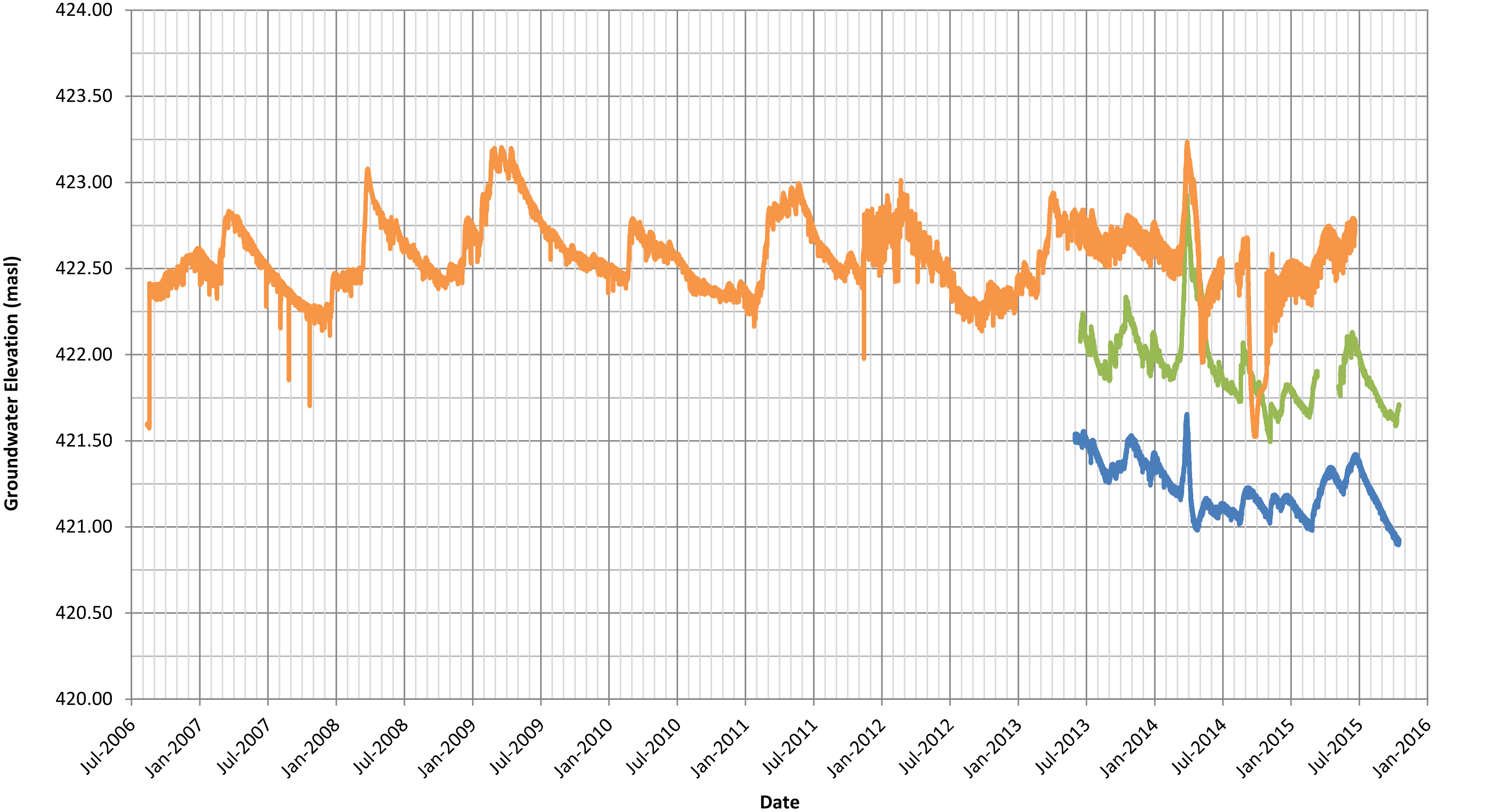
Water Level Monitoring at Middlebrook Well

Date:	Project:	Technical:	Reviewer:	Drawn:
25 Oct 2017	23876	J. Melchin	P. Meyer	J. Melchin

Figure
E2



SR18 - 961 HWY6

SR18 - 114

SR18 - 46

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Grand River Conservation Authority
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Shallow Water Level Monitoring at Side Road 18 Dewatering

Date:	Project:	Technical:	Reviewer:	Drawn:
25 Oct 2017	23876	J. Melchin	P. Meyer	J. Melchin

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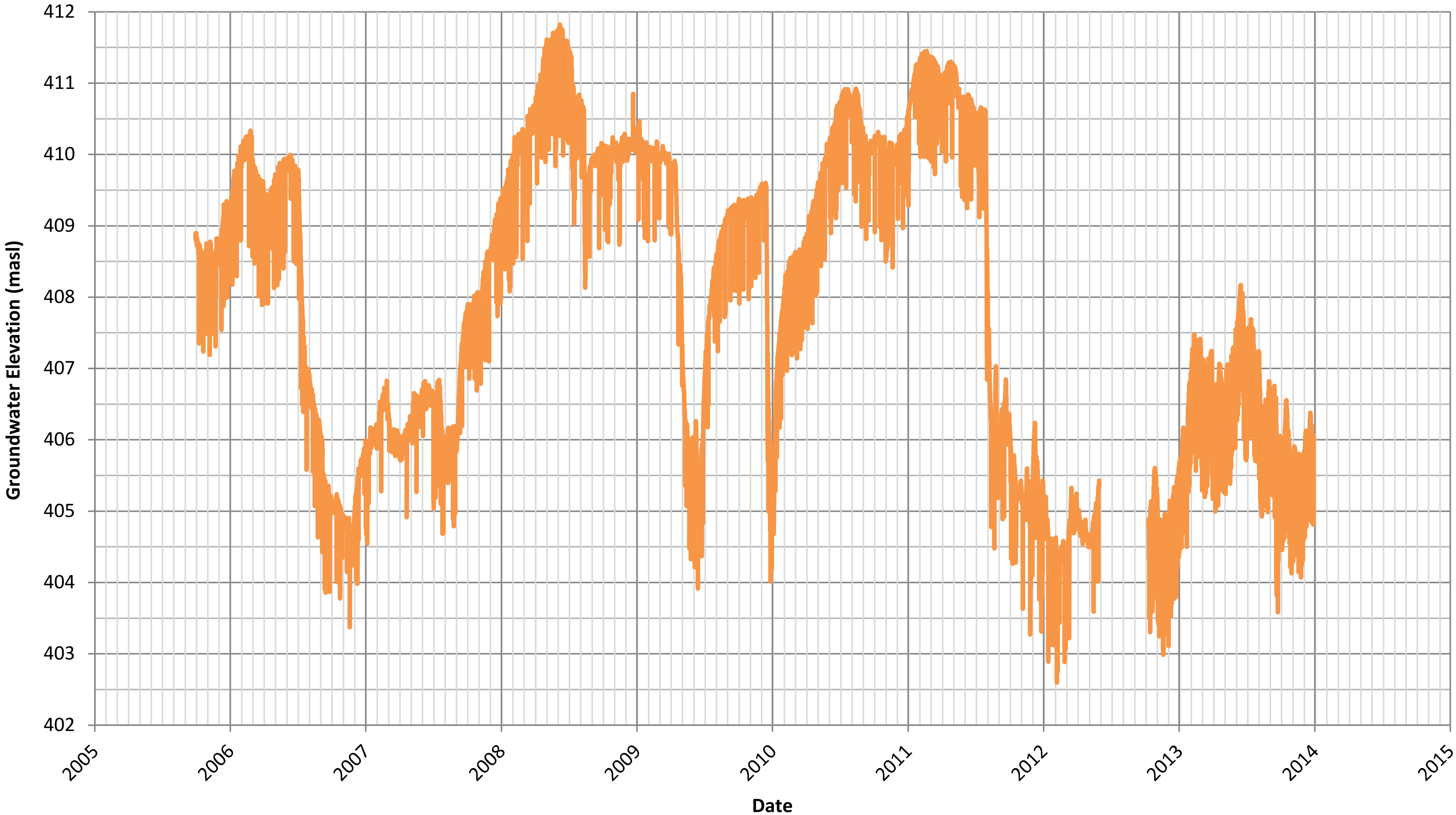
Figure
E3



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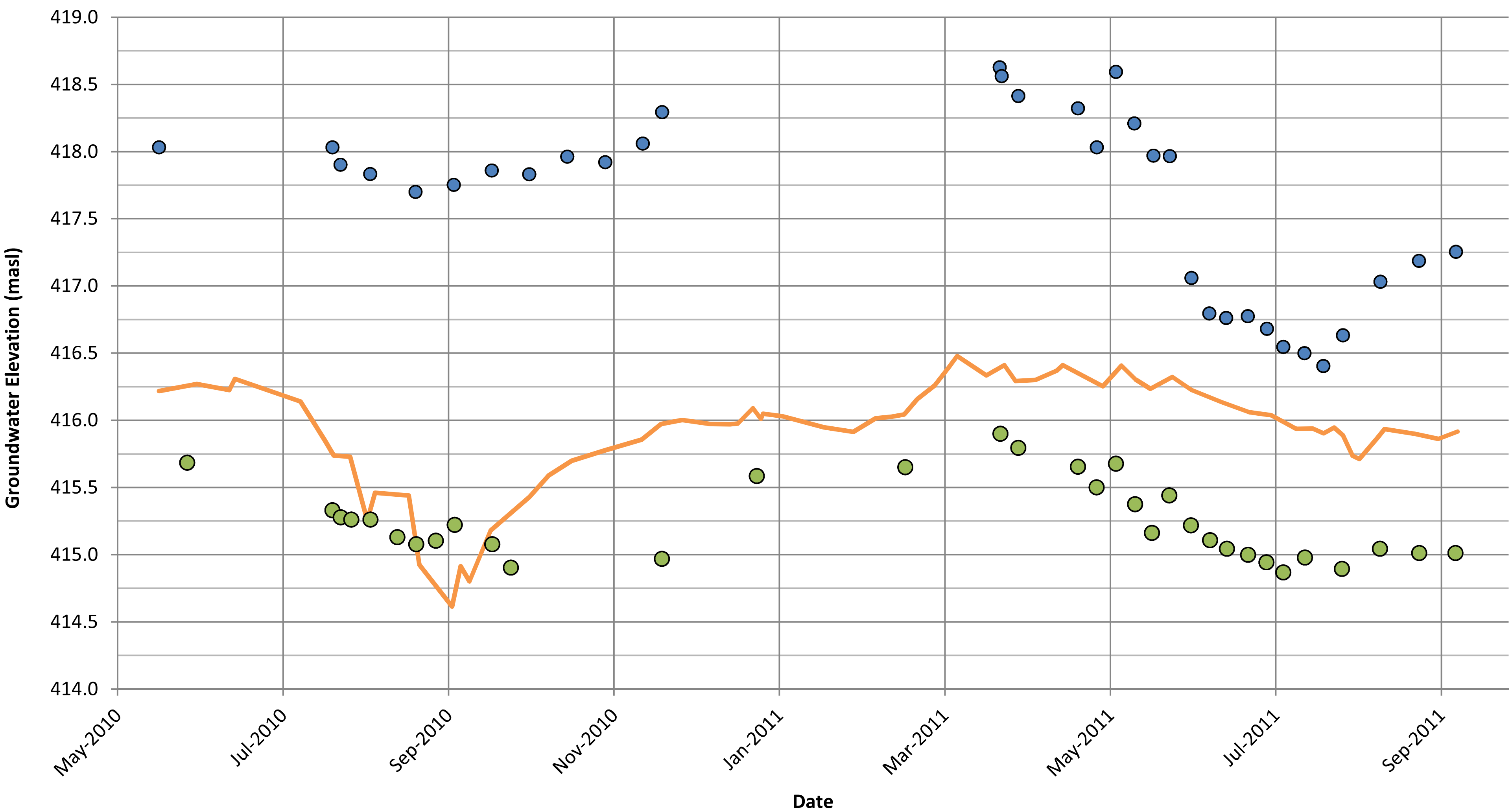
Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Deep Water Level Monitoring at Side Road 18 Dewatering

Date:	Project:	Technical:	Reviewer:	Drawn:
25 Oct 2017	23876	J. Melchin	P. Meyer	J. Melchin

Figure
E4



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Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Shallow Water Level Monitoring at Side Road 19 Dewatering

Date:	Project:	Technical:	Reviewer:	Drawn:
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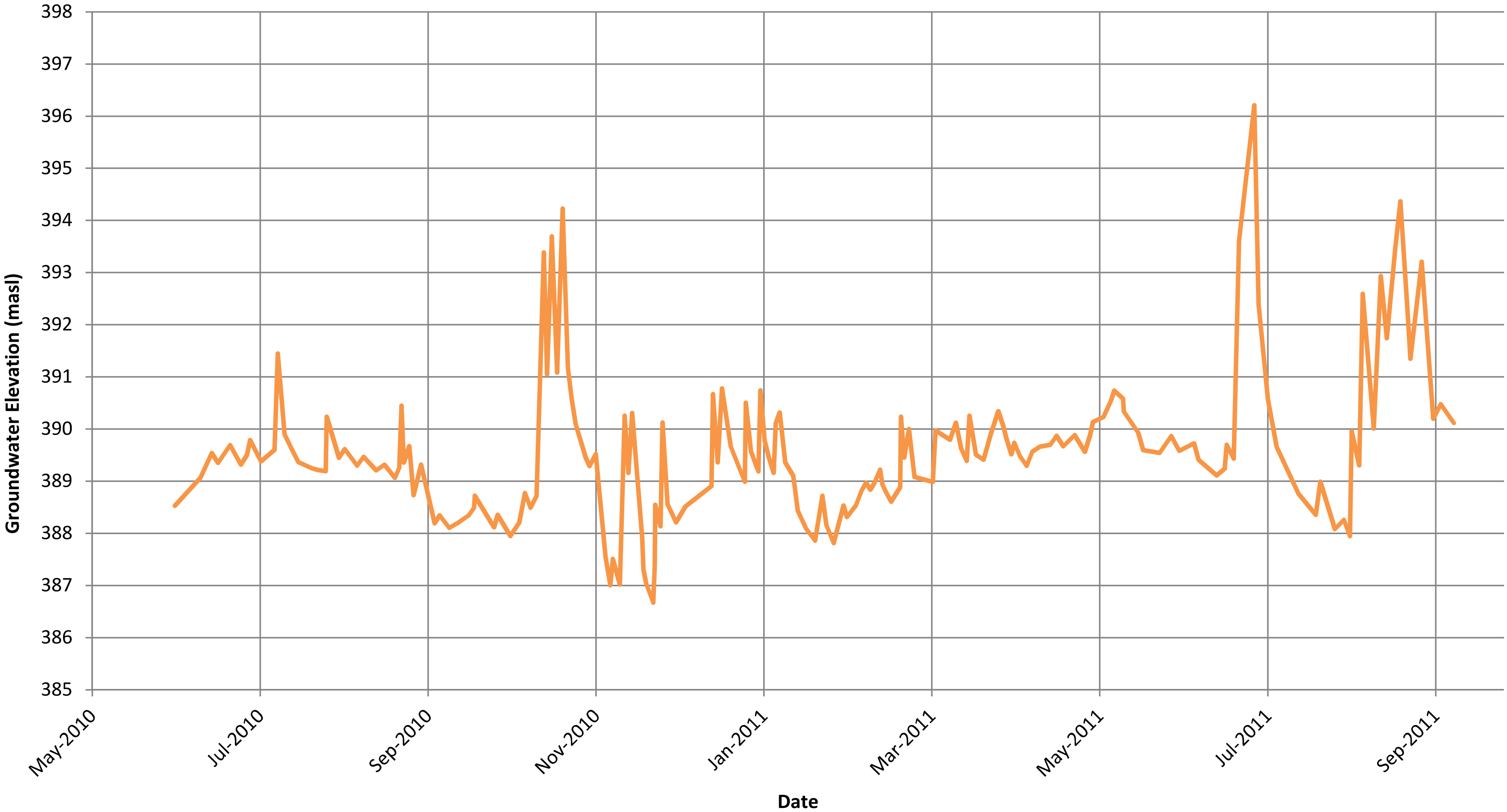
Figure E5



SR19 - MW4

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Centre Wellington Tier Three Water Budget and Local Area Risk Assessment

Deep Water Level Monitoring at Side Road 19 Dewatering

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Figure
E6