Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

CENTRE WELLINGTON TIER THREE WATER BUDGET
FINAL RISK ASSESSMENT REPORT

Prepared for:
GRAND RIVER CONSERVATION AUTHORITY

Prepared by:
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EXECUTIVE SUMMARY

This report describes the Tier Three Water Budget Assessment (Tier Three Assessment) completed for the municipal drinking water systems of the Township of Centre Wellington (Centre Wellington) in the Province of Ontario. As a requirement under the *Clean Water Act* (Bill 43; Government of Ontario 2017a), the purpose of this project was to assess the impact of changes in pumping, land use development, and drought conditions on the Centre Wellington municipal wells and then identify water quantity threats to these wells. The project also included an assessment of potential impacts to other water uses, such as coldwater streams and Provincially Significant Wetlands.

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

The Tier Two Water Budget and Subwatershed Stress Assessment completed for the Grand River Watershed (AquaResource 2009a, 2009b) identified the Irvine Creek Groundwater Assessment Area (Figure 33 from AquaResource 2009b) as having a Moderate potential for hydrologic stress when considering future water demands in a drought scenario. The Grand River Conservation Authority completed a subsequent analysis (Shifflett 2015) using an updated water taking dataset and also found a potential for stress when uncertainty was taken into account, while also considering future demands and future demands with reduced recharge. The findings suggested that the potential for hydrologic stress in the area was linked to growth in Centre Wellington. As a result, a Tier Three Assessment for the municipal (i.e., Township of Centre Wellington) water supply sources in the Irvine Creek Groundwater Assessment Area was initiated.

Two companion reports summarize the development of the conceptual hydrogeologic model (Appendix A) and the development of a numerical groundwater flow model (Appendix B) used to complete the Tier Three Assessment.

Scope of Work

The scope of work completed in this Tier Three Assessment and documented in this report was completed in accordance with the Province's *Technical Rules: Assessment Report, Clean Water Act, 2006* (*Technical Rules*; MOECC 2017) and *Technical Bulletin: Part IX Local Area Risk Level* (MOE and MNR 2010; MOE 2013).

The following tasks were completed for this study:

- Develop a conceptual model of the Study Area that includes a detailed characterization of the hydrologic and hydrogeologic systems.
- Develop and calibrate a new FEFLOW groundwater flow model that is founded on the conceptual model and with sufficient detail to simulate groundwater flow near the municipal wells and surface water features.
- Apply the FEFLOW groundwater flow model to assess the water budget components within the Study Area.
- Apply the FEFLOW groundwater flow model to complete a Risk Assessment for the Centre Wellington municipal wells.
- Identify Significant drinking water quantity threats within the delineated Vulnerable Area.

Physical Characterization

The physical setting in the Study Area is characterized by Quaternary-aged overburden sediment deposited 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 Ontario Geological Survey (OGS) in the eastern half of the Study Area (Burt and Dodge 2016). The overburden geologic characterization and interpretations from Burt and Dodge (2016) 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. This enhanced understanding of the distribution of the hydrostratigraphy on a regional and local-scale set the foundation for subsequent phases of the Tier Three Assessment. Specifically, the interpreted elevations at the tops of the hydrostratigraphic units, as well as the understanding of the geologic history of the area, formed the basis of the three-dimensional hydrostratigraphic layer structure of the groundwater flow model that was developed.

Streamflow monitoring data at three long-term stream gauges were evaluated to improve the understanding of groundwater discharge and groundwater recharge in the Study Area.

Water demand within the Study Area was assessed in detail and included review of permitted and non-permitted water takings. The characterization of the water demands included a review of data contained within the Permit To Take Water (PTTW) database, the Water Taking and Reporting System dataset, data provided by permit holders and estimated demands for non-permitted domestic and agricultural water takers. 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 non-municipal parties within the Study Area for use as water level observation targets in the development and calibration of the groundwater flow model.

Water Budget Tools

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

The groundwater flow model was developed using FEFLOW (Finite-Element Simulation System for Subsurface Flow and Transport Processes; v7.1, Diersch 2014) and calibrated by adjusting model parameters until the simulated model results agreed favorably with the following:

- observed water levels in 48 high-quality monitoring wells (i.e., water level observation targets)
- transient water level response data from a municipal well shutdown/pumping test
- static water levels from the Province's water well database
- observed baseflow at Irvine Creek

Groundwater recharge in the FEFLOW model (Tier Three model) was assigned using output from the GAWSER (Guelph All-Weather Storm-Event Runoff) streamflow generation model (Schroeter & Associates 2004). This GAWSER model was previously developed for the Grand River Watershed during the Tier Two Assessment (AquaResource 2009a) and then updated as part of the Tier Three Assessments completed for the City of Guelph and Township of Guelph/Eramosa (Matrix 2017a) and Region of Waterloo (AquaResource and SSP&A 2014).

The Tier Three model was developed and calibrated to a level where it was agreed upon by the project team and peer review committee to sufficiently represent both interpreted and observed conditions. While the degree of calibration achieved indicates the model represents observed conditions, model parameter values and boundary conditions remain uncertain. Furthermore, the conceptualization of karst hydrogeology will always remain uncertain given the sparseness of high-quality geological boreholes.

An uncertainty assessment was completed to further investigate the implications of the uncertainty of hydrogeologic parameters and boundary conditions on calibration and the water balance. The uncertainty assessment suggested that a scenario where existing groundwater recharge was lower than currently simulated had the greatest potential to further increase drawdown at municipal wells in the Risk Assessment scenarios and impact the Water Quantity Risk Level. While this assessment highlights groundwater recharge as a sensitive parameter, the estimates are derived from a calibrated watershed hydrology model that is believed to have a relatively lower range of uncertainty. The assessment also indicated that while there is uncertainty in the key model parameter hydraulic conductivity, the estimates developed during the calibration exercise are close to the best estimates possible given the available monitoring data and conceptual model.

The uncertainty assessment illustrated that while there is uncertainty in the predicted groundwater flows across the model boundary, these flows are relatively small compared to the overall water balance.

Risk Assessment

A Groundwater Vulnerable Area was delineated for the Centre Wellington municipal supply wells following the *Technical Rules*. This area was based on a combination of the cone of influence of each pumping well (WHPA-Q1), as well as land areas where reductions in recharge have the potential to have a measurable impact on the municipal wells (WHPA-Q2). The Groundwater Vulnerable Area encompasses the Centre Wellington municipal wells and many of the non-municipal takings simulated in the Study Area. This Vulnerable Area extends toward the west, encompassing non-municipal PTTWs in the west including a relatively larger aquaculture taking (PTTW 3347-84VQV5) that contributes to the extension of the area into parts of the Township of Mapleton and Township of Woolwich. The Groundwater Vulnerable Area does not extend into the vicinity of the communities of Arthur or Marsville or their municipal wells.

The Province designed the Tier Three Assessment to assess the ability of water supply wells to meet average water demand under existing and future conditions up to 2041. The Tier Three Assessment considers the influence of future land use change, seasonal and drought conditions, and potential impacts to other water uses (e.g., coldwater streams). The Tier Three Assessment is designed to assess existing permitted municipal water supply wells and non-permitted municipal water supply wells that have been tested and evaluated under the Environmental Assessment process.

The Tier Three Assessment assesses the additional capacity of water supply wells as defined under the term ‘Allocated’ water demand. The Allocated water demand is attributed to existing water supply wells or non-permitted water supply wells that been tested and evaluated under the Environmental Assessment process. For this assessment, Allocated water demand is considered as the maximum amount of water that existing wells can meet on an average annual basis. According to the draft Water Supply Master Plan (WSMP; AECOM 2019), the water supply capacity of the existing municipal wells will exceed the projected water demand sometime between 2031 and 2036.

Based on the results of the Risk Assessment modelling scenarios, Centre Wellington's water supply wells can reliably meet the Allocated water demand under average and drought conditions (i.e., a Low Risk Level) without impacting other water uses. Meeting this Allocated water demand will satisfy Centre Wellington's water supply requirement until the period 2031 to 2036, and this falls short of the Tier Three goal of having a reliable water supply until 2041. As a result, Centre Wellington's water supply source and its associated Groundwater Vulnerable Area is assigned a Water Quantity Risk Level of Significant. With this classification, all consumptive water uses and reductions of groundwater recharge within this area are considered Significant drinking water quantity threats. In total, 2,741 consumptive water uses and 4.3 km^2 of recharge reduction areas were identified as Significant threats in this Vulnerable Area.

The WSMP estimates future average day demand to 2041 which exceeds the capacity of the existing municipal wells. The WSMP presents various alternatives to meet water supply requirements beyond this period, however, these alternatives are not considered within the Tier Three Assessment until they have been thoroughly assessed as viable water supply sources.

The potential effects related to climate change have been assessed as part of a separate report (Matrix 2020).

Recommendations

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

1. Reduce uncertainty through collection of additional field data:

    a. The results of the model calibration and Risk Assessment process suggest that there remains uncertainty relating to the conceptual model along the western model boundary, western lower aquifer, and the localized influence of karst features. This results in less certainty in the model conceptualization and predictions in areas farther from the Centre Wellington municipal wells. There is an opportunity to increase certainty by filling the existing important knowledge gaps with high-quality geological data and completion of aquifer pumping tests. Recent and future publications that provide more clarity of the regional conceptual model for karst could also be used to refine the regional bedrock characterization in the future.

    b. The model's simulation of drawdown at the Middlebrook Well due to pumping from that well is also uncertain. There is an opportunity to reduce this uncertainty by similarly collecting additional local high-quality data and completing an aquifer pumping test in the area.

2. Re-evaluate Risk Assessment scenarios following the completion of The Centre Wellington WSMP (AECOM 2019): The WSMP will be recommending new areas for municipal groundwater supply exploration. The Tier Three Assessment scenarios should be repeated as new data becomes available through the results of the study to assess new sources regarding their sustainability in meeting future municipal demands.

3. Use of the Tier Three model in assessing water taking applications: If new permitted water takings are proposed within the Groundwater Vulnerable Area, the Tier Three model may be applied to determine the impact of the proposed water taking on municipal water supply reliability. In the event of such an application of the model, refinements may be needed in the area of that taking to account for new geological data and should utilize additional field data collected as part of the application. If the Tier Three model is selected for utilization in a water taking application, the necessity of these refinements may be assessed, at the time of a proposed taking, in conjunction with Centre Wellington, the Grand River Conservation Authority (GRCA), the Ministry of Environment, Conservation and Parks (MECP) and applicant.

4. Continue monitoring municipal well performance in a well-maintenance program: The Risk Assessment scenarios analyzed groundwater level decline assuming maintained well performance. The ability of the wells to sustain future pumping rates is dependent on ongoing monitoring of water levels within the municipal wells, as well as regular well maintenance. It is recommended that Centre Wellington continue to monitor water levels in the municipal wells, well performance, and to rehabilitate the wells when needed to ensure the validity of the Risk Assessment results.

5. Continue water conservation programs: Current water conservation programs should be continued to maintain or reduce water demand per capita. Additional opportunities to reduce water demand within Centre Wellington could also be considered as outlined in the WSMP. Any reduction in the per capita water use will enhance water supply reliability and local ecosystem health.

6. Improve model calibration using expanded baseflow locations: Model calibration to baseflow was limited by a single surface water gauge on Irvine Creek. Data from additional flow gauging stations should be obtained and used to better characterize the streamflow in other parts of the Study Area and the interaction between the streams and the groundwater flow system.

7. Regular updates of water budgets by the GRCA: The GRCA maintains water budget modelling tools to help manage and protect the water resources across the watershed. These modelling tools should be updated periodically as new information is gathered and insights evolve within the watersheds.

8. Consider conducting a partial or full Risk Management Measures Evaluation Process (RMMEP): As a Significant Risk Level was assigned to the Groundwater Vulnerable Area and as all consumptive water uses and areas of groundwater recharge reductions within this Vulnerable Area are classified as Significant Drinking Water Threats, a RMMEP may be initiated. A RMMEP involves using the Tier Three model to rank the relative impact of individual or groups of water quantity threats on the municipal wells and then evaluate possible measures that may be implemented to reduce the Water Quantity Risk Level in the Vulnerable Area. The RMMEP may expand on the recommended risk management measure and provide recommendations to the municipality, conservation authority and Province for maximizing the benefits of each measure. It is recommended that an RMMEP include an evaluation of the relative significance of the simulated non-municipal, non-permitted domestic and agricultural

takings on water levels in the municipal wells. This is because the boundary of the Groundwater Vulnerable Area was predicted to extend past the subset of wells simulated to represent non-municipal, non-permitted takings within a 1 km (i.e., domestic wells) and 3 km (i.e., agricultural wells) buffer of the Centre Wellington municipal wells.

9. Evaluate Land Use Change Outside of Fergus and Elora: Recharge reduction due to anticipated future land use change was evaluated for Fergus and Elora and these areas were identified as Significant water quantity threats within the WHPA-Q. While Fergus and Elora are considered key growth areas within the Study Area, additional areas of anticipated future land use change that will cause recharge reduction would also be considered Significant threats within the WHPA-Q and should be identified outside of Fergus and Elora.

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1 INTRODUCTION

This report describes the completion of a Tier Three Water Budget Assessment (Tier Three Assessment) to assess the sustainability of drinking water sources for the Township of Centre Wellington, Ontario (Centre Wellington). Centre Wellington contains the communities of Fergus and Elora and relies entirely on groundwater for its drinking water source. Centre Wellington's serviced population is projected to grow from approximately 19,000 in 2016 to more than 40,000 people in 2041 (AECOM 2019). The Tier Three Water Budget Assessment is required under the rules of the *Clean Water Act* (Bill 43; Government of Ontario 2017a) in the Province of Ontario to assess the sustainability of the municipality's water supply source in regards to meeting future population growth.

1.1 Clean Water Act Water Budget Framework

The Province of Ontario introduced the *Clean Water Act* to ensure that all residents have access to safe drinking water. Under the *Clean Water Act*, Source Protection Authorities are required to complete technical studies to identify water quality and quantity threats to municipal drinking water. The *Clean Water Act* requires that Source Protection Committees prepare an Assessment Report for their Source Protection Area in accordance with Ontario Regulation 287/07 (General Regulation; Government of Ontario 2017a) and the *Technical Rules: Assessment Report, Clean Water Act, 2006* (*Technical Rules*; MOECC 2017).

An Assessment Report must include a water budget to assess the water quantity threats through a tiered framework. Water Budgets developed under the *Clean Water Act* provide a quantitative description of the hydrologic cycle components and a conceptual understanding of the processes and pathways by which surface water and groundwater flow through a watershed or subwatershed. Key deliverables of the water budget analyses include the watershed-based flow generation models and groundwater flow models, which are available for future use and application. Tier One Water Budget and Tier Two Water Budget and Subwatershed Stress Assessments (Tier Two Assessment) within this tiered framework evaluate the subwatershed's hydrological stresses, while a 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.

1.1.1 Tier Three Water Quantity Risk Assessments

Under the requirements of the *Clean Water Act*, municipalities must complete a Tier Three Assessment when their water supply is located within a subwatershed that has been assigned a Moderate or Significant water quantity hydrologic stress level in the Tier Two Assessment. A Tier Three Assessment focuses a water budget assessment around municipal drinking water wells or surface water intakes and is completed for a Water Quantity Vulnerable Area. For groundwater wells, such as those in Centre Wellington, the Groundwater Vulnerable Area includes 1) the combination of the cone of influence of the municipal wells and other water takings whose cones of influence intersect that of the municipal wells, and 2) areas where reductions in recharge would have a measurable impact on drawdown at the municipal wells.

Calibrated Tier Three Assessment models estimate the impact of increased water demand, variations in climate, and land use development on water levels at a groundwater well or surface water intake. Where these scenarios identify the potential that a well or intake will not be able to supply their future (Allocated) rates, the Vulnerable Area is assigned a Moderate or Significant Water Quantity Risk Level. The Risk Assessment modelling scenarios consider the need to meet water demand requirements of other uses, such as the ecological flow requirements of a coldwater fish habitat.

Where a Moderate or Significant Risk Level is assigned to the Vulnerable Area, drinking water quantity threats are identified within that area. These threats include activities that remove water from an aquifer or surface water body without returning that water to the same aquifer or surface water body (i.e., consumptive water uses), or they can be activities that reduce groundwater recharge to an aquifer.

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

A Tier Three Assessment typically includes the completion of the following tasks:

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

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

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

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

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

- Characterize and identify other water uses (e.g., ecological flow requirements) that might be influenced by municipal pumping and identify water quantity constraints according to those other uses.
- Delineate Vulnerable Areas for groundwater (i.e., WHPA-Q1 and WHPA-Q2) and/or surface water (i.e., IPZ-Q) using water budget models developed for the Tier Three Assessment.
- Evaluate the Risk Assessment scenarios, using the numerical model(s) to simulate the conditions at each well and intake during average and drought conditions, and under varied municipal pumping and recharge conditions due to future land use development. The scenarios are evaluated in terms of the ability to sustain pumping at each well or intake along with the impact to other water uses.
- Assign a Risk Level (Low, Moderate, or Significant) to the Vulnerable Areas based on the results of the Risk Assessment scenarios. An uncertainty level (i.e., High and Low) will accompany each Risk Level.
- Identify drinking water quantity threats such as consumptive water uses or reductions in recharge for Vulnerable Areas where the Risk Level is Significant and Moderate.

1.2 Tier Three Assessment for the Township of Centre Wellington

AquaResource (2009a, 2009b) completed a Tier Two Assessment for the Grand River Watershed in 2009. The study identified subwatersheds and groundwater assessment areas containing municipal water supply systems having a 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 Irvine Creek Groundwater Assessment Area as having a percent water demand of 5% under current conditions (low potential for hydrologic stress) and 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 analysis predicted 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 identified a potential for hydrologic stress in this area linked to population growth within Centre Wellington. As a result, the Province initiated a Tier Three Assessment for Centre Wellington in 2016.

1.2.1 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 is southeast of the Study Area.

Land use within the Study Area is predominantly agricultural with urban areas and natural heritage features, such as wetlands and forests, scattered throughout. The largest urban areas are located within Fergus and Elora.

The Grand River is the largest watercourse in the Study Area (Figure 1). It enters the Study Area in the northeast and flows southwest into Centre Wellington where it enters the Belwood Reservoir. The Grand River flows on bedrock from the Belwood Reservoir, through the centre of Fergus and Elora where it enters the Elora Gorge. As the Grand River continues southward, it transitions to flowing on modern alluvium deposits and exits the Study Area north of West Montrose, within the Region of Waterloo. The main tributaries to the Grand River within the Study Area include Irvine Creek, Carroll Creek, Swan Creek, Cox Creek, and Canagagigue Creek. Other 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 (e.g., Lutteral and Marden creeks) to the east and southeast.

Centre Wellington relies completely on groundwater to meet its municipal water demand. Three municipal water supply wells are located in Elora (Wells E1, E3, and E4), and six municipal wells are located in Fergus (Wells F1, F2, F4, F5, F6, and F7). Each of the water supply wells are completed in bedrock and were constructed between 1935 and 2002. The separate Fergus and Elora water distribution systems were combined into a single combined distribution system in October 2005. This system provides drinking water to approximately 19,330 residents in Fergus and Elora (MOECC 2016).

1.3 Project Objectives, Scope, and Report Outline

The objective of this Tier Three Assessment is to evaluate the sustainability of the municipal water supply sources in Centre Wellington, and to identify potential water quantity threats to these water sources. The assessment evaluates the impact of increased municipal water demand, changes in land use development and drought conditions using quantitative water budget tools. The assessment evaluates impacts to the source by reviewing the simulated changes in water levels in the municipal wells, and reductions in groundwater discharge to coldwater streams and Provincially Significant Wetlands. The conclusions gained through this evaluation will help Centre Wellington plan and manage a reliable water supply for current and future populations.

This Tier Three Assessment was initiated in 2016 as a 'scoped' study, because at that time long-term municipal demand projections were not available. As a result, only Risk Assessment scenarios that evaluated the impact of Existing municipal demands could be evaluated. In 2018, Centre Wellington initiated a Water Supply Master Plan (WSMP) that is now substantially complete (AECOM 2019). Future municipal water demand projections were developed as part of the WSMP that are now available to assess within the Risk Assessment scenarios. As a result, this Tier Three Assessment is no longer considered a scoped study.

Separate Physical Characterization and Groundwater Flow Model Development and Calibration Reports were completed during earlier phases of the project and are included as Appendix A and Appendix B to this report, respectively. The Physical Characterization Report provides a review of available data; a characterization of the physical setting in the regional and local well field areas; an estimation of the consumptive groundwater demands in the area; the development of conceptual hydrostratigraphic layers that represent the regional and local three-dimensional hydrostratigraphy; and an analysis of available groundwater monitoring data across the Study Area. The Groundwater Flow Model Development and Calibration Report summarizes model input parameters and boundary conditions; discusses the calibration approach, observation datasets, and calibration results; discusses the water budget completed for the Study Area; summarizes data gaps identified within the Study Area; and describes insights gained from and limitations of the groundwater model.

The scope of work completed in this Tier Three Assessment and documented in this report was completed in accordance with the *Technical Rules*. The following report outline summarizes the tasks completed for this study and the report sections describing these tasks:

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

- Section 2: Physical Characterization - summarizes the physical characterization of the Study Area, including physical setting, hydrogeologic setting, groundwater flow, groundwater testing and monitoring, and recent studies.

- Section 3: Tier Three Groundwater Flow Model - summarizes the development and calibration of the numerical groundwater flow model (Tier Three model), an assessment of model uncertainty, and updates to the Tier Three model made since the model Calibration Report.

- Section 4: Water Quantity Vulnerable Area and Risk Assessment Approach - outlines the method of delineating vulnerable areas and summarizes the groundwater Risk Assessment scenarios for the Centre Wellington municipal wells.

- Section 5: Risk Assessment Data Requirements - summarizes available land use data, anticipated land use change and consumptive water uses and demand within the Study Area.

- Section 6: Risk Assessment Thresholds - summarizes the drawdown and ecological thresholds.
- Section 7: Vulnerable Area Delineation and Risk Assessment Results - summarizes the delineation of vulnerable areas and the Risk Assessment Scenario results using the Tier Three model; summarizes how the water budget components may change under each scenario; assigns a Risk Level to the Vulnerable Area; and presents an assessment of model uncertainty and uncertainty of this Risk Level.
- Section 8: Water Quantity Threats - identifies water quantity threats identified in this study.
- Section 9: Summary and Conclusions - summarizes the key components of the study; outlines the study conclusions and provides recommendations for future work.
- Section 10: References - lists resources used to provide information in this document.
- Appendix A: Physical Characterization Report - provides a detailed description of the conceptual model and physical setting of the Study Area.
- Appendix B: Groundwater Flow Model Development and Calibration Report - summarizes the development and calibration of the water budget model used to carry out the Risk Assessment, including a summary of the water budget components.
- Appendix C: Selection of WHPA-Q1 Drawdown Contour - summarizes the methodology used to select a WHPA-Q1 drawdown contour.
- Appendix D: Drought Risk Assessment Scenario Results - provides hydrographs for each Centre Wellington municipal well for each of the drought Risk Assessment scenarios.

1.4 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 MECP. Consultation and/or recommendations were provided by Frank Brunton, Elizabeth Priebe and Abigail Burt of the Ontario Geological Survey (OGS). Appendix F contains a summary of the report comments received by these parties, along with responses to those comments.

This report and the supporting documents (Appendix A and Appendix B) were 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). Appendix E contains a summary of the report comments received by these individuals, along with responses to those comments.

1.5 Stakeholders and Other Review

The interim results of the Tier Three project were presented to a Community Liaison Group (CLG) at key milestones of the project (i.e., physical characterization and model development). The CLG provided a forum for the community and diverse range of stakeholders to be informed on the project, the project progress and provide feedback and advice on the study's technical components. The CLG was comprised of ten individuals representing the public, industry, and different interest groups. Appendix G contains a summary of the comments received by these parties, along with responses to those comments.

Additional review and comments throughout the project were provided by R.J. Burnside & Associates Ltd. (Burnside) on behalf of the Township of Mapleton, Township of East Garafraxa with respect to the Marsville municipal water supply system and Township of Wellington North with respect to the Arthur municipal water supply system. Appendix F contains a summary of the comments received by Burnside, along with responses to those comments.

2 PHYSICAL CHARACTERIZATION

The Physical Characterization Report (Appendix A) was developed from the review of reports and datasets previously prepared in Centre Wellington and the surrounding area. This section summarizes the physical setting, hydrogeologic setting, groundwater flow, groundwater testing and monitoring and a summary of learnings from recent studies completed in southern Ontario since the Characterization Report (Appendix A) was completed.

2.1 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. The Elora Gorge contains steep vertical cliff faces where the Grand River eroded through the overburden and bedrock in the Elora area. The Grand River flows 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. Coldwater fish species such as brook trout and brown trout rely on groundwater discharge, which is the discharge of groundwater into rivers and streams. The temperature of groundwater remains fairly constant (approximately 13°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 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 deposited 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). This conceptualization adopted the overburden model layering completed by the OGS (Burt and Dodge 2016).

Overburden thickness in the Study Area ranges from 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 and the bedrock model layering was derived with the support of the OGS (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 sand, silt or clay soils.

2.2 Hydrogeologic Setting and Groundwater Flow

The overburden and bedrock within the Study Area were subdivided into hydrostratigraphic layers, each having unique geological and hydrogeological conditions. These layers sometimes behave as aquifers or aquitards depending on the location within the Study Area. Aquifers are layers of permeable rock, sand or gravel from which groundwater can be extracted. Aquitards, in contrast are layers of relatively impermeable rock or soil that restrict the flow of water from one area to another. Four main overburden aquifers are characterized within the Study Area, including the Grand River Outwash Aquifer; Orangeville, Elmira, and Upper Waterloo Moraine Sands and Equivalents Aquifer; the Pre-Catfish Creek Outwash Aquifer; and the Pre-Canning Aquifer. Four bedrock aquifers are characterized including: upper fractured bedrock; and parts of the Guelph, Goat Island, and Gasport Formations. 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 in the Guelph, Goat Island, and Gasport formations flows 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 in Centre Wellington in response to municipal pumping.

2.3 Groundwater Testing and Monitoring

The municipal wells in Fergus and Elora have been assessed through several water supply studies and pumping tests over the years. In general, the wells have transmissivities that are consistent with typical dolostone aquifers of this area ranging from 52 to 395 m^2/day in Fergus, and 38 to 158 m^2/day in Elora. Table 12 of Appendix A provides a summary of different transmissivity, hydraulic conductivity, and storativity estimates derived from hydraulic testing of different wells documented in different studies in the Study Area. These data guided the parameterization of the different hydrostratigraphic layers represented in the Tier Three model. Table 6 of Appendix B summarizes the ranges of field and calibrated hydraulic conductivity values applied to different hydrostratigraphic units represented in the Tier Three model.

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. Water quality in the Fergus wells is also good, with treatment in place at one well for trichloroethylene (TCE), and at another well for 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 monitors 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 higher seasonal groundwater recharge rates. Water levels are also monitored by non-municipal parties such as the GRCA, Highland Pines Campground, and Nestlé Waters Canada, who all contributed monitoring data to this project.

2.4 Recent Studies

The physical characterization phase of the Tier Three Assessment took place in 2016 and 2017. Since that time, several papers have been released by the OGS and others related to karstic groundwater systems (Banks and Brunton 2017; Hamilton et al. 2017; Priebe et al. 2019) in southern Ontario. The OGS made these papers available to the project team to capture the latest work that may be applicable to the current Study Area. Although the conceptual and numerical models do not reflect advancements published in these papers, the more recent research should be considered when making future updates to the models. The following sections summarize these papers.

2.4.1 Municipal Bedrock Groundwater Supply for the Town of Shelburne (Banks and Brunton 2017)

The Town of Shelburne, located approximately 22 km northeast of the Tier Three Assessment Study Area, undertook a groundwater exploration study in 2009. The purpose of the study was to help locate additional water supplies to accommodate the water quantity needs of its rapidly growing population and to address naturally occurring Arsenic concentrations in existing groundwater wells completed in the overburden/bedrock contact zone aquifer. The project team leveraged recent work completed by the OGS that suggested that deeper bedrock karstic flow zones may occur at the contacts of bedrock units, Formations and Members where there is a contrast in lithology and represent a break in time.

The ultimate goal was to locate adequate water quantity and quality to meet the future needs of the population. The OGS drilled and tested two new deeper bedrock wells in the vicinity of the Town and discovered groundwater karstic flow zones in the Goat Island Formation and Gasport Formation. Testing of a municipal test well revealed adequate water quality and a capacity that more than doubled the expectations of the Town. As a result, a new water supply system was commissioned in 2016 to meet the water supply needs of the Town.

2.4.2 Mapping of Karstic Groundwater Systems (Hamilton et al. 2017)

The OGS used dissolved CO_2 and O_2 in groundwater to map buried, surface-connected karstic groundwater systems in southern Ontario to expand upon current karst mapping that has been conducted where those features are located close to ground surface. Trends in the groundwater chemistry datasets suggest that concentrations of CO_2 and O_2 are higher near the source of recharge, and where overburden is thin in carbonate bedrock environments near known surface karst. The OGS developed a CO_2-O_2 factor and delineated zones of ‘karst-inferred rapid recharge’ and ‘non-karst rapid recharge’ where the CO_2-O_2 factor was relatively high. Non-karst rapid recharge was mapped where Precambrian rocks and sandstones were mapped; karst-inferred rapid recharge was mapped in areas where carbonate-dominated rock units and evaporitic units exist. The mapping showed a good correlation between known surface karst and inferred, relatively deeper buried karst; however, the mapping also showed that the karst-inferred areas are much larger than the mapped surface karst. The study concluded that surface-connected subsurface karst was more extensive than previously thought.

While the majority of the mapped known surface karst and inferred karst areas appear to lie in a band along the Niagara Escarpment and a band extending from Lake Simcoe to east of Kingston, much smaller isolated and discontinuous areas appear to be mapped within the current Tier Three Assessment Study Area. Additional details regarding the vertical elevation of these features and their continuity were not available in this paper.

2.4.3 Geologic Controls on Hydraulic Conductivity (Priebe et al. 2019)

The OGS and others completed a study that investigated how different geologic controls (i.e., proximity to bedrock valleys, rock texture, and sequence stratigraphic breaks) might affect the hydraulic conductivity in a karst-influenced bedrock groundwater system. The area studied focused on the City of Guelph but extended to the northwest, into the current Tier Three Assessment Study Area, including Elora and Fergus; the authors assembled a dataset of hydraulic conductivity estimates from wells located in this area. The results indicated that: 1) there is a lack of evidence to support a correlation between hydraulic conductivity and proximity to bedrock valleys; 2) rock texture influences hydraulic conductivity but it may not be the most significant factor (e.g., fractures and karst may also be influencing hydraulic conductivity trends); and 3) higher hydraulic conductivity values were observed where there were karstic sequence stratigraphic breaks in the Gasport Formation.

The study results also indicated that there may be a combination of geological controls that together may be influencing the hydraulic conductivity trends of different areas. For example, relatively higher hydraulic conductivity values coincided with areas where the Gasport Formation was sub-cropping/outcropping; therefore, carbonate dissolution may have been enhanced in these areas due to a greater amount of vertical recharge. While a higher hydraulic conductivity was not found to be explicitly correlated with the proximity to buried valleys, deep bedrock valleys and frequent jointing and fracturing found in areas with relatively higher hydraulic conductivity were interpreted to provide conduits for enhanced dissolution.

The OGS conceptual model for groundwater flow in the Guelph, Eramosa, Goat Island and Gasport bedrock formations includes flow within discrete, horizontal features representing temporal breaks in the stratigraphy either within formations or at/within formation contacts; these breaks may provide a place for enhanced dissolution (karst) to occur. The OGS describes the Gasport Formation in the southeast part of Guelph as containing two kinds of reef cycles with a cap of karst and shelly reefs. In the northwest part of the City and toward Elora and Fergus, the shelly reefs and karst development are not observed in the Gasport Formation and therefore a relatively lower hydraulic conductivity was observed in that area. These results corroborate observations by water management staff at the City of Guelph who acknowledge that exploration for groundwater resources have been challenging as groundwater flow features have not been consistently found.

3 TIER THREE GROUNDWATER FLOW MODEL

3.1 Model Summary

The Tier Three model was developed using the FEFLOW (Finite-Element Simulation System for Subsurface Flow and Transport Processes) software code (v7.1; Diersch 2014) and was based on the conceptual hydrostratigraphic framework outlined in the Physical Characterization Report (Appendix A). The outer model boundaries were extended laterally to surface water features or natural flow divides, where possible. The model includes 21 computational layers representing 16 physical hydrostratigraphic units.

Boundary conditions were included to allow water to enter or leave the model. Boundary conditions were included along the perimeter to allow water to enter the model in the bedrock aquifers in the north and to leave the model through the overburden and bedrock aquifers in the south. Boundary conditions were also applied to represent groundwater that discharges into surface water features such as the Grand River, Irvine Creek, or Swan Creek. The average groundwater recharge rate was applied as a boundary condition to the top layer of the Tier Three (FEFLOW) model. The recharge rate is estimated based on the Guelph All Weather Storm Event Runoff (GAWSER) watershed-based flow generation model (Schroeter & Associates 2004), representing a simulated climate period from 1961 to 2005. The GAWSER model was previously developed and calibrated for the Grand River Watershed as part of the Tier Two Subwatershed Stress Assessment (AquaResource 2009a) and subsequently updated (AquaResource 2009c) as part of the Tier Three Risk Assessments completed for the City of Guelph and Township of Guelph/Eramosa (Matrix 2017b) and Region of Waterloo (AquaResource and SSP&A 2014).

The GAWSER model calibration was not updated in this current study as the only streamflow gauge located outside the Grand River within the Study Area is the Irvine Creek in Salem gauge, and only minor changes in land cover within the Irvine Creek subwatershed area have taken place since the completion of the Tier Two Assessment. The GAWSER model was calibrated to baseflow, or low-flow conditions, so the estimated overall average recharge rate across the model are considered reliable estimates for use in the groundwater flow model. Recharge rates estimated with the GAWSER model are associated with Hydrologic Response Unit polygons across the watershed. Hydrologic Response Units are based on soil type and climate zone within the watershed. Recharge was mapped to the elements in the FEFLOW model, ranging in size from approximately 20 m to 200 m, using area-weighted averaging. There were minor adjustments made in the FEFLOW model to the GAWSER-derived recharge rates to account for uncertainty of recharge rates in low permeability soils. For example, the groundwater recharge rates applied to portions of the Tavistock Till in northwestern portions of the Study Area was increased from approximately 20 to 50 mm/y to improve the baseflow calibration in Irvine Creek.

Hydrogeologic properties (e.g., hydraulic conductivity and specific storage) were initially assigned to zones within the model layers based on the results of hydraulic tests (e.g., pumping tests) where available, and literature values in other areas; these values were iteratively updated within the ranges of expected values based on lithologic and geologic knowledge during the model calibration process.

The Tier Three model was calibrated to equilibrium conditions (steady-state), as well as a six-week coordinated pumping and shut down test involving all the Fergus and Elora wells conducted in 2012. Calibration data included baseflow measurements from the Irvine Creek near Salem gauge and observed groundwater levels (average and time-varying response to pumping) from water wells across the Study Area; as such it has been calibrated to both water level and groundwater flow observations to help reduce the non-uniqueness of the calibration. Groundwater observation data was derived from wells contained in the water well information system (considered lower quality data), and 48 monitoring wells managed by Centre Wellington and others in the Study Area (considered higher quality data).

The ability of the model to represent observed hydrogeological conditions confirms that the hydrogeologic interpretation is reasonable and consistent with the available data. Observations providing confidence in the current interpretation include:

- Simulated groundwater levels are generally consistent with measured values. This is evident through matching of observed horizontal gradients (e.g., contour maps) and vertical gradients (e.g., at observation well pairs or multi-level installations).
- Model parameter values, such as hydraulic conductivity, are consistent with the conceptual hydrostratigraphic units (i.e., aquifers and aquitards have parameter values that are consistent with that conceptualization).

- Groundwater recharge rates are consistent with understanding of the shallow water balance (i.e., partitioning of precipitation to evapotranspiration, overland runoff, shallow interflow, and deep groundwater recharge).

- Groundwater discharge rates to surface water bodies are consistent with observed discharge rates. Cumulative discharge over a larger area (e.g., entirety of the Irvine Creek subwatershed) provides more-reliable evidence of recharge-discharge conditions over a larger area.

- The model's ability to achieve an exceptional match to observed transient water levels observed during the 6-week pumping and shutdown testing increases confidence in the conceptual model and parameterization.

The above calibration evidence supports the applicability of the numerical model to assess the sustainability of the municipal aquifer system. A full description of the Tier Three model structure, input parameters and boundary conditions, and calibration is provided in the Groundwater Flow Model Development and Calibration Report (Appendix B). A discussion of groundwater model limitations, as well as a description of what types of applications the model is suitable for evaluating in the Study Area is provided in Section 3.4.

3.2 Model Uncertainty Assessment

The Tier Three model was developed and calibrated to a level that was agreed upon by the project team and peer review committee where the model sufficiently represents both interpreted and observed conditions. The level of calibration reflects that the model is a good representation of observed conditions. Models are merely numerical approximations of actual conditions, and as with all models, there remains uncertainty relating to the model parameter values (e.g., hydraulic conductivity) and boundary conditions (e.g., recharge and model perimeter boundary conditions).

The purpose of this section is to describe a series of scenarios designed to assess the range of uncertainty of the model parameters, boundary conditions, and conceptual model, and to evaluate the significance of that uncertainty on potential model results. The specific areas of model uncertainty evaluated include:

- Hydraulic Conductivity and Groundwater Recharge. The first evaluation utilizes a parameter optimization algorithm called Parameter Estimation (PEST; Doherty 2018) to estimate the extent to which hydraulic conductivity and groundwater recharge may be varied while maintaining an acceptably calibrated model.

- Model Boundary Conditions and Water Balance. The second evaluation adjusts the values of model boundary conditions around the perimeter of the model within a reasonable range and estimates the extent to which these adjustments affect the water balance estimated using the model.

3.2.1 Hydraulic Conductivity and Recharge Uncertainty Assessment

There is an infinite combination of hydraulic conductivity and recharge values that may result in an acceptably calibrated groundwater flow model. Uncertainty in the understanding of groundwater flow systems arises from incomplete hydrogeological knowledge, imperfect measurements (e.g., water levels/flows, slug tests, etc.) and the simplification of the real-world system. These sources of uncertainty are embedded in how the model is assigned parameters or boundary conditions (e.g., hydraulic conductivity or recharge) and result in multiple combinations of parameters and boundary conditions that can reproduce field observations. The level of uncertainty depends on the complexity of the site; and the type, location, and number of observations. Uncertainty in model inputs translates to uncertainty in model outputs (i.e., predictions). An uncertainty analysis provides insight into the range of predictions that are compatible with the conceptual model and available data and provides a means of quantifying and communicating the level of confidence in a prediction.

In the context of a simple conceptual model, numeric uncertainty can be analyzed by making small adjustments to parameter and boundary condition values and evaluating the fit to the observed data. Exploring these minor changes provides insight into parameter/boundary condition-specific numeric uncertainty. However, to examine the uncertainty in the overall flow system, alternative conceptual models with various parameter or boundary condition value combinations provide even more insight into the uncertainty associated with the overall groundwater flow system, and the potential impact on model predictions. In this assessment, a series of alternative conceptual models (herein termed "scenarios") were created using the software program PEST (Doherty 2015). Some alternatives are considered statistically calibrated to a level that is as good, or slightly better, than the original 2018 calibrated model presented in the Appendix B.

Three scenarios, described below, were developed to evaluate the uncertainty of select areas of hydraulic conductivity and groundwater recharge. The first two sets of scenarios were designed to test the range in potential hydraulic conductivities of the Upper Guelph Formation and the Goat Island/Gasport formations, respectively. The third uncertainty scenario was designed to evaluate the potential range of the applied groundwater recharge.

The model's various hydrogeological units were grouped into seven units for the purposes of the uncertainty assessment: overburden, Upper Guelph (two regions), Lower Guelph, Upper Goat Island, Lower Goat Island, and Gasport formations. Each model uncertainty scenario was completed by first making a specific adjustment to recharge or the horizontal and vertical hydraulic conductivity of a hydrogeologic unit. Depending on the scenario, the anisotropy ratio between the horizontal and vertical hydraulic conductivities was fixed or allowed to vary from the base case calibrated model. During the base case calibration, the vertical hydraulic conductivity was set to be 10% of the horizontal hydraulic conductivity for all layers, except for one small overburden area where a higher anisotropy value was applied to account for interpreted interbeds of coarse- and fine-grained material. The model was then recalibrated to the steady-state and transient observation data sets using PEST (Doherty 2015) by allowing all parameters to be modified except the initial adjustment specific to a scenario which was kept constant. The results of the PEST recalibrations indicate the model can be successfully recalibrated with small changes to model parameter and recharge values. Table 1 summarizes the average percent change for conductivity and recharge from the original realization.

Table 1 also presents each scenario's calibration statistics. The objective function is defined as the sum of squared weighted residuals (Doherty 2015). The objective function for the 2018 calibrated model was 3,098. Values lower than this would reflect a statistically better model calibration, and values higher than this would reflect a statistically worse calibration. The observed data was consistently weighted so that the steady-state and transient data had nearly equivalent weight. The observed data was also weighted to place a higher emphasis on the high-quality data versus low-quality data. The residual root mean squared (RMS) statistic of each observation group is also listed; RMS is not affected by the assigned weighting of the observation set.

3.2.1.1 Uncertainty of the Upper Guelph Formation Hydraulic Conductivity

Centre Wellington maintains groundwater monitoring wells in locations near the municipal pumping wells, and the model calibration exercise resulted in an excellent match between simulated and observed water levels at these wells. Appendix B provides additional details on model calibration. The calibration results indicate that the Upper Guelph Formation in the vicinity of the municipal pumping wells has a relatively low hydraulic conductivity, and this is consistent with previously developed conceptual models of the area. The conceptualization incorporated into the FEFLOW model assumes that this low hydraulic conductivity in the Upper Guelph Formation extends across the entire model domain. This assumption is a source of uncertainty in model. The purpose of this assessment was to evaluate if the model calibration would be affected by increasing or decreasing the hydraulic conductivity of the Upper Guelph Formation in the areas outside of Fergus and Elora.

For this scenario, the Upper Guelph Formation was subdivided into two regions: a region surrounding Fergus and Elora and the remaining extent to the north and west of the two towns (Figure 2). The hydraulic conductivities in the Upper Guelph extents outside of the Fergus/Elora region were set to constant values of 0.5 (Scenario 1A) and 2 (Scenario 1B) times the base case calibrated values, while all other hydraulic conductivities in the model (including the Upper Guelph Formation surrounding Fergus and Elora) were adjustable.

Both increasing and decreasing the hydraulic conductivity of the Upper Guelph Formation outside of the Fergus and Elora area resulted in an acceptably calibrated model, as demonstrated by a negligible change to the objective function. Hydraulic conductivity changes with respect to these adjustments are relatively small, except for an increase greater than 300% in the Upper Goat Island Formation in Scenario 1B. This change was required to transmit the additional leakage introduced into the Upper Goat Island Formation through a more permeable unit. The increase in the Upper Guelph Formation hydraulic conductivity also resulted in the model estimating a reduction of 37% in groundwater recharge. This recharge reduction is outside the range of uncertainty and it is therefore very unlikely that that the hydraulic conductivity of the Upper Guelph Formation would increase to the amount considered in the scenario.

This analysis suggests that the calibrated Upper Guelph Formation hydraulic conductivity outside of the Fergus and Elora area, where less high-quality data are available, is appropriate, but has a potential to be lower than the calibrated value. This assessment does not consider the likely physical situation where there will be local zones of higher and lower hydraulic conductivity that cannot be mapped without having high-quality local data.

3.2.1.2 Uncertainty of the Goat Island and Gasport Formation Hydraulic Conductivities

An uncertainty assessment of the deeper formations (i.e., Goat Island and Gasport formations) included a modification of the hydraulic conductivities of these units by a factor of 0.5 (Scenario 2A) and 2 (Scenario 2B). Both increasing and decreasing the hydraulic conductivity of the deeper units worsened the calibration and a similar or improved calibrated solution could not be reached by modifying other parameter values. A large portion of the calibration water level targets are completed in these units and are highly sensitive to their hydraulic properties. Due to the high sensitivity of the hydraulic conductivity in the deeper formations, it is unlikely that a realization of the model with a hydraulic conductivity significantly different than the calibrated value is plausible. The model, as calibrated, likely reflects the spatial variation of transmissivity of the deeper aquifer between pumping wells and high-quality monitoring wells.

This analysis suggests that the calibrated hydraulic conductivity and transmissivity of the Goat Island and Gasport formations appears to be close to optimized and should be maintained at the 2018 calibrated level for Risk Assessment scenarios. This assessment does not consider the likely physical situation where there will be local zones of higher and lower hydraulic conductivity that cannot be mapped without having high-quality local data.

3.2.1.3 Recharge Uncertainty Assessment

Recharge uncertainty was assessed by decreasing (Scenario 3A) and increasing (Scenario 3B) recharge rates by 20%. In both scenarios a calibrated solution was reached through adjustment of the parameter sets. Scenario 3A, a recharge reduction of 20%, resulted in a calibration that was statistically better than the 2018 calibrated model. The hydraulic conductivity of the overburden increased in both scenarios 3A and 3B. The increase in recharge and overburden hydraulic conductivity in Scenario 3B created an increase in boundary outflows, particularly in the upper bedrock and overburden.

This analysis suggests that groundwater recharge rates could be lower than those calibrated. As a result, a potential scenario with 20% less recharge than that included in the 2018 calibrated model was evaluated as an extension to the Risk Assessment scenarios. This scenario is documented in Section 7.4.3.3 to assess the potential effect that reduced recharge may have on predicted water level decline in municipal wells and on the Water Quantity Risk Level. Although the parameter uncertainty analysis suggests that groundwater recharge rates could be lower and achieve an acceptable measure of calibration, the source of the groundwater recharge estimates is the GRCA’s GAWSER model. The GAWSER model has been well calibrated to watershed hydrology conditions and its groundwater recharge estimates should remain the most reliable long-term estimates as part of the complete water balance across the watershed.

TABLE 1 Summary of Parameter and Recharge Uncertainty Assessment

Parameter Uncertainty Scenario:	2018 Calibration Data	1A	1B	2A	2B	3A	3B
Notes:		Decrease Kxyz	Increase Kxyz	Decrease Kxyz	Increase Kxyz	Decrease Recharge	Increase Recharge
Horizontal Hydraulic Conductivity (Kxy)	[m/s]						
Overburden	$5.0 \times 10^{-9} – 5.7 \times 10^{-4}$	+ 6 %	+ 3 %	- 2 %	+ 48 %	+ 13 %	+ 14 %
Upper Guelph Fm. (around Fergus/Elora)	$1.0 \times 10^{-9} – 5.0 \times 10^{-7}$	- 24 %	- 34 %	+ 1 %	- 42 %	+ 3 %	- 4 %
Upper Guelph Fm. (outside Fergus/Elora)		-50%	+ 100 %				
Lower Guelph Fm.	$1.0 \times 10^{-8} – 1.0 \times 10^{-6}$	- 11 %	- 35 %	0%	- 38 %	- 4 %	- 7 %
Upper Goat Island Fm.	$5.0 \times 10^{-8} – 8.5 \times 10^{-5}$	+ 108 %	+ 371 %	- 50 %	+ 100 %	- 1 %	- 6 %
Lower Goat Island Fm.	$2.0 \times 10^{-6} – 8.0 \times 10^{-5}$	+ 6 %	- 20 %	- 50 %	+ 100 %	- 2 %	+ 6 %
Gasport Fm.	$1.0 \times 10^{-6} – 1.0 \times 10^{-4}$	+ 11 %	+ 19 %	- 50 %	+ 100 %	0%	+ 2 %
Conductivity Anisotropy (Kxy:Kz)	[-]						
Overburden	10	- 6 %	- 12 %	- 1 %	+ 30 %	- 1 %	0 %
Upper Guelph Fm. (around Fergus/Elora)	10	- 17 %	+ 66 %	0 %	+ 62 %	- 1 %	+ 2 %
Upper Guelph Fm. (outside Fergus/Elora)	10	fixed	fixed				
Lower Guelph Fm.	10	- 16 %	+ 4 %	- 1 %	+ 5 %	- 4 %	+ 2 %
Upper Goat Island Fm.	10	- 33 %	- 2 %	fixed	fixed	+ 11 %	+ 1 %
Lower Goat Island Fm.	10	- 7 %	+ 12 %	fixed	fixed	+ 2 %	0 %
Gasport Fm.	10	0%	+ 66 %	fixed	fixed	- 3 %	- 7 %
Groundwater Recharge	-	- 2 %	- 37 %	0%	- 30 %	- 20 %	+ 20 %
Calibration Statistics	[m]						
RMS - Low Quality Wells	6.4	6.5	6.3	6.8	7.3	6.3	6.4
RMS - High-Quality Wells	4.4	4.4	4.3	4.9	5.4	4.3	4.4
RMS - Pump Monitor Wells	6.2	6	6.1	6.2	5.9	5.9	6.3
RMS - Pump Wells	8.7	7.1	7	17.6	9.1	7	6.9
RMS - Transient Pump Monitor Wells	0.6	0.7	0.6	1	0.8	0.6	0.7
RMS - Transient Pump Wells	8.7	7.8	8.7	14.9	7.3	8.3	8.6
Objective Function	3089	3046	3095	8772	3689	2974	3094

(pink)	Parameter has been decreased and fixed
(green)	Parameter has been increased and fixed
fixed	Parameter has not been made adjustable

3.2.2 Model Boundary Uncertainty Assessment

Stakeholder consultation following the release of the draft modelling report (Appendix B) identified questions and concerns regarding the amount of groundwater flow across the model boundaries. The purpose of this assessment was to estimate the range of uncertainty of cross-boundary groundwater flow given the characterization used to build and calibrate the numerical model.

The thickness and transmissivity of the Gasport Formation along the northern boundary of the model is uncertain and will also influence the rate of groundwater flow into the model. This uncertainty assessment does not consider these physical parameters; it focusses specifically on the applied boundary condition.

Boundary conditions represent an interpretation of how the groundwater flow model interacts with surrounding groundwater flow systems. External boundary conditions applied in a groundwater flow model have uncertainty due to data gaps and the simplification of the conceptual model. The Tier Three model is driven by groundwater recharge (338,600 m^3/day) and groundwater discharge to internal surface water boundaries (304,000 m^3/day). The groundwater flow rates in and out of external groundwater boundary conditions account for a small percentage of the model water balance. In this model, the groundwater flow boundaries are assigned as constant head boundary conditions, which means a hydraulic head is assigned to a boundary that is representative of either the conceptualized or measured head in that region and groundwater flows through that boundary to maintain that assigned head value. The modelling report (Appendix B) describes the process of estimating the hydraulic head at these boundaries, which was based on equipotential contour maps estimated largely from domestic water well records. The uncertainty of the water levels used to define the boundary conditions is estimated to be +/-10 m. The boundary conditions vary over depth depending on the unit and the hydraulic head data available in these units, which results in vertical gradients along some boundary reaches. Details of assigning boundary conditions are in the Calibration Report (Appendix B of the Risk Assessment Report).

For the purposes of this analysis, the model domain boundaries were divided into six segments labelled A through F (Figure 3). These segments were analyzed in the overburden, Upper Bedrock (Guelph Formation), and Lower Bedrock (Eramosa Formation to Gasport Formation). Municipal pumping was maintained at constant rates.

In this assessment, the change in boundary flow was evaluated for six scenarios where different boundary segments were increased or decreased by 10 m. The boundary segments altered included the northern inflow (segments A and B), western outflow (segments C and D), and southern outflow (segments E and F) boundaries. The impact of these boundary value changes was evaluated based on changes to the inflow and outflow volumes (Table 2).

A review of the values in Table 2 illustrates the following additional observations:

- Increases or decreases in one boundary condition often lead to complementary changes on adjacent boundary reaches, indicating that when more or less water enters from one area, other boundary conditions compensate.
- Increasing boundary heads by 10 m increases the total inflow by <1.0 to 1.5%. That maximum inflow occurs when the northern boundary is increased.
- The increase of inflow at the northern boundary of 5,300 m^3/d (1.5% increase in total inflow) when heads are raised at this location, produces an additional inflow to the deep bedrock units that is comparable to the current water demand within that unit. When this inflow is forced to occur, the additional flow is simulated to exit the western boundary rather than flowing toward the municipal pumping system.

The net boundary flow in the model, calculated as the difference between inflow and outflow, ranges from an outflow of 12,200 m^3/day to an outflow of 30,200 m^3/day. This range corresponds to 3.6% to 8.9% of the total recharge into the model. Groundwater flow into the deep bedrock layers along the northern boundary (segments A and B) ranged from -2,600 m^3/day (outflow) to 8,100 m^3/day (inflow) with calibrated conditions being 2,800 m^3/day (inflow). This amount of local variability is small compared to groundwater recharge into the model but it is relatively large compared to the total flow through the lower bedrock layers. When looking at all of the boundaries together, however, an increase in flow into one boundary is typically offset by a flow out of another adjacent boundary. As an example, an increase into Boundary B (Lower Bedrock) is associated with an increase out of Boundary C (Lower Bedrock). The results of all scenarios together illustrate that the changes in boundary condition values influence the amount of flow into or out of the model, but they do not change the amount of lateral flow across the model and into the area captured by the municipal wells. The model scenarios validate that the model boundaries are at sufficient distance from the municipal wells.

TABLE 2 Boundary Assessment Flows

Notes:	Risk Assessment Scenario C:	Scenario 1a: +10 m North	Scenario 1b: -10 m North	Scenario 2a: +10 m West	Scenario 2b: -10 m West	Scenario 3a: +10 m South	Scenario 3b: -10 m South
Recharge (m³/day)	+338,600	+338,600	+338,600	+338,600	+338,600	+338,600	+338,600
Pumping (m³/day)	-13,100	-13,100	-13,100	-13,100	-13,100	-13,100	-13,100
Internal Surface Water Boundaries (m³/day)	-304,000	-306,100	-301,900	-313,300	-295,200	-311,700	-296,600
Boundary Flows (m³/day)							
A (Lower Bedrock)	+300	+700	-200	+300	+300	+300	+300
B (Lower Bedrock)	+2,500	+7,400	-2,400	-800	+5,700	+2,500	+2,500
C (Upper Bedrock)	-10,800	-10,800	-10,800	-6,200	-14,900	-10,800	-10,800
C (Lower Bedrock)	+300	-2,900	+3,500	+5,400	-4,800	+300	+300
D (Overburden)	-1,100	-1,100	-1,100	-1,800	-500	-1,100	-1,100
D (Upper Bedrock)	-2,400	-2,400	-2,400	-400	-4,500	-2,400	-2,400
D (Lower Bedrock)	-2,700	-2,700	-2,600	-1,200	-4,100	-2,700	-2,600
E (Overburden)	-1,500	-1,500	-1,500	-1,500	-1,500	-500	-2,300
E (Upper Bedrock)	-500	-500	-500	-500	-400	0	-800
E (Lower Bedrock)	-3,100	-3,100	-3,100	-3,100	-3,000	-700	-5,400
F (Lower Bedrock)	-2,400	-2,400	-2,400	-2,400	-2,400	+1,500	-6,400
Sum of Boundary Flows	**-21,400**	**-19,300**	**-23,500**	**-12,200**	**-30,200**	**-13,600**	**-28,700**

3.2.3 Summary of Uncertainty Assessment

The uncertainty assessment provides some important results that can be used to better understand the reliability of the calibrated model, and the value of future refinements to support future decision making.

As described previously, the model has been shown to adequately represent observed high-quality monitoring data under both steady-state (average) and transient conditions. The uncertainty analysis illustrates that the level of calibration achieved with the manual calibration can not be improved with a rigorous parameter optimization routine unless additional high-quality data is collected. Within the area of groundwater that is influenced by the municipal pumping wells, it is unlikely that significant improvements to the model and model parameterization can be made based on the result of this assessment. The results indicate that the model can be relied upon to make decisions regarding pumping optimization near and within the municipal pumping wells.

There is minimal quality data at distances farther away from the municipal pumping wells and as a result there is greater uncertainty with respect to groundwater flow including hydraulic connections within the water supply aquifer and between deep and shallow systems. The model calibration is relatively insensitive to modifications to hydraulic conductivity and to adjustments to the outer boundary conditions that control flow into and out of the model. The level of certainty will increase closer to the municipal system; however, there is not a clear distinction between areas that can be concerned to have either low or high certainty.

For future decision making (e.g., the installation of new municipal wells) the most appropriate way to address parameter uncertainty will be to evaluate scenarios of various acceptable combinations of hydraulic conductivity and groundwater recharge. The method illustrated in this section can be applied to design these scenarios to ensure that prediction of future groundwater impacts can encompass the likely range of uncertainty.

3.3 Model Updates for Risk Assessment Modelling

As described in the previous section, there is uncertainty relating to the western Lower Bedrock boundary condition. There is no high-quality groundwater monitoring data and very little low-quality data available to accurately describe groundwater flow conditions along this boundary. During the model calibration phase described in Appendix B, this boundary was assumed as ‘no flow’, meaning that groundwater could not flow across it. However, as the model was applied to higher future pumping rates subsequent to the model calibration phase, it was concluded that water flow across this boundary should be allowed to occur. For the Risk Assessment described in this report, the boundary conditions along the western boundary of the model domain (Figure 4) in the lower bedrock (i.e., top and bottom of the model layer representing the Goat Island Fm.) is assigned a value equal to the original steady-state model calibrated hydraulic heads in 2018 (see Appendix B for model details).

3.4 Groundwater Model Limitations

Regardless of the level of refinement of the groundwater modelling analysis, uncertainty in subsurface hydrogeologic continuity and parameters cannot be eliminated. Numerical models are approximations of the real world. Generalizations are necessary to represent a complex hydrogeologic system with a modelling tool. Outside Fergus and Elora, the number of high-quality boreholes available to characterize the geology and hydrogeology in the bedrock is limited. Consequently, there is uncertainty associated with the layer structure and the properties applied in the model, particularly in areas further away from the municipal wells.

The groundwater flow model was designed to incorporate the key hydrogeologic features of the regional Study Area and localized features (noted in the Physical Characterization Report [Matrix 2017b]) beneath and surrounding Fergus and Elora. Small-scale features located outside the municipal well field areas (e.g., localized karst features or localized artesian conditions), where higher quality wells are unavailable, may not be represented in the model. As such, additional data collection, characterization, and calibration of the model is required if predictions are required in areas that lie outside the focus area of this study, including in the vicinity of the Middlebrook Well.

The groundwater flow model may be used to address water budget questions within the Fergus and Elora areas; however, additional characterization and refinement of the model may be necessary to characterize the groundwater flow system before it is applied to help address site-specific questions regarding changes in water levels or contaminant fate and transport. The groundwater flow model is suitable for use as a tool to evaluate the potential effects caused by municipal and non-municipal pumping in the Centre Wellington area. Potential effects include declines in water levels in the bedrock over periods of months to years, interference between wells, and changes to overall water budget components. The model is also suitable for use in evaluating changes in water levels and groundwater discharge under different land development scenarios and under short-term (e.g., 1 to 2 year) and long-term (e.g., 5 to 10 year) droughts.

4 WATER QUANTITY VULNERABLE AREA AND RISK ASSESSMENT SCENARIO APPROACH

The *Technical Rules* developed by the Province outline the Water Quantity Vulnerable Areas and Risk Assessment scenarios that should be developed as part of a Tier Three Assessment. These are described in the following sections.

4.1 Water Quantity Vulnerable Areas

Water Quantity Vulnerable Areas are delineated to identify the area of land where water quantity management practices may protect the quantity of water required by a municipality to meet their current or future water supply needs. There are two Water Quantity Vulnerable Areas for groundwater systems: the Wellhead Protection Areas for Quantity 1 and 2 (i.e., WHPA-Q1 and WHPA-Q2). For surface water intakes, the Surface Water Quantity Vulnerable Area, IPZ-Q, is delineated. The *Technical Rules* require that WHPA-Q1, WHPA-Q2, and IPZ-Q areas be delineated for all municipal water supply wells and intakes that extract water from a subwatershed assigned a stress level of Moderate or Significant in the Tier Two Assessment. However, since the Centre Wellington municipal water supply system does not include a surface water intake, delineation of an IPZ-Q is not required. The methodology used to delineate the Water Quantity Vulnerable Areas for groundwater is outlined in the following subsections.

4.1.1 WHPA-Q1 Delineation

The *Technical Rules* define the Vulnerable Area, WHPA-Q1, as the combined area that is the cone of influence of the well (e.g., a municipal well) plus the whole of the cones of influence of all other wells (e.g., municipal, non-municipal, permitted, and non-permitted wells) that intersect that area and any surface water drainage area upstream of, and including, a losing reach of a stream that contributes a significant proportion of surface water to the wells. This area is delineated based on a model scenario where the municipal wells are pumped at a rate equivalent to their Allocated Quantity of Water.

The cones of influence for the wells are estimated by calculating the difference in the potentiometric heads in each of the municipal production aquifers in the following two scenarios:

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

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

The model-predicted heads in each model layer under the non-pumping and pumping conditions are subtracted to produce drawdown contour maps for each of the model layers. The contour maps are then overlain to produce a composite WHPA-Q1 area that encompasses the full extent of the zone of influence associated with the Allocated rates.

4.1.2 WHPA-Q2 Delineation

The WHPA-Q2 is defined in the *Technical Rules* as the WHPA-Q1 plus any area where a future reduction in recharge would have a measurable impact on the municipal wells. Land use change has the potential to reduce recharge and, as a result, reduce the available drawdown at the municipal wells. Land use change is outlined in Section 5.1.

4.1.3 Groundwater Vulnerable Area Delineation

The final Groundwater Vulnerable Area for the Centre Wellington municipal wells is represented by the WHPA-Q1 (area that combines the cone of influence of the municipal supply wells plus the whole of the cones of influence of all other wells [e.g., permitted and non-permitted] that intersect that area) and WHPA-Q2 (the areas where a reduction in recharge would have a measurable impact on the cone of influence of the wells).

4.2 Risk Assessment Scenarios

In a Tier Three Assessment, a series of Risk Assessment scenarios are evaluated using available water budget tools (e.g., groundwater flow models) to evaluate the water quantity risk to municipal water supply systems and to other water uses. The *Technical Rules* summarize all the possible groundwater Risk Assessment scenarios that may be applied in a Tier Three Assessment; these scenarios are summarized in Table 3.

TABLE 3 Summary of Groundwater Risk Assessment Scenarios

Scenario	Time Period	Land Cover	Municipal Water Demand	Other Permitted Demand	Model Simulation
C	The period for which climate and streamflow data are available	Existing	Existing	Existing	Steady-state, simulating water levels and flows using average annual recharge and monthly pumping
D	2-year or greater drought period	Existing	Existing	Existing	Transient, simulating water levels and flows using monthly recharge and monthly pumping
G(1)	The period for which climate and streamflow data are available	Recharge reduction	Allocated + Planned	Anticipated	Steady-state, simulating water levels and flows using average annual recharge and monthly pumping
G(2)		Existing	Allocated + Planned	Existing	
G(3)		Recharge reduction	Existing	Anticipated	
G(4)		Existing	Allocated	Existing	
G(5)		Existing	Planned	Existing	
H(1)	2-year or greater drought period	Recharge reduction	Allocated + Planned	anticipated	Transient, simulating water levels and flows using monthly recharge and monthly pumping
H(2)		Existing	Allocated + Planned	Existing	
H(3)		Recharge reduction	Existing	Anticipated	

In Table 3, scenarios C and D correspond to Existing pumping rates and land use under average climate (Scenario C) and drought conditions (Scenario D). Scenarios G and H use multiple scenarios to evaluate the impact of Allocated pumping rates separate from impacts of land cover and the cumulative impact of both under average climate (Scenario G) and drought conditions (Scenario H). The scenarios are further interpreted as follows:

- Scenarios representing average climate (i.e., C and G) are evaluated using steady-state conditions.
- Scenarios representing drought conditions (i.e., D and H) are evaluated using a transient model representing groundwater recharge rates that vary over a long period of time.

Impacts to other water uses (e.g., coldwater fisheries and wetlands) are only evaluated under steady-state conditions and not evaluated for the drought scenarios (i.e., D, and H). The drought scenarios are evaluated only to identify the potential for water levels to fall beneath a minimum operating elevation for each municipal well. Specific thresholds for Centre Wellington pumping wells are discussed in Section 6.

Table 4 summarizes the specific Risk Assessment scenarios conducted for the Centre Wellington water supply system. Scenario G(5) was not carried out for this Tier Three Assessment as there is no identified Planned municipal demand (see additional discussion in Section 5.2.1.2). Section 4.2.1 to 4.2.4 describes the scenarios in greater detail and the associated data requirements are summarized in Section 5.

The projected effects related to climate change are not evaluated as part of this Tier Three Assessment; however, these effects will be evaluated and documented in a subsequent report, similar to the climate change study completed in support of the Guelph-Guelph Eramosa Water Quantity Policy Study (Matrix 2018a).

TABLE 4 Groundwater Risk Assessment Scenarios Applied for Centre Wellington Tier Three Assessment

Scenario	Time Period	Land Cover	Municipal Water Demand	Other Permitted Demand	Model Simulation
C	Average of climate record (1961 to 2005[1])	Existing	Existing	Existing	Steady-state, simulating water levels and flows using average annual recharge and pumping
D	45-year climate record (1961 to 2005[2]), including drought periods	Existing	Existing	Existing	Transient, using monthly recharge and average annual pumping
G(1)	Average of climate record (1961 to 2005[1])	Planned	Allocated[3]	anticipated	Steady-state, simulating water levels and flows using average annual recharge and pumping
G(2)		Existing	Allocated[3]	Existing	
G(3)		Planned	Existing	anticipated	
G(4)		Existing	Allocated	Existing	
H(1)	45-year climate record (1961 to 2005[2]), including drought periods	Planned	Allocated[3]	anticipated	Transient, using monthly recharge and average annual pumping
H(2)		Existing	Allocated[3]	Existing	
H(3)		Planned	Existing	anticipated	

[1] The 1961 to 2005 average climate timeframe is based on GAWSER model recharge update work completed for the Region of Waterloo and City of Guelph (AquaResource 2009c; Matrix 2017) and represents the reported modelling period for that study.

[2] The 1961 to 2005 transient climate timeframe was carried forward to this project using transient recharge scaling factors that were applied as part of the City of Guelph and Township of Guelph/Eramosa (GGET) Water Quantity Policy Study (Matrix 2018a, b), which was based on recharge output generated from the GAWSER model developed for the GGET Tier Three Assessment (Matrix 2017).

[3] There is no Planned municipal demand in this Tier Three Assessment (see additional discussion in Section 5.2.1.2)

4.2.1 Scenario C - Existing Demand, Average Climate

Scenario C evaluates the ability for current municipal water supply wells to maintain Existing average annual pumping rates under average climate conditions and current land use. This scenario was simulated in steady-state in the Tier Three model using average annual groundwater recharge. While the *Technical Rules* suggest that monthly pumping be used in all steady-state scenarios, this is not possible in a steady-state model; therefore, average 2018 (Existing) pumping rates (Section 5.2.1) were applied. Non-municipal demands (i.e., permitted, non-permitted domestic, and non-permitted agricultural; Section 5.2.2) identified and assembled during model development and calibration phase were applied in all Risk Assessment scenarios. The main output from this scenario was simulated groundwater levels at the municipal wells, and changes to predicted groundwater discharge rates to coldwater streams and Provincially Significant Wetlands.

4.2.2 Scenario D - Existing Demand, Drought

Scenario D evaluates whether each municipal well is able to pump at the same constant Existing rates applied in Scenario C during an extended drought period. This scenario was simulated using the calibrated groundwater flow model in continuous transient mode (1961 to 2005). While the *Technical Rules* refer to a minimum 2-year period to define drought conditions, this assessment went beyond these requirements and examined both the 1960s and 1990s drought periods that occurred within the 45-year climate period examined. The 45-year period examined with the transient model also included periods where precipitation and groundwater recharge were above normal. Existing non-municipal permitted and non-permitted demands were applied consistent with Scenario C.

The transient scenarios were evaluated by adjusting average monthly recharge rates in the Tier Three model using the transient recharge scaling factors applied as part of City of Guelph and Township of Guelph/Eramosa (GGET) Water Quantity Policy Study (Matrix 2018b). These transient recharge scaling factors were based on recharge output generated from the GAWSER streamflow generation model that was developed for the Grand River Watershed as part of the GGET Tier Three Assessment (Matrix 2017a). Since the Centre Wellington and GGET Tier Three study areas are so close and partially overlap, relying on the GGET Tier Three long-term groundwater recharge time series was considered appropriate.

4.2.3 Scenario G - Allocated Demand, Future Land Development, Average Climate

Scenario G evaluates the ability for existing wells to maintain the Allocated plus Planned pumping rates under average climate conditions and considering future development conditions (reductions in recharge). As there was no demand that fit the definition of Planned demand for the Centre Wellington water supply system (see Section 5.2.1.2), this and other scenarios considering future demand will only consider Allocated demands (detailed in Table 6). This scenario was simulated using the calibrated groundwater flow model in steady-state conditions, using groundwater recharge rates that reflect long-term average climate conditions.

Scenario G is subdivided into four scenarios: G(1), G(2), G(3), and G(4). The purpose of multiple scenarios is to isolate the impacts of municipal pumping from impacts related to land developments and assess the cumulative impact of the two stresses. Scenario G(1) evaluated the impact of both future land use and increased municipal pumping rates (i.e., Allocated rates), while Scenario G(2) and G(3) evaluated the impact of Allocated rates and future land use separately. Existing non-permitted demands were applied in scenarios G(1) through G(4), consistent with Scenario C. Scenario G(1) and G(3) permit the consideration of anticipated future takings from existing non-municipal permitted water takers; however, no increases for existing permitted takers were identified to the project team. As a result, existing takings from current non-municipal PTTWs were applied in all sub-scenarios of Scenario G, consistent with Scenario C. Scenario G(4) is essentially the same scenario as G(2); however, it is designed to evaluate the impact of increased municipal pumping rates to other water uses (e.g., assessing reduction in groundwater discharge to coldwater streams and Provincially Significant Wetlands).

4.2.4 Scenario H - Allocated Demand, Future Land Development, Drought

Similar to Scenario G, Scenario H is subdivided into three scenarios: H(1), H(2), and H(3) to evaluate the relative impact of municipal water takings and land use development on groundwater elevations at the municipal wells under drought conditions. Scenario H(1) evaluated the impact of both future land use and increased municipal pumping rates (i.e., Allocated rates), while Scenario H(2) and H(3) evaluated the impact of Allocated rates and future land use separately. Existing non-municipal permitted and non-permitted demands were applied consistent with Scenario C in all sub-scenarios of Scenario H. Impacts to other water uses were not considered in Scenario H. Pumping rates were assumed to be constant throughout each transient scenario.

5 RISK ASSESSMENT DATA REQUIREMENTS

The following sections document the data compiled and evaluated for the Tier Three Assessment. Key datasets including land use cover, municipal and non-municipal water demands, and municipal pumping well setpoints that will be represented in the Risk Assessment model scenarios are discussed.

5.1 Land Use Change

The *Technical Rules* identify reductions in groundwater recharge due to land use development as potential water quantity threats. The Tier Three Risk Assessment modelling scenarios consider the effect of increased imperviousness from future land development on groundwater recharge and municipal groundwater levels. As the *Technical Rules* require the assessment of unmitigated threats as part of the Risk Assessment, the potential impact of stormwater management measures and low impact development techniques was not considered when estimating recharge reductions on future land development areas. This evaluation of land use change is a sensitivity assessment of the impacts from the maximum recharge reduction where urban development within Fergus and Elora is expected to occur.

To identify where land development and increased imperviousness is likely to occur in Fergus and Elora, Centre Wellington planning staff provided digital maps of existing and future land use consistent with the Centre Wellington Official Plan. The existing land use polygons were overlain with Official Plan land use polygons and new polygons were created to map areas with planned land use changes. Changes in land use that may lead to increased imperviousness and decreased groundwater recharge were mapped (Figure 5) for use in Risk Assessment Scenario G(1), G(3), H(1), and H(3).

The groundwater flow model represented land development by decreasing groundwater recharge proportionally to the percentage of impervious area. Each land use change polygon was assigned a percent imperviousness value consistent with value applied in a neighbouring Tier Three Assessment (Table 5; Matrix and SSP&A 2014; AquaResource 2009c).

TABLE 5 Land Use Impervious Estimates (from Matrix and SSP&A 2014)

Land Use Type	Imperviousness (%)
Agriculture	0%
Open Space	0%
Institutional	32%
Low Density Residential	40%
Medium Density Residential	50%
High-Density Residential	80%
Low Density Commercial	60%
Medium Density Commercial	80%
Industrial	80%
Urban Commercial Core	90%

These imperviousness values represent the worst-case groundwater recharge reduction arising when a parcel of land is developed. For example, if an undeveloped plot of land has an estimated recharge rate of 100 mm/year, groundwater recharge will be reduced to 20 mm/year after the construction of a high-density residential subdivision (reduction of 80%). This groundwater recharge reduction is attributed to a decrease in infiltration (subsequently, groundwater recharge) and an increase in runoff. The approach is assumed to be conservative, as decreases in groundwater recharge are typically less than the corresponding increase in impervious due to features such as swales that may introduce additional pathways for recharge coupled with a decrease in evapotranspiration. Figure 5 illustrates the polygons of land use change and the associated future recharge rates.

5.2 Water Demand

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

The following subsections summarize the consumptive water takers within the Study Area, including the municipal (Section 5.2.1) and non-municipal (Section 5.2.2) water uses that have been identified for this assessment and included in the Tier Three model. The evaluation of water demands within the Study Area also considers non-consumptive water uses, such as groundwater discharge for ecological use. These other water uses are described in Section 5.2.3.

5.2.1 Municipal Water Demand

The *Technical Rules* and relevant technical guidance (MOE 2013) require a determination of the Existing, Committed, and Planned demand for a Tier Three Assessment. These terms are defined as follows:

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

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

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

- **Allocated demand** is the combined demand of the Existing plus Committed demands up to the Current Lawful PTTW Taking (MOE 2013).

All of the municipal pumping rates proposed in this project are within the permitted rates for each well.

5.2.1.1 *Existing Demand*

Existing demand refers to the amount of water required to be currently taken from each well during the study period. The municipal pumping rates for the 2018 calendar year are considered as Existing demand and were provided by Centre Wellington for each municipal well in Fergus and Elora. Table 6 summarizes these annual average demands along with the maximum permitted rate for comparison. These average annual Existing municipal pumping rates were applied in Risk Assessment Scenario C, D, G(2), G(4), and H(2). Demands for Well F2 were not included. This municipal well is inactive and modifications such as replacing or deepening of the existing well are currently under consideration. Since plans about future pumping and setpoint elevation at the F2 location are subject to the WSMP, Well F2 was not included in the Tier Three Assessment and will not be discussed further.

Water demands associated with three municipal wells in the Town of Arthur (Wells 7b, 8a, and 8b) and one municipal well in the community of Marsville (Well 1) are also within the Study Area and represented in the Tier Three model (Table 6); however, as these wells are not the focus of this Tier Three Assessment the 2016 rates compiled during model development were maintained for the Risk Assessment.

TABLE 6 Municipal Pumping Rates Applied in the Risk Assessment

Town	Well Name	Maximum Permitted Rate (m^3/day)	Existing Rate (m^3/day)	Well Capacity / Allocated Rate (m^3/day)	Committed Increase (Allocated Rate - 2018 Rate) (m^3/day)
Fergus	Fergus - F1	1,833	730[1]	1,300	570
	Fergus - F2	409	0[1]	0	0
	Fergus - F4	1,964	1,023[1]	1,300	277
	Fergus - F5	1,963	372[1]	400	28
	Fergus - F6	1,964	517[1]	700	183
	Fergus - F7	1,964	616[1]	1,960	1,344
Elora	Elora - E1	1,741	868[1]	1,500	632
	Elora - E3	1,964	725[1]	900	175
	Elora - E4	1,228	252[1]	1,000	748
	Total	**15,031**	**5,103**[1]	**9,060**	**3,957**
Arthur	Well 7b	1,965	335[2]	n/a	n/a
	Well 8a	2,261	316[2]	n/a	n/a
	Well 8b	2,261	317[2]	n/a	n/a
	Total	**6,487**	**968**[2]	n/a	n/a
Marsville	Well 1	182	25[2]	n/a	n/a
	Total	**182**	**25**[2]	n/a	n/a

[1] Existing Rate is for 2018 calendar year

[2] Existing Rate is for 2016 calendar year

n/a - not applicable: Allocated and Committed Rates not developed for Arthur and Marsville as focus of Tier Three Assessment is on Fergus and Elora

5.2.1.2 Population Growth, Committed Demand and Allocated Demand

As part of the development of an updated WSMP for Centre Wellington, AECOM (AECOM 2019) reported the projected population growth in Fergus and Elora and associated future water demands summarized in Table 7.

TABLE 7 Projected Population and Water Demand Based (from AECOM 2019)

Year	Centre Wellington Serviced Population	Average Demand (m^3/day)	Max Day Demand (m^3/day)
2011	17,141	4,936*	8,638
2016	19,331	5,021*	8,786
2021	22,905	6,110	10,692
2026	26,632	7,105	12,434
2031	31,970	8,523	14,916
2036	37,429	9,969	17,445
2041	41,698	11,104	19,433

*actual values
Current estimated average annual system capacity = 9,060 m^3/day
Current estimated peak system capacity (30 day period) = 12,410 m^3/day
Current estimated peak system capacity (7 day period) = 13,510 m^3/day

Based on the projected population growth and a max day ratio of 1.75, the current permitted capacity (15,031 m^3/d) will be exceeded for max day demand by 2031. The WSMP presents 7-day and 30-day peak capacities of 13,510 m^3/d and 12,410 m^3/d, respectively (Table 7). The WSMP uses the 7-day peak capacity as a basis for the implementation of additional water supply capacity projects to service future growth to 2041.

The current lawful maximum daily pumping rate is 15,031 m^3/day according to the current PTTW. However, the current configured system of wells and pumps can only achieve an average daily rate of 9,060 m^3/day based on AECOM's well capacity assessment (AECOM 2019); this amount is equivalent to the projected average demand between 2031 and 2036. Therefore, for the purposes of this Tier Three Assessment, the Allocated demands are based on this estimate of total average well capacity rather than the total permitted capacity (Table 6). The Committed demand (i.e., increase in demand above the Existing demand) was back calculated as the difference between the Allocated rates and the Existing rates and is summarized on Table 6.

The infrastructure required to meet the water demands associated with the full projected population growth to 2041 (Table 7) has not been identified within a completed Master Plan or Class EA, and therefore no Planned demands were included in this assessment. Once completed, the WSMP for Centre Wellington may identify potential locations for future municipal wells that may meet these future demands. Risk Assessment scenarios capturing Planned demands may be evaluated using the Tier Three model when these locations are tested. Allocated demands shown in Table 6 were applied in Risk Assessment Scenario G(1), G(2), H(1), and H(2) (Table 4) and used to delineate the WHPA-Q1.

5.2.2 Non-Municipal Water Demand

5.2.2.1 Permitted Water Uses

In addition to the municipal supply wells, the Study Area contains nine permitted non-municipal groundwater takings. These permits were examined as part of the Tier Three Assessment Physical Characterization Report and individual permitted sources (e.g., wells) were represented in the Tier Three model using 18 simulated wells (Table 8). Pumping rates for these non-municipal permitted takings were assembled using rates reported in the Water Taking Reporting System (WTRS) and other data sources identified in Table 8, for a total non-municipal permitted taking of 5,474 m^3/day.

Simulated pumping from the Middlebrook Well is not included in the calibrated base case model (Appendix B), nor is it included in the Risk Assessment scenarios (Section 4.2). The Middlebrook Well is not currently pumping because it does not have a Permit To Take Water (PTTW). Only known municipal and non-municipal groundwater takings are considered for inclusion in the groundwater flow model. The location of the Middlebrook Well is found in Figure 21 of Appendix A.

TABLE 8 Non-Municipal Permitted Pumping Rates Applied in the Risk Assessment

Permit	Source	Easting	Northing	Average Annual Consumptive Rate (m^3/d)	Data Source for Consumptive Demand
1733-8QKR4S	1	557767	4835969	42	2015 WTRS
2633-9XARF2	1	551512	4843928	2	2015 WTRS
	2	551512	4843819	2	
3277-7RDSJW	1	552675	4846378	114	2016 Pumping Data
	2	552662	4846325	3	
3347-84VQV5	1	537484	4838121	1,791	2015 WTRS
	2	537461	4837989	1,800	
	3	537435	4838042	669	
	4	537548	4838114	519	
4348-9NYNX3	1	538344	4835742	301	Max Permitted Rate × Consumptive Use Factor
5817-8JQN3B	1	551146	4844524	2	2015 WTRS
	2	551159	4844481	2	
5874-955TM9	1	552769	4847410	42	2015 WTRS and Data Provided by Permit Holder
	2	552437	4846991	8	
8304-6XWRVZ	1	549400	4838965	17	2014 WTRS
	2	549409	4838788	8	
	3	549546	4838999	16	
8813-9NYQXV	1	542421	4833563	135	2015 WTRS
			Total		**5,474**

5.2.2.2 Non-Permitted Water Uses

With some exceptions, water takings lower than 50,000 L/day do not need a PTTW. Among other purposes, non-permitted takings typically refer to domestic water supply and livestock water uses.

Domestic Demands

The details for estimating domestic water demands in the areas surrounding Fergus and Elora are described in the model development and Calibration Report (Appendix B). Eighteen surrogate wells are included in the model to represent all domestic water wells with a total combined demand of 943 m^3/day. These wells represent the distribution of domestic well clusters within approximately 1 km of a municipal well, and the domestic demands in the communities surrounding Belwood Reservoir and Inverhaugh.

Agricultural Demands

The Tier Three model includes agricultural water uses associated with livestock water demands within a 3 km buffer surrounding the Fergus and Elora municipal wells. Water takings associated with a large poultry operation located near Ponsonby, outside of the 3 km buffer, are included. In total, livestock demands are represented in the model using 36 pumping wells, with a combined estimated consumptive demand of 596 m^3/day. Additional details regarding the estimation of these agricultural demands are found in Appendix B.

5.2.3 Other Water Uses

Other water uses that are relevant to the Study Area for this current assessment include aquatic habitat uses (e.g., coldwater streams) and Provincially Significant Wetland uses (Figure 6). Streamflow in the Grand River below the Belwood Reservoir and Shand Dam provide wastewater assimilation capacity. During periods of normally-low baseflow in summer and autumn, baseflow in the Grand River downstream of the Shand Dam is maintained by releasing water from the Belwood Reservoir. The contributions to the Grand River from the Study Area as groundwater discharge were found to be a minor component (approximately 10%) of the flow maintained from the Belwood Reservoir. As a result, any impacts of reduced groundwater discharge to baseflow would have an insignificant impact on wastewater assimilation in the Grand River and have not been assessed.

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

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

- Ecological function of wetlands depends on additional factors other than a unit flow rate of water and may also depend on water table elevation. At the scale of this Tier Three model, accurate estimates of wetland impact may be uncertain.

The Province of Ontario introduced the use of thresholds to evaluate other water uses. Thresholds applied in this Tier Three Assessment are discussed in Section 6.

5.2.3.1 Aquatic Habitat

There has been increasing recognition of the water needs of aquatic ecosystems in legislation and policy. For example, water takings in Ontario are governed by the *Ontario Water Resources Act* (Revised Statutes of Ontario 1990, Chapter O. 40) and O. Reg. 387/04 - *Water Taking*. Section 34 of the *Ontario Water Resources Act* requires anyone taking more than a total of 50,000 L/day from a lake, stream, river or groundwater source (with some exceptions) to obtain a PTTW.

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

Figure 6 illustrates the coldwater streams found in the Study Area, as mapped by the Ministry of Natural Resources and Forestry that are subject to the Province's groundwater discharge reduction thresholds (discussed in Section 6.2.1). Coldwater streams that support coldwater fish communities are present along the Grand River, south of Belwood Reservoir toward West Montrose; Swan Creek; Lutteral Creek; tributaries of Speed River; tributaries of Butler Creek; and tributaries of Canagagigue Creek, including West Montrose Creek in the vicinity of North Woolwich Swamp.

5.2.3.2 Provincially Significant Wetlands

Wetlands are classified and evaluated by biologists and ecologists under a standard methodology, taking into account the biological, hydrological, and socio-economic features and functions of a wetland. When wetlands are evaluated as Provincially Significant Wetlands, they are protected under the wetland component of the *Provincial Policy Statement* (MAH 2014). The *Technical Rules* identify Provincially Significant Wetlands as other water uses that, if significantly impacted by municipal pumping, would result in an elevated Risk Level for the Groundwater Vulnerable Area.

Provincially Significant Wetlands within the Centre Wellington Study Area (Figure 6) include 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 wetlands are composed of both marsh and swamp wetland classes.

6 RISK ASSESSMENT THRESHOLDS

Following delineation of the vulnerable areas, a series of Risk Assessment scenarios were run to assess change in groundwater elevations at the municipal wells, and the change in groundwater discharge to coldwater streams and Provincially Significant Wetlands (Section 7). The predicted change in water levels and groundwater discharge values were compared to an established set of water level and ecological thresholds to determine if the predicted changes exceeded the respective thresholds. The following sections outline the thresholds used in this Tier Three Assessment.

6.1 Groundwater Level Thresholds

Groundwater level thresholds represent the water level elevation within a municipal pumping well where further drawdown may introduce operational problems. This elevation may be related to the well screen elevation, open bedrock interval, pump intake elevation, top of aquifer, elevation of highly productive zones, or other operational limitations (e.g., a water level below which the quality of the pumped water deteriorates).

The groundwater thresholds used in this Risk Assessment (called ‘setpoints’) are based on those established as part of the WSMP that is in progress for Centre Wellington. These thresholds were based on low level lock-out elevations provided by the municipal well operators for the pumps in each municipal well. These elevations were subsequently adjusted to consider model error and local geological/operational knowledge. These setpoint elevations were used in place of the concept of ‘Safe Available Additional Drawdown’ that has been used in Tier Three Assessments in neighbouring municipalities (e.g., GGET Tier Three Assessment [Matrix 2017]) to evaluate simulated impacts to municipal wells.

As the model is not a perfect representation of the natural three-dimensional system, the lock-out levels were adjusted consistent with the calibration residual at some municipal wells. Such adjustments were applied at Wells E3, E4, F1, and F6, where the model-simulated values were in excess of those observed. Adjustments were not made for thresholds where the model-simulated water level was below that observed to ensure the results of the Risk Assessment were conservative. Specific details regarding Wells F5 and F6 are provided below:

- Well F5 - The low-level lock-out elevation for this well was reported to be 384.6 m above sea level (asl) and is related to turbidity concerns that arise from shallow fracture inflow. The upper portion of this well is expected to be cased to an elevation of approximately 375 m asl to limit shallow inflow in the future. However, for this assessment, the existing well configuration was used.

- Well F6 - While the low-level threshold was recorded as 353.8 m asl for this well, some of the most productive fractures within the well were recorded at an elevation of 370 m asl. In addition, the model calibration offset is upwards of 10 m at this location under 2016 pumping rates (lower rate) and 7 m at peak rates (2014); 8 m was selected as the additional offset from 370 m asl to account for calibration residuals at the expected future pumping rate.

Table 9 lists the original lock-out levels and adjusted setpoint threshold elevations applied for the existing wells for the Risk Assessment.

TABLE 9 Conservative Threshold Elevations Applied in Assessment

Well Name	Pump Lock-out Level (m asl)	Calibration Offset (m asl)	Conservative Setpoint Threshold Elevation (m asl)
Elora - E1	338.4	-10.1	338
Elora - E3	345.7	2.3	348 [1]
Elora - E4	323.6	0.9	325 [1]
Fergus - F1	343.1	2.4	345 [1]
Fergus - F2	currently inactive; not included in analysis		
Fergus - F4	352.6	-7.2	352
Fergus - F5	384.6	-5.0	385
Fergus - F6	353.8	8.0	378 [2]
Fergus - F7	355.1	-7.1	355

m asl - metres above sea level
[1] Setpoint adjusted to reflect calibration offset.
[2] Setpoint adjusted to reflect elevation of major fracture feature (370 m asl) and calibration offset.

Estimated Non-linear Well Losses at Each Well

Well losses refer to the difference between the theoretical drawdown in a well and the observed drawdown, are due to factors such as turbulence in the well itself, and momentum changes as the water flows through the screen, up the well casing, and into the pump intake. These well losses were incorporated within the Tier Three Assessment, as 1) the threshold setpoint values refer to the groundwater elevation in the well and not the groundwater elevation in the aquifer outside the well, and 2) the groundwater model was calibrated transiently to water levels within production wells from a pumping/shutdown test conducted in 2012.

Pumping at rates beyond those calibrated as part of the 2012 pumping test may; however, result in additional non-linear well losses. Such additional well losses are not calculated by the model; however, increased drawdown within the pumping wells due to the incremental increase from the Existing to Allocated rates is estimated to be small relative to the overall pumping rate. A comparison of the Allocated rates with the pumping rates used in the 2012 pumping/shutdown test indicated that only Well F7 is proposed to pump at a rate (1,960 m^3/d) exceeding the rate used during calibration (1,685 m^3/d). The resulting non-linear well loss is estimated to be approximately 1.5 m. This additional well loss is not expected to appreciably limit the productivity of the well and therefore the threshold level for Well F7 was not further adjusted.

6.2 Ecological Thresholds

As the Tier Three Assessment evaluates whether or not municipal groundwater wells can meet their Allocated rates, while maintaining the requirements of other water uses in the area, the assessment also includes the identification of those other water uses and estimates the water quantity requirements for them where possible. This included an evaluation of potential impacts on coldwater streams and Provincially Significant Wetlands, as the health of these features are at least partially reliant on groundwater discharge.

6.2.1 Coldwater Fisheries

Specific groundwater discharge requirements to maintain coldwater aquatic habitat depend on the geomorphologic and ecologic nature of each watercourse, and a definitive estimation of the impacts of a reduction in groundwater discharge cannot be predicted using groundwater flow models. Consequently, the Province introduced the use of generic thresholds to evaluate the potential for impacts due to reductions in groundwater discharge into coldwater streams.

The Province prescribed (MOECC 2017; MOE 2013) specific baseflow reduction thresholds to be used when assigning a Risk Level associated with predicted impacts to coldwater fish community streams due to increased municipal pumping. For coldwater streams (Figure 6), and when considering only an increase from the Existing demand (i.e., Risk Assessment Scenario C only) to the Allocated Quantity of Water (i.e., Risk Assessment Scenario G[4] only), a Moderate Risk Level is assigned when groundwater discharge is predicted to be reduced by:

- at least 10% of the existing estimated streamflow that is exceeded 80% of the time (Qp80)
- at least 10% of the existing estimated average monthly baseflow of the stream

6.2.2 Provincially Significant Wetlands

While the Province does not prescribe specific thresholds for assigning Risk Levels based on impacts to Provincially Significant Wetlands, they do provide some guidance that states that a Moderate Risk Level would result where the difference between the Existing and Allocated rates would result in a reduction to flows or levels of water thereby creating a measurable and potentially unacceptable impact to other water uses (MOECC 2017; MOE 2013).

For this Tier Three Assessment, and similar to the evaluation of coldwater streams, a simulated reduction in groundwater discharge to Provincially Significant Wetlands between Risk Assessment Scenario G(4) and C in the amount of 10% or more was used as the threshold for evaluating potentially unacceptable impacts to Provincially Significant Wetlands resulting in a Moderate Risk Level.

7 VULNERABLE AREA DELINEATION AND RISK ASSESSMENT RESULTS

7.1 Vulnerable Area Delineation

The first step in the Risk Assessment was the delineation of vulnerable areas. Water Quantity Vulnerable Areas were delineated to protect the quantity of water required by Centre Wellington's Existing and Allocated rates. The methodology used to delineate the WHPA-Q1 and WHPA-Q2 areas were outlined in Section 4.1, and the results are described in the following sections.

7.1.1 WHPA-Q1

The WHPA-Q1 was delineated as the combined area that is the cone of influence of a well (e.g., a municipal well) and the whole of the cones of influence of all other wells (e.g., municipal, non-municipal, permitted, and non-permitted wells) that intersect that area. As the Centre Wellington municipal wells are completed within bedrock aquifers, model-predicted heads from bedrock model layers were used to delineate the WHPA-Q1 for this Tier Three Assessment.

A WHPA-Q1 may also include any surface water drainage area upstream of, and including, a losing reach of a stream that contributes a significant proportion of surface water to the wells; however, model analysis indicates that surface water influx is not significant for this deep bedrock setting. More details on the WHPA-Q1 delineation method are provided in Section 4.1.1.

A guidance document developed for the Province (AquaResource 2011) recommends the consideration of seasonal water level fluctuations in the aquifer when selecting an appropriate drawdown threshold for the WHPA-Q1 delineation. The average seasonal water level fluctuation within regional bedrock monitoring wells is approximately ±2.0 m; therefore, the 2.0 m drawdown contour is used to define the boundary of the WHPA-Q1 for this study (see Appendix C for further details regarding selection of drawdown threshold). This drawdown threshold is consistent with the 2.0 m threshold used in the GGET Tier Three Assessment (Matrix 2017) for the municipal wells completed within the neighbouring bedrock groundwater system and has been accepted by the Province. The delineation is a conservative screening area to identify the area of the water supply aquifer that may be impacted by pumping of groundwater wells at their Allocated rates. The presence of groundwater takings or recharge reduction activities within this area does not imply that they will threaten the reliability of the municipal water supply.

The delineated WHPA-Q1 area encompasses Elora, Fergus, the Centre Wellington municipal wells, and many of the non-municipal takings simulated in the Study Area (Figure 7). The WHPA-Q1 extends toward the west, encompassing non-municipal PTTWs in the west including a relatively larger aquaculture taking (PTTW 3347-84VQV5) that contributes to the extension of the WHPA-Q into a portion of the Township of Mapleton and Township of Woolwich. The WHPA-Q1 does not extend into the vicinity of the communities of Arthur or Marsville or their municipal wells.

7.1.2 WHPA-Q2

The WHPA-Q2 is defined in the *Technical Rules* as the WHPA-Q1 area, plus any area where a future reduction in recharge may have a measurable impact on the municipal wells located in that area. Figure 5 illustrates the proposed land development areas considered in this Tier Three Assessment. All of the areas that have the potential to reduce the water level in a municipal well are already included within the WHPA-Q1; therefore, the WHPA-Q2 is delineated as the same as the WHPA-Q1 (Figure 7).

7.1.3 Groundwater Vulnerable Areas

The Groundwater Vulnerable Area used to identify water quantity threats was delineated by combining the cone of influence of the groundwater wells (WHPA-Q1; Figure 7) and the areas where a reduction in recharge would have a measurable impact on the cone of influence of the wells (WHPA-Q2). As noted in Section 7.1.2, the WHPA-Q1 and WHPA-Q2 areas are coincident; therefore, the Groundwater Vulnerable Area is represented by the WHPA-Q1/WHPA-Q2 (Figure 7).

7.2 Risk Assessment Scenario Results

As mentioned previously, the model results of each Risk Assessment Scenario were evaluated relative to a set of thresholds. For the municipal wells, the model results were evaluated with respect to low groundwater elevation thresholds called ‘setpoints’. For groundwater discharge along coldwater streams and Provincially Significant Wetlands, simulated impacts were evaluated based on whether groundwater discharge was reduced by 10% or more when increasing municipal demands from the Existing to Allocated rates. Ultimately, the Water Quantity Risk Level assigned to the Groundwater Vulnerable Area will be based on whether these setpoints and groundwater discharge thresholds are exceeded (Section 7.2.1 to 7.2.3), the ability of the municipal system to meet peak demands (Tolerance; Section 7.4.2), and an evaluation of uncertainty surrounding the results (Section 7.4.3).

7.2.1 Groundwater Level Decline at Centre Wellington Municipal Wells

The minimum simulated groundwater elevation at each of the municipal wells, for each of the Risk Assessment scenarios except G(4), was compared to the setpoint at each municipal well. A Low Risk Level would be assigned if municipal wells were to meet their Existing or Allocated demands without water levels falling below the setpoint in a scenario. These results are shown graphically in Chart 1 and tabulated in Table 10 for each of the Risk Assessment scenarios. Appendix D contains hydrographs of the transient drought scenarios (i.e., Scenario D, H[1], H[2], and H[3]). Scenario G(4) assessed impacts to other water uses (i.e., coldwater streams and Provincially Significant Wetlands) and therefore was not included in Chart 1 or Table 10.

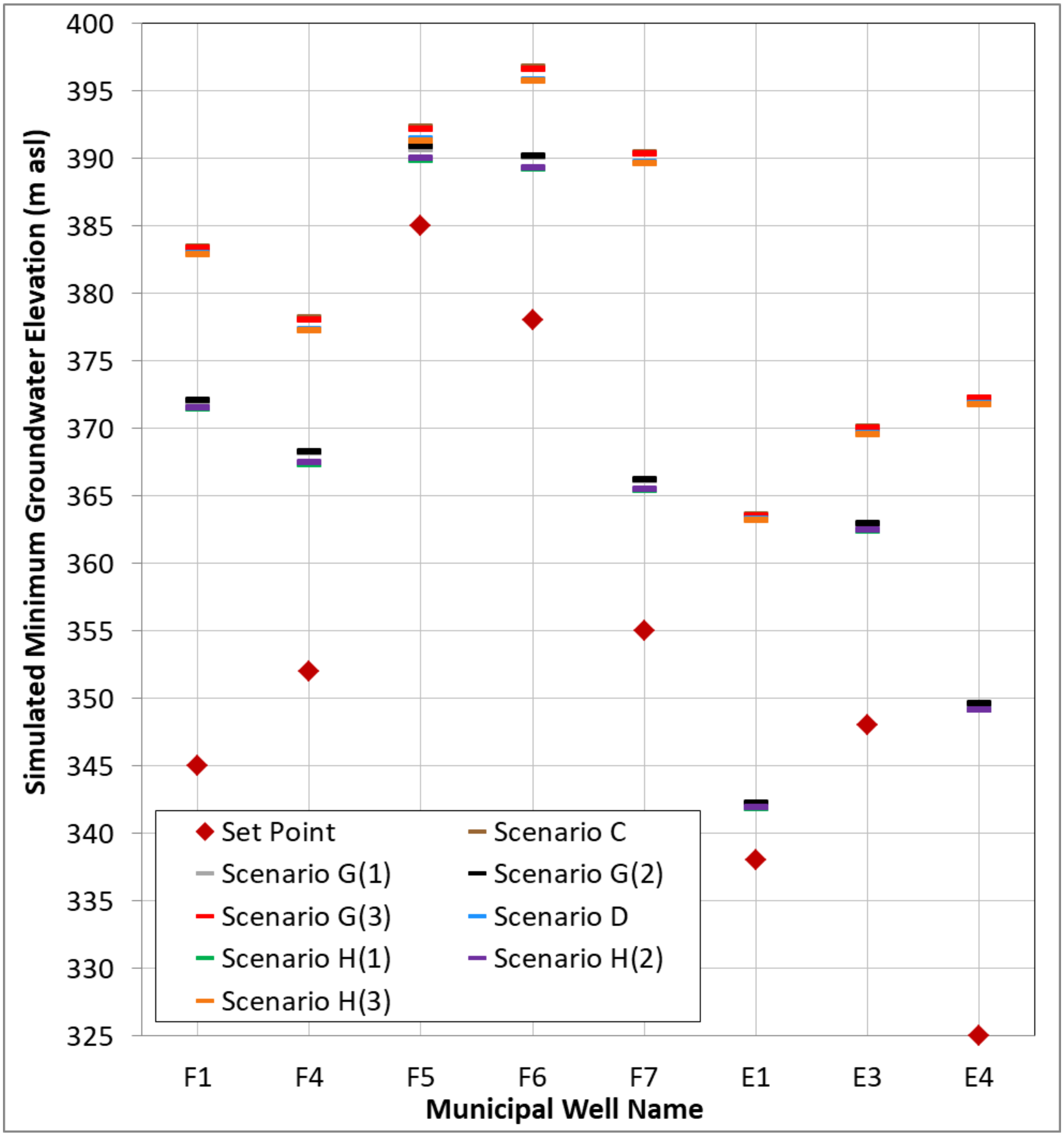

CHART 1 Risk Assessment Results - Simulated Groundwater Level Decline

TABLE 10 Risk Assessment Results - Simulated Groundwater Level Decline

Well Name	Low Water Level Setpoint Elevation (m asl)	Average Climate (Steady-State) Scenarios				Drought (Transient) Scenarios			
		Simulated Groundwater Elevation (m asl)				Minimum Simulated Groundwater Elevation (m asl)			
		C	G(1)	G(2)	G(3)	D	H(1)	H(2)	H(3)
		Existing Demand/ Existing Land Cover	Allocated Demand/ Planned Land Cover	Allocated Demand/ Existing Land Cover	Existing Demand/ Planned Land Cover	Existing Demand/ Existing Land Cover	Allocated Demand/ Planned Land Cover	Allocated Demand/ Existing Land Cover	Existing Demand/ Planned Land Cover
F1	345	383.5	371.9	372.1	383.3	383.0	371.4	371.5	382.9
F4	352	378.2	368.2	368.3	378.1	377.3	367.4	367.4	377.2
F5	385	392.4	390.7	390.9	392.1	391.5	389.8	390.0	391.3
F6	378	396.7	390.1	390.2	396.6	395.8	389.2	389.3	395.7
F7	355	390.4	366.1	366.2	390.3	389.7	365.4	365.5	389.6
E1	338	363.6	342.2	342.2	363.5	363.2	341.8	341.9	363.2
E3	348	370.1	362.9	362.9	370.0	369.6	362.4	362.5	369.6
E4	325	372.3	349.5	349.6	372.2	371.8	349.1	349.2	371.8

The simulated water level elevations in all the Risk Assessment scenarios were greater than the setpoint elevations at each of the Centre Wellington wells (Chart 1 and Appendix D), indicating the wells are able to pump at their Existing and Allocated rates over the long-term (including drought conditions), under existing and future land use development conditions. The closest that any one simulation came to exceeding the setpoint threshold of a municipal well was at Well E1, where simulated water levels declined to within 3.8 m of the setpoint during the 1960s drought conditions of Scenario H(1). Based on these results considering Existing and Allocated demands, a Low Risk Level would be assigned based on impacts to groundwater levels at municipal wells.

While the demands assessed in these scenarios do not include Planned demands (Section 5.2.1.2), the Low Water Quantity Risk Level assigned based on impacts to municipal well drawdown is revisited in Section 7.4.3 through an assessment of future water demand uncertainty associated with the ability to meet future water supply demands with the current water supply infrastructure.

7.2.2 Impacts to Groundwater Discharge

The *Technical Rules* specify that streams and creeks hosting coldwater fish communities cannot be negatively impacted by increases in municipal pumping from the Existing to the Allocated rates. Any reduction in groundwater discharge to coldwater streams under the G(4) scenario of 10% or more of the Existing conditions groundwater discharge would result in the assignment of a Moderate Risk Level for the Groundwater Vulnerable Area.

The simulated impact of increased municipal pumping at the Allocated rates on groundwater discharge to coldwater streams was evaluated using the Tier Three model for seven coldwater stream segments (Figure 8), including: tributaries of Canagagigue Creek (1), West Montrose Creek (2), the main branch of the Grand River south of Belwood Reservoir (3), tributaries of Butler Creek (4), Swan Creek and associated tributaries (5), tributaries of Speed River (6), and Lutteral Creek and associated tributaries (7). The results of this assessment are tabulated in Table 11.

TABLE 11 Risk Assessment Results - Simulated Reduction in Groundwater Discharge to Coldwater Streams

Coldwater Surface Water Feature	Simulated Groundwater Discharge (m^3/day)		% Change
	Scenario C - Existing Demand/ Existing Land Cover	Scenario G(4) - Allocated Demand/ Existing Land Cover	
Canagagigue Creek Tributaries	5,200	5,100	-1.9
West Montrose Creek	7,800	7,800	0.0
Grand River	31,700	30,000	-5.4
Butler Creek Tributaries	2,300	2,300	0.0
Swan Creek	12,200	11,800	-3.3
Speed River Tributaries	4,800	4,800	0.0
Lutteral Creek	12,500	12,500	0.0

The greatest absolute simulated groundwater discharge reduction between scenarios C and G(4) is 1,700 m^3/day. This result is from an analysis of a stretch of the Grand River, which extends from just east of Fergus, to the model domain boundary south of Elora. This reduction is approximately 5% of the total estimated groundwater discharge, and less than 1% of the typical minimum flow of the Grand River through this reach. All recharge reductions are less than the 10% threshold specified through the *Technical Rules*; therefore, a Low Risk Level would be assigned based on impacts to coldwater streams.

7.2.3 Impacts to Provincially Significant Wetlands

Guided by the *Technical Rules*, and following the approach used for coldwater streams, a 10% reduction in groundwater discharge to Provincially Significant Wetlands was used as the minimum threshold for assessing impacts to these features. Any simulated decline of groundwater discharge that equalled or exceeded 10% would result in the assignment of a Moderate Risk Level for the Groundwater Vulnerable Area.

The simulated impact of increased municipal pumping at the Allocated rates on groundwater discharge to Provincially Significant Wetlands was evaluated using the Tier Three model for seven wetlands (Figure 9). The simulated groundwater discharge under Existing pumping (Scenario C) was subtracted from the simulated groundwater discharge under Allocated pumping (Scenario G[4]) and the resulting change was tabulated (Table 12). The modelling indicates that the simulated reduction in groundwater discharge to Provincially Significant Wetlands is well below 10% and; therefore, a Low Risk Level would be assigned based on impacts to these features.

TABLE 12 Risk Assessment Results - Simulated Reduction in Groundwater Discharge to Provincially Significant Wetlands

Provincially Significant Wetland Feature	Simulated Groundwater Discharge (m^3/day)		% Change
	Scenario C - Existing Demand/ Existing Land Cover	Scenario G(4) - Allocated Demand/ Existing Land Cover	
Alma Wetland Complex	700	700	0.0
Ritch Tract Swamp	600	600	0.0
North Woolwich Swamp	10,500	10,500	0.0
Inverhaugh Valley Wetland Complex	15,900	15,800	-0.6
North Cumnock Wetland Complex	5,200	5,200	0.0
Living Springs Wetland Complex	9,500	9,500	0.0
Speed Lutteral Swan Creek Wetland Complex	117,600	117,400	-0.2

7.3 Water Budget Assessment of Risk Assessment Scenarios

The water budget for the groundwater flow system summarizes inflows including recharge and cross-boundary flow; and outflows including groundwater discharge (to surface water features), water takings from wells, and cross-boundary flows. The simulated flow rates for Risk Assessment Scenario C, G(1), G(2)/G(4), and G(3) are summarized in Table 13. Figure 10 illustrates a schematic drawing of the water budget components for Scenario C. Positive groundwater flows indicate flow into the assessment area and negative values indicate flows out of the assessment area. Cross-boundary groundwater flow into and out of the model domain was calculated using the groundwater model results. Consistent with the regional flow system, inflow and outflow occur primarily through the northern and southern boundaries, respectively. The western boundaries have a net outflow.

Based on Scenario C (existing demand/existing land cover), the average annual groundwater recharge rate in the model is 338,600 m^3/day, and the inflow from neighbouring catchments is approximately 6,100 m^3/day. Simulated groundwater discharge to surface water features is estimated to be 304,000 m^3/day, which accounts for approximately 88% of the model outflows. All groundwater takings totaled 13,100 m^3/day, representing approximately 4% of the total model outflows. The remaining groundwater outflow occurs across the model boundary to downgradient areas, with a rate of 27,600 m^3/day. The Risk Assessment scenarios, described in Section 4.2, test the impacts of altered recharge rates and groundwater pumping rates applied to the model. The impact of these changes on the overall model water budget are minor.

The water balance for the lower bedrock units (Goat Island and Gasport formations, Figure 10) indicates that lateral inflows account for 3,600 m^3/day and net inflow due to leakage from overlying units accounts for 8,200 m^3/day. This result suggests that a greater proportion of water in the lower bedrock units is sourced vertically from overlying geological layers, rather than laterally from the regional flow system. The uncertainty assessment described in Section 3.2.2 estimates the range of uncertainty of lateral flows along model perimeter boundaries. The water balance results suggest that an increase in municipal pumping in scenarios G(1) and G(2)/G(4) is balanced by a small increase in lateral inflow in the lower bedrock, but mostly through increased vertical leakage (Table 13).

The magnitude of vertical leakage is linked to the hydraulic conductivity of the Upper Guelph Formation, which was parameterized in the Tier Three model through calibration process. The simulated horizontal hydraulic conductivity needed to be low enough to account for the 11 to 20 m observed vertical head differences across that unit (Appendix B). The lower range of calibrated horizontal conductivity values applied for the Upper Guelph Formation is slightly lower than the field-derived range of values. This is because many of the hydraulic tests conducted within and outside the Study Area were targeting new water supply sources and aimed to complete the wells in zones of enhanced transmissivity. The available field-derived values were therefore expected to be on the high side. Vertical hydraulic conductivity of the bedrock was set to be 10% of the horizontal hydraulic conductivity across the model domain. Uncertainty in the hydraulic conductivity values is greater outside the Fergus and Elora area. Vertical hydraulic conductivity in the Guelph Formation and leakage into the deeper bedrock units will vary depending on the presence of local unmapped heterogeneities such as weathered surfaces, fractures, buried valleys, and karst features.

TABLE 13 Water Budgets of Risk Assessment Scenarios

Component	Flow (m^3/day)			
	Scenario C - Existing Demand/ Existing Land Cover	Scenario G(1) - Allocated Demand/ Planned Land Cover	Scenario G(2)/G(4) - Allocated Demand/ Existing Land Cover	Scenario G(3) - Existing Demand/ Planned Land Cover
Recharge	**338,600**	**337,200**	**338,600**	**337,200**
Inflow	**6,100**	**6,400**	**6,400**	**6,100**
Overburden & Guelph Formation	2,500	2,500	2,500	2,500
Goat Island & Gasport Formations	3,600	3,900	3,900	3,600
Outflow	**-27,600**	**-27,400**	**-27,500**	**-27,600**
Overburden & Guelph Formation	-21,600	-21,500	-21,600	-21,600
Goat Island & Gasport Formations	-6,000	-5,900	-5,900	-6,000
Pumping	**-13,100**	**-17,100**	**-17,100**	**-13,100**
Overburden & Guelph Formation	-7,300	-7,300	-7,300	-7,300
Goat Island & Gasport Formations	-5,800	-9,800	-9,800	-5,800
Discharge to Surface Water	**-304,000**	**-299,100**	**-300,400**	**-302,600**
Leakage from Guelph Formation to Goat Island Formation[1]	8,200	11,800	11,800	8,200

[1] This vertical leakage term represents an internal flow component in the overall water budget.

7.4 Water Quantity Risk Level Assignment

The Groundwater Vulnerable Area for the Centre Wellington municipal wells are illustrated on Figure 7. The Water Quantity Risk Level is assigned to the Groundwater Vulnerable Area based on the results of the Risk Assessment scenarios, the ability to meet peak demand ("Tolerance"), and consideration of the uncertainty surrounding those results as described in the following sections.

7.4.1 Summary of Risk Assessment Scenario Results

As summarized in Section 7.2, based on an evaluation of exceedance of thresholds, a Low Risk Level would be assigned to the Groundwater Vulnerable Area based on the following:

- The prediction that groundwater in the production aquifer will be maintained at an elevation above the low water level setpoint elevation for each municipal well, under each Risk Assessment Scenario.
- The prediction that the reduction in groundwater discharge to coldwater streams will be less than 10%, considering the increase in municipal pumping to Allocated rates (Scenario G[4]).
- The prediction that the reduction in groundwater discharge to Provincially Significant Wetlands will be less than 10%, considering the increase in municipal pumping to Allocated rates (Scenario G[4]).

7.4.2 Tolerance

Municipalities may implement physical solutions (e.g., storage reservoirs, peaking / back-up wells) and water conservation measures to reduce the amount of instantaneous water demand required from a primary drinking water source. These types of measures are implemented to increase a municipality's "Tolerance" to short-term water shortages. For long-term Tolerance, a municipality may maintain additional wells or intakes (i.e., peaking or back-up wells) that can be brought online when a longer-term need arises.

Tolerance effectively reduces the potential that a municipality will face short- or long-term water shortages. A municipality's existing water supply system may be designed such that the wells or intakes alone cannot meet peak water demands; however, storage systems such as reservoirs and water towers may be in place for this purpose. The *Technical Rules* (Part IX.1) specify that if the municipality's system is able to meet existing peak demands, the Tolerance level for the existing system is assigned as High; otherwise, the Tolerance is Low. If it is determined that the drinking water system is not able to meet peak water demands (Low Tolerance), then a Significant Risk Level would be assigned to the Groundwater Vulnerable Area.

The municipal water supply system of Centre Wellington has two elevated water storage tanks in Elora and two in Fergus with a combined storage capacity of just over 11,800 m^3 (MOECC 2016); this volume is just over twice the average total daily volume used in 2018 (i.e., 5,103 m^3/day; Table 6). Further, the Fergus and Elora distribution systems were connected by the Wellington Road Booster Station in 2005 to create a single Centre Wellington water distribution system. Therefore, when a well goes offline (e.g., for maintenance), there is enough redundancy in the number of wells and flexibility in the distribution system to accommodate the associated demand. Since the Centre Wellington water supply system has not had difficulty meeting existing demands, the Tolerance for the system is classified as High, and a Low Risk Level would be assigned to the Groundwater Vulnerable Area.

7.4.3 Uncertainty Analysis

Recognizing that the Risk Assessment is subject to uncertainty in the model predictions, the potential for those uncertainties to affect the Risk Level designation is tested as part of the Tier Three analysis. The Risk Level could be elevated in a situation where an uncertainty analysis characterizes the uncertainty as High, and there is a potential within this degree of uncertainty for the Risk Assessment results to exceed one of the thresholds. The uncertainty in the model parameters and exterior boundary conditions was evaluated in Section 3.2. In addition to those changes, the uncertainty analysis needs to consider the potential variability of future pumping conditions.

7.4.3.1 Hydraulic Conductivity Uncertainty

A series of scenarios were evaluated to better understand the uncertainty associated with the hydraulic conductivity of the Upper Guelph Formation outside of Fergus and Elora (Section 3.2.1.1), and the uncertainty associated with the deeper Goat Island and Gasport formation hydraulic conductivities overall (Section 3.2.1.2). The analysis indicated that the calibrated Upper Guelph Formation hydraulic conductivity outside of the Fergus and Elora area, where less high-quality data are available, is appropriate, but has a potential to be even lower. The results also showed that the calibrated hydraulic conductivity and transmissivity of the Goat Island and Gasport formations appear to be close to optimized and therefore the current values should be maintained in the Tier Three model. The range of uncertainty of the regional hydraulic conductivity zones is unlikely to affect the results of this Risk Assessment. As a result, the uncertainty of the Risk Level with respect to hydraulic conductivity is considered Low.

7.4.3.2 Lateral Model Boundary Uncertainty

Section 3.2.2 describes the scenarios designed to assess the sensitivity of the model results to the outer model boundaries. Although there is uncertainty in the magnitude of the outer boundary flows, the scenarios illustrate that the changes in boundary condition values influence the amount of flow into or out of the model, but they do not change the amount of lateral flow across the model and into the area captured by the municipal wells. The model scenarios validate that the model boundaries are at sufficient distance from the municipal wells. As a result, the uncertainty of the Risk Level with respect to lateral boundaries is considered Low.

7.4.3.3 Reduced Recharge Uncertainty

Of the uncertainties tested in Section 3.2, the change that could have the most significant impact on the Risk Assessment was identified to be a lower recharge rate across the entire model. The analysis presented in Section 3.2.1 indicated that the model calibration would remain acceptable under conditions of a 20% lower recharge, and such a condition might have an effect on the Water Quantity Risk Level. To evaluate this potential, Risk Assessment Scenario G1 (Table 4) was re-evaluated using 20% lower recharge. This amount of recharge reduction is not practical, as the hydrologic model used to estimate groundwater recharge is considered well calibrated and the groundwater recharge rates are representative at a watershed level. However, the results indicated that a 20% recharge reduction would not lead to simulated groundwater levels at municipal wells declining below the setpoints and therefore not lead to a change in the Risk Level. Therefore, the uncertainty with respect to this Risk Level is Low.

7.4.3.4 Future Demand Uncertainty

The second key uncertainty evaluated was the amount of municipal water demand that may be expected for 2041 planning horizon. As noted in Section 5.2.1, the Allocated rates for the existing system do not extend to the planning horizon of 2041 because the infrastructure (i.e., wells, water towers, pumping stations, etc.) are not yet defined to meet this demand. A concurrent WSMP has identified the potential average demand at 2041 to exceed 11,000 m^3/d. This demand estimate is based on the designated growth for the municipality defined by the Growth Plan for the Greater Golden Horseshoe (Government of Ontario 2017b), prepared under the *Places to Grow Act* (Government of Ontario 2012).

The estimated future water demand is greater than what can be reliably supplied by the current municipal wells. This circumstance, which would increase the municipal demand to a level that is unsustainable with the current infrastructure, results in High uncertainty with respect to the Risk Level. As a result, the Risk Level is increased to Significant. Groundwater model scenarios completed in support of the WSMP indicate that the future demand estimate can be met by the installation of new additional municipal supply wells. These results suggests that the ability to meet future demands is due to insufficient water supply infrastructure (i.e., municipal wells) and not an inadequacy of the groundwater resource or the sustainability of that resource.

7.4.4 Final Risk Level

The model scenarios illustrate that the current municipal wells can meet their Allocated rates under average and drought conditions without causing adverse effects to other water uses. However, the results indicate that the current system cannot meet the future (2041) demand and this results in a Significant Risk Level designation. This Significant Risk Level designation is applied to the Groundwater Vulnerable Area as presented in Figure 7.

8 WATER QUANTITY THREATS

As outlined in the *Technical Rules,* drinking water quantity threats need to be identified for vulnerable areas assigned a Significant or Moderate Risk Level. Drinking water quantity threats are identified as follows:

- an activity that takes water from an aquifer or a surface water body without returning the water taken to the same aquifer or surface water body (i.e., a consumptive demand)
- an activity that reduces the recharge to an aquifer

As the Groundwater Vulnerable Area was assigned a Significant Risk Level, all existing consumptive demands or future areas of recharge reduction (due to land use development) within this policy area are classified as Significant water quantity threats. This classification is based on a consumptive demand or recharge reduction area occurring within the Groundwater Vulnerable Area and does not imply that an individual groundwater taking or recharge reduction activity will reduce the reliability of the municipal water supply. The relative impact of groundwater takings, groups of water takings, and areas of recharge reduction in the Groundwater Vulnerable Area on the municipal water supply may be examined in greater detail as part of a Risk Management Measures Evaluation Process (see Recommendation 8 of Section 9.3). New PTTW applications and associated groundwater takings within the Groundwater Vulnerable Area should require additional technical work to determine potential impact to the municipal water supply.

8.1 Consumptive Water Demands

Figure 11 illustrates the 9 municipal permitted water supply wells and 17 non-municipal permitted consumptive water uses within the Groundwater Vulnerable Area that would be classified as Significant water quantity threats. Table 14 summarizes additional details for the non-municipal permitted consumptive water uses within the Groundwater Vulnerable Area.

All non-permitted water uses (e.g., domestic water and non-permitted agricultural) located within the Groundwater Vulnerable Area are classified as Significant water quantity threats. These non-permitted water users extract very little water compared to permitted consumptive water users on the scale of the Tier Three Assessment; however, they remain classified as Significant water quantity threats under the *Technical Rules*. Detailed data specifying the current quantity and location of the different types of non-permitted water uses (e.g., domestic vs. agriculture) was not available throughout the entire Study Area; therefore, non-permitted threats were identified as a general category in this study using information contained within the MECP Water Well Information System.

TABLE 14 Non-municipal Permitted Consumptive Water Uses - Groundwater Vulnerable Area

Permit No.	Easting (NAD83)	Northing (NAD83)	Purpose - Specific Purpose	Maximum Permitted Rate (m^3/day)
1160-887HN4	537890	4838561	Miscellaneous - Wildlife Conservation	824
8315-887KDV	548515	4842807	Miscellaneous - Wildlife Conservation	301
8315-887KDV	548515	4842897	Miscellaneous - Wildlife Conservation	301
5587-9Y2QMX	550686	4839951	Industrial - Other	578,888
4348-9NYNX3	538344	4835742	Industrial - Aggregate Washing	3,000
8813-9NYQXV	542421	4833563	Industrial - Aggregate Washing	3,000
3347-84VQV5	537484	4838121	Commercial - Aquaculture	2,399
3347-84VQV5	537461	4837989	Commercial - Aquaculture	2,399
3347-84VQV5	537435	4838042	Commercial - Aquaculture	982
3347-84VQV5	537548	4838114	Commercial - Aquaculture	982
3347-84VQV5	537491	4837967	Commercial - Aquaculture	2,399
3347-84VQV5	537499	4838084	Commercial - Aquaculture	982
8304-6XWRVZ	549400	4838965	Remediation - Groundwater	87
8304-6XWRVZ	549434	4838900	Remediation - Groundwater	35
8304-6XWRVZ	549436	4838776	Remediation - Groundwater	34
8304-6XWRVZ	549409	4838788	Remediation - Groundwater	34
8304-6XWRVZ	549546	4838999	Remediation - Groundwater	34

Note: Permits were obtained from the Permit to Take Water Database and were current as of February 2017.

8.2 Reductions in Groundwater Recharge

The *Technical Rules* specify that reductions in groundwater recharge are a potential water quantity threat within vulnerable areas. The Risk Assessment scenarios considered the impact of existing and future land development defined by the Official Plans in Fergus and Elora, on groundwater recharge and the resulting impact on water levels in the municipal wells. All reductions in groundwater recharge in Fergus and Elora within the Groundwater Vulnerable Area as identified through this Tier Three Assessment are also classified as Significant water quantity threats. Specific areas where recharge may be reduced according to land development in the Official Plan are illustrated on Figure 11. Any additional or future areas where recharge may be reduced due to land development outside of Fergus and Elora but inside the WHPA-Q would also be considered and included as Significant water quantity threats in the future.

8.3 Significant Water Quantity Threat Enumeration

A summary of the number of municipal and non-municipal permitted, and non-permitted Significant water quantity threats, lying within various management areas (i.e., Vulnerable Area, Source Protection Area, and Municipal Area), is provided in Table 15. A total of 26 permitted threats were identified. The Water Well Information System (MOECC 2017) was used to estimate the number of water wells that may represent non-permitted (e.g., domestic or non-permitted agricultural) takings within the various areas. These takings are exempt from permitting if they are taking less than 50,000 L/day. A total of 2,715 individual non-municipal, non-permitted Significant water quantity threats are found within the Groundwater Vulnerable Area (Figure 11).

Significant water quantity threats represented by areas of reduced groundwater recharge are also summarized in Table 15. To avoid the subjective nature of grouping and counting individual polygons of land area, which may or may not be related, these threats are provided as the area of recharge reduction contained within the areas of interest. While these recharge reduction areas total 4.3 km^2 in size, they represent just 2.2% of the total area of the Groundwater Vulnerable Area, 0.1% of the total area of the Grand River Source Protection Area, and 1.0% of the total area of Centre Wellington. The total approximate volume of recharge reduction (1,300 m^3/day) represents a small fraction (0.4%) of the total estimated recharge in the Study Area under existing conditions (338,600 m^3/day).

TABLE 15 Count of Significant Water Quantity Threats by Threat Group

Threat Group	Vulnerable Area	Source Protection Area	Municipal Area		
	Groundwater Vulnerable Area (WHPA-Q1/Q2)	Grand River Source Protection Area	Township of Centre Wellington	Township of Mapleton	Township of Woolwich
Municipal Permitted	9	9	9	0	0
Non-municipal Permitted	17	17	17	0	0
Non-Municipal, Non-Permitted[1]	2,715	2,715	2,419	269	27
Recharge Reduction[2]	4.3 km^2 (2.2% of Groundwater Vulnerable Area)[4]	4.3 km^2 (0.1% of Grand River Source Protection Area)[4]	4.3 km^2 (1.0% of Township of Centre Wellington Area)[4]	n/a [4]	n/a [4]
Total Number of Significant Threats[3]	Within all Vulnerable Areas of the Tier Three Assessment: 2,741	Within all Source Protection Areas of the Tier Three Assessment: 2,741	Within all Municipalities of the Tier Three Assessment: 2,741		

[1] Only wells recorded in the Water Well Information System database (February 2017) are included.
[2] Recharge reduction threats are summarized by identifying the total area represented by recharge reduction polygons as a percentage of the total area of interest. Recharge reduction threats include only those located within the towns of Fergus and Elora.
[3] Total number of Significant threats does not include individual Recharge Reduction Polygons as those threats have been identified on a per-area basis.
[4] Only recharge reduction areas in Fergus and Elora were identified as part of this Tier Three Assessment.

9 SUMMARY AND CONCLUSIONS

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

Under the requirements of the *Clean Water Act*, municipalities may be required to complete a Tier Three Assessment to assess the ability of the municipal water sources to meet their Existing and Allocated rates, while considering land use change and drought conditions, as well as impacts to other water uses (e.g., coldwater streams and Provincially Significant Wetlands). Municipalities that are unable to meet their water demands, or the demands from other water uses, are required to identify the Moderate or Significant threats that may prevent them from meeting these demands.

This report detailed the Tier Three Assessment carried out for the municipal groundwater supplies of the Township of Centre Wellington. Two companion reports summarized the background physical characterization of the Study Area (Appendix A) including the geology, hydrology, hydrogeology, and estimated water demands; and the development of a groundwater flow model (Appendix B) including calibration approach and estimation of a water budget.

9.1 Summary of the Water Budget Tools and Results

A Tier Two Assessment completed for the Grand River Watershed (AquaResource 2009a, 2009b) identified the Irvine Creek Groundwater Assessment Area as having a Moderate potential for hydrologic stress when considering future water demands in a drought scenario. A subsequent analysis conducted by the GRCA (Shifflett 2015) using updated water taking data also showed a potential for stress when uncertainty was taken into account, while considering future demands and future demands with reduced recharge. These results suggested that the potential for hydrologic stress in this area is linked to growth in Centre Wellington. As a result, the Province initiated a Tier Three Assessment for the municipality.

The Tier Three Assessment involved a detailed review and representation of the physical system within the area of the Centre Wellington municipal water supplies. The conceptual model used within the Tier Three Assessment was refined from earlier conceptualizations and was enhanced using data from numerous geology, hydrogeology, and water resources studies. The Tier Three Assessment also capitalized on recent work completed by the OGS that included the refinement and characterization of bedrock unit continuity across the Study Area, including the adoption of a revised bedrock unit nomenclature. Further, the representation of overburden hydrostratigraphic layers was also based on the recent overburden conceptual model developed by the OGS (Burt and Dodge 2016).

A FEFLOW groundwater flow model was developed for the Centre Wellington area, with bedrock and overburden model layers that were based on the conceptual model developed during the characterization phase of the study. The areas of refinement were focused around the Tier Three municipal wells to assess groundwater flow at a well field scale. The groundwater flow model was calibrated to observed water levels in 48 high-quality monitoring wells, to static water levels from the MECP water well database, to observed baseflow at Irvine Creek, and using recharge estimates developed using the GAWSER streamflow generation model. The groundwater flow model was also calibrated to transient water level response data from a municipal well shutdown/pumping test over a six-week period in 2012. Calibration to multiple data sets of groundwater level, average flow, and response to major pumping changes has resulted in a calibration level that meets or exceeds that achieved within most other Tier Three Assessments in Ontario.

The model was ultimately applied to evaluate a groundwater budget for the Study Area and to carry out a number of uncertainty scenarios as part of the Risk Assessment phase. The uncertainty assessment evaluated model sensitivity to hydraulic conductivity, groundwater recharge and lateral model boundary conditions. The uncertainty scenario that was found to have the greatest potential to impact municipal well drawdown, and the results of the Risk Assessment, was a scenario where existing groundwater recharge was lower than currently simulated. This reduction is groundwater recharge is lower than the range of uncertainty expected using the GAWSER watershed hydrology model. Further evaluation of this scenario revealed that this uncertainty does not reduce the reliability of the municipal wells.

9.2 Risk Assessment Summary

A Groundwater Vulnerable Area was delineated surrounding the municipal wells and other water takers in the Study Area (Figure 7). The area was delineated based on a combination of the cone of influence of municipal and non-municipal wells (WHPA-Q1) and land areas where recharge has the potential to have a measurable impact on the municipal wells (WHPA-Q2). In this study WHPA-Q1 and WHPA-Q2 were coincident.

A set of Risk Assessment scenarios were developed to assess the impact of municipal wells pumping at Existing and Allocated rates, while considering land use change, drought conditions and impacts to other water uses (e.g., coldwater streams). The Tier Three Assessment assesses existing permitted municipal water supply wells and non-permitted municipal water supply wells that have been tested and evaluated under the EA process. In this study, average annual pumping rates for the 2018 calendar year were considered as the Existing demand. The Allocated demand represented the estimated average annual water supply system capacity of the existing municipal wells for the average amount of water that is available to meet current and future water supply requirements. According to the draft WSMP (AECOM 2019), the average municipal water supply requirements will exceed this capacity sometime between 2031 and 2036. As a result, the Tier Three Assessment can only evaluate the reliability of the current municipal wells in meeting future average annual demands to 2031-2036.

The calibrated groundwater model was used to simulate groundwater level decline in the existing Centre Wellington municipal supply wells, and reduced groundwater discharge to cold water streams and Provincially Significant Wetlands. Simulated groundwater level decline in all scenarios were based on the assumption that the municipal wells are maintained in their current conditions to ensure constant well performance with no deterioration over time. The results from the Risk Assessment scenarios assume this level of maintenance is continued.

The Risk Assessment scenarios predicted that there was a Low Risk Level associated with groundwater level decline at the municipal wells, and groundwater discharge to coldwater streams and Provincially Significant Wetlands when considering the Allocated pumping rates (approximately representing future demands between 2031 and 2036). A Low Risk Level was also assigned considering the Tolerance of the municipal water supply system; the system is considered to have a High Tolerance due to sufficient water storage and well redundancy that supports the system in meeting existing demands. However, the current municipal well infrastructure cannot meet the WSMP's estimated average annual 2041 water demand estimate. This circumstance results in a Significant Risk Level designation for the Groundwater Vulnerable Area.

The WSMP evaluated alternatives to meet the 2041 population demand and outlined a process whereby the municipality will locate and test new water supply wells. However, the preliminary water supply alternatives considered in the WSMP do not currently meet the requirements to be considered under this Tier Three Assessment. The municipality may complete Tier Three scenarios to assess additional future risk when they have located, tested and evaluated these future supply wells.

Following the *Technical Rules*, existing consumptive water users and identified areas of future recharge reduction in the Groundwater Vulnerable Area were classified as Significant water quantity threats. These consumptive water users include the permitted water demands (i.e., 9 municipal and 17 non-municipal takings) and non-permitted (e.g., domestic and agricultural) water demands (i.e., 2,715 non-municipal, non-permitted takings). Finally, 4.3 km^2 of reduced groundwater recharge areas were also identified as Significant water quantity threats within the boundaries of the towns of Fergus and Elora.

9.3 Recommendations

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

1. Reduce uncertainty through collection of additional field data:

    a. The results of the model calibration and Risk Assessment process suggest that there remains uncertainty relating to the conceptual model along the western model boundary, western lower aquifer, and the localized influence of karst features. This results in less certainty in the model conceptualization and predictions in areas farther from the Centre Wellington municipal wells. There is an opportunity to increase certainty by filling the existing important knowledge gaps with high-quality geological data and completion of aquifer pumping tests. Recent and future publications that provide more clarity of the regional conceptual model for karst could also be used to refine the regional bedrock characterization in the future.

    b. The model's simulation of drawdown at the Middlebrook Well due to pumping from that well is also uncertain. There is an opportunity to reduce this uncertainty by similarly collecting additional local high-quality data and completing an aquifer pumping test in the area.

2. Re-evaluate Risk Assessment scenarios following the completion of The Centre Wellington WSMP (AECOM 2019): The WSMP will be recommending new areas for municipal groundwater supply exploration. The Tier Three Assessment scenarios should be repeated as new data becomes available through the results of the study to assess new sources regarding their sustainability in meeting future municipal demands.

3. Use of the Tier Three model in assessing water taking applications: If new permitted water takings are proposed within the Groundwater Vulnerable Area, the Tier Three model may be applied to determine the impact of the proposed water taking on municipal water supply reliability. In the event of such an application of the model, refinements may be needed in the area of that taking to account for new geological data and should utilize additional field data collected as part of the application. If the Tier Three model is selected for utilization in a water taking application, the necessity of these refinements may be assessed, at the time of a proposed taking, in conjunction with Centre Wellington, the GRCA, the Ministry of Environment, Conservation and Parks (MECP) and applicant.

4. Continue monitoring municipal well performance in a well-maintenance program: The Risk Assessment scenarios analyzed groundwater level decline assuming maintained well performance. The ability of the wells to sustain future pumping rates is dependent on ongoing monitoring of water levels within the municipal wells, as well as regular well maintenance. It is recommended that Centre Wellington continue to monitor water levels in the municipal wells, well performance, and to rehabilitate the wells when needed to ensure the validity of the Risk Assessment results.

5. Continue water conservation programs: Current water conservation programs should be continued to maintain or reduce water demand per capita. Additional opportunities to reduce water demand within Centre Wellington could also be considered as outlined in the WSMP. Any reduction in the per capita water use will enhance water supply reliability and local ecosystem health.

6. Improve model calibration using expanded baseflow locations: Model calibration to baseflow was limited by a single surface water gauge on Irvine Creek. Data from additional flow gauging stations should be obtained and used to better characterize the streamflow in other parts of the Study Area and the interaction between the streams and the groundwater flow system.

7. Regular updates of water budgets by the GRCA: The GRCA maintains water budget modelling tools to help manage and protect the water resources across the watershed. These modelling tools should be updated periodically as new information is gathered and insights evolve within the watersheds.

8. Consider conducting a partial or full Risk Management Measures Evaluation Process (RMMEP): As a Significant Risk Level was assigned to the Groundwater Vulnerable Area and as all consumptive water uses and areas of groundwater recharge reductions within this Vulnerable Area are classified as Significant Drinking Water Threats, a RMMEP may be initiated. A RMMEP involves using the Tier Three model to rank the relative impact of individual or groups of water quantity threats on the municipal

wells and then evaluate possible measures that may be implemented to reduce the Water Quantity Risk Level in the Vulnerable Area. The RMMEP may expand on the recommended risk management measure and provide recommendations to the municipality, conservation authority and Province for maximizing the benefits of each measure. It is recommended that an RMMEP include an evaluation of the relative significance of the simulated non-municipal, non-permitted domestic and agricultural takings on water levels in the municipal wells. This is because the boundary of the Groundwater Vulnerable Area was predicted to extend past the subset of wells simulated to represent non-municipal, non-permitted takings within a 1 km (i.e., domestic wells) and 3 km (i.e., agricultural wells) buffer of the Centre Wellington municipal wells.

9. Evaluate Land Use Change Outside of Fergus and Elora: Recharge reduction due to anticipated future land use change was evaluated for Fergus and Elora and these areas were identified as Significant water quantity threats within the WHPA-Q. While Fergus and Elora are considered key growth areas within the Study Area, additional areas of anticipated future land use change that will cause recharge reduction would also be considered Significant threats within the WHPA-Q and should be identified outside of Fergus and Elora.

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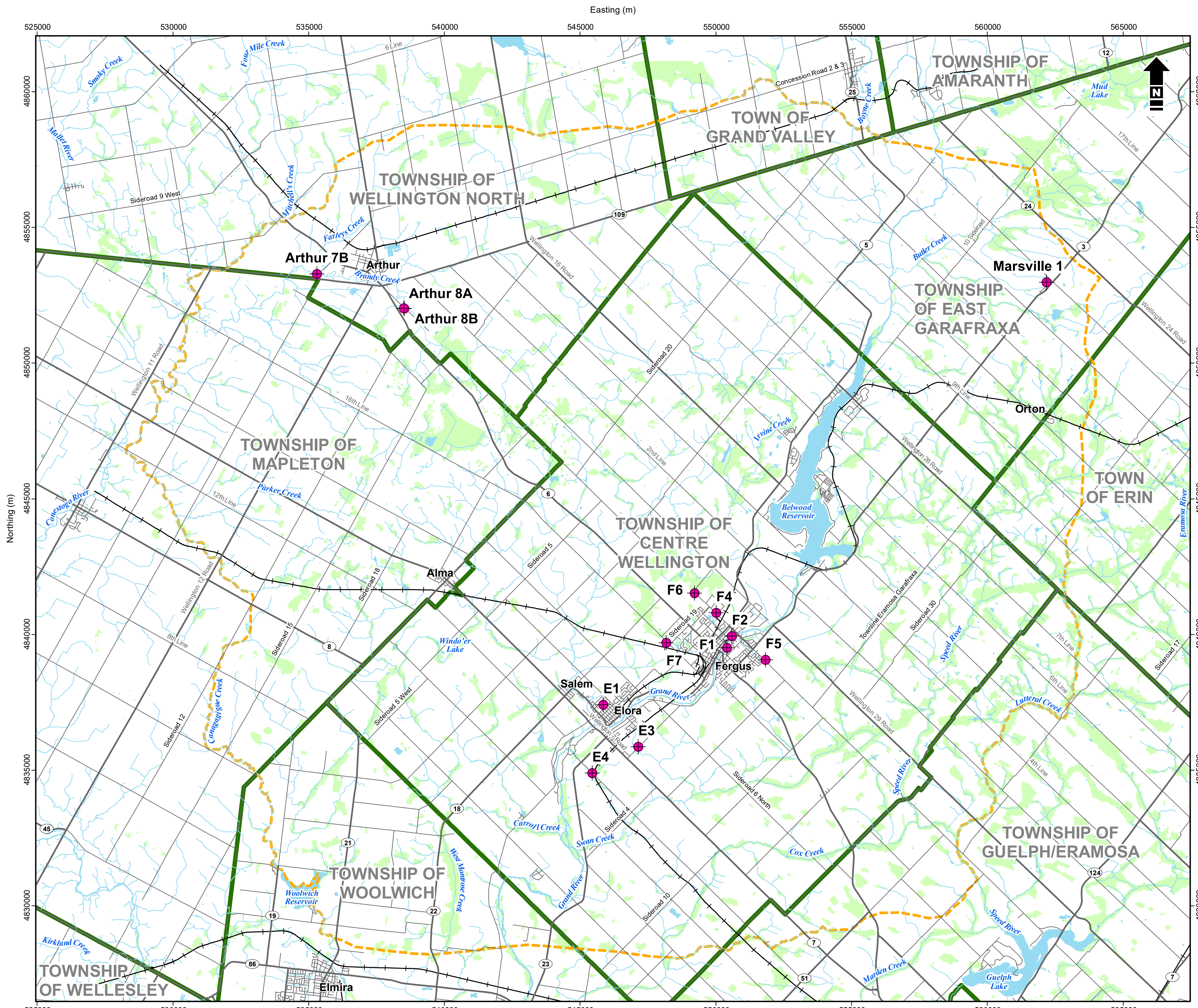

- Study Area
- Municipal Boundary
- Wetland
- Water Body
- Watercourse
- Highway
- Road
- Railroad Trail
- Municipal Well

1:145,000 metres

1,500 0 1,500 3,000

NAD 1983 UTM Zone 17N

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

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Grand River Conservation Authority
Centre Wellington Tier Three Water Budget Assessment - Risk Assessment Report

Study Area

Date:	Project:	Submitter:	Reviewer:
October 2019	23876	J. Melchin	D. Van Vliet

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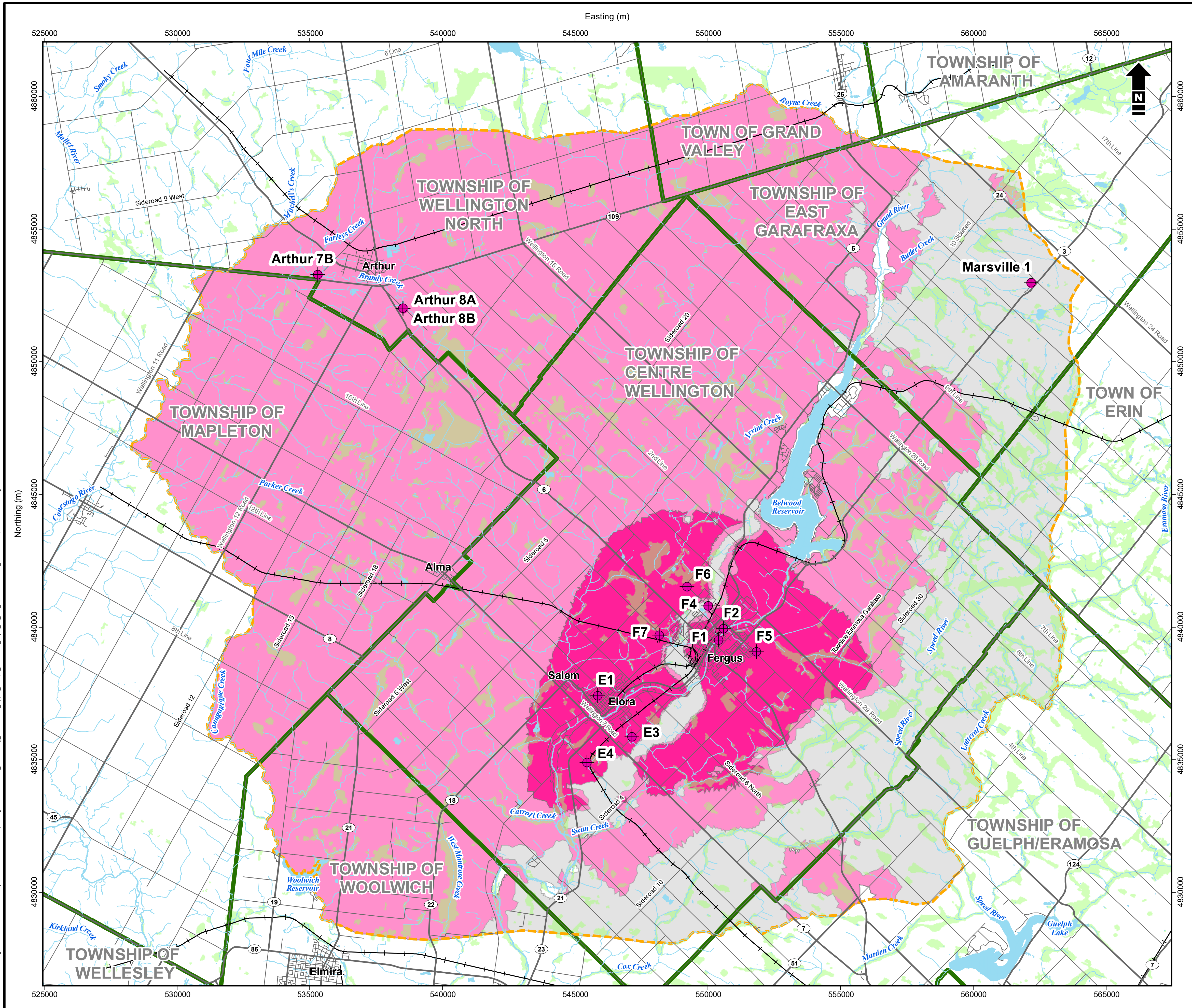
Figure 1



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Centre Wellington Tier Three Water Budget Assessment - Risk Assessment Report

Parameter Uncertainty Assessment Upper Guelph Formation (Layer 11 and 12)

Date:	Project:	Submitter:	Reviewer:
October 2019	23876	J. Melchin	D. Van Vliet

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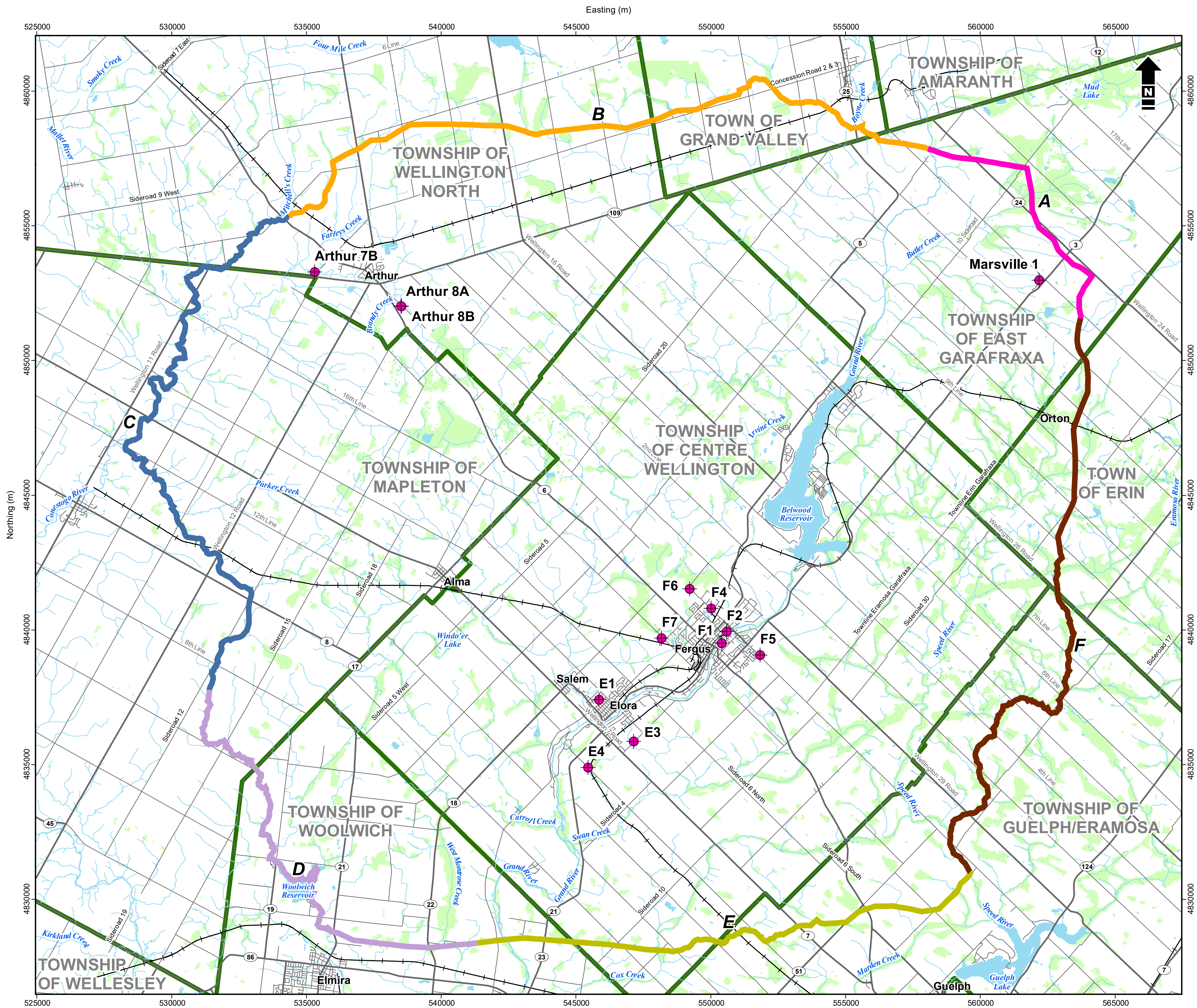
Figure 2



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

Model Boundary Assessment Segment

- A
- B
- C
- D
- E
- F

1:145,000 metres
1,500 0 1,500 3,000
NAD 1983 UTM Zone 17N

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Model Boundary Assessment - Segments

Date:	Project:	Submitter:	Reviewer:
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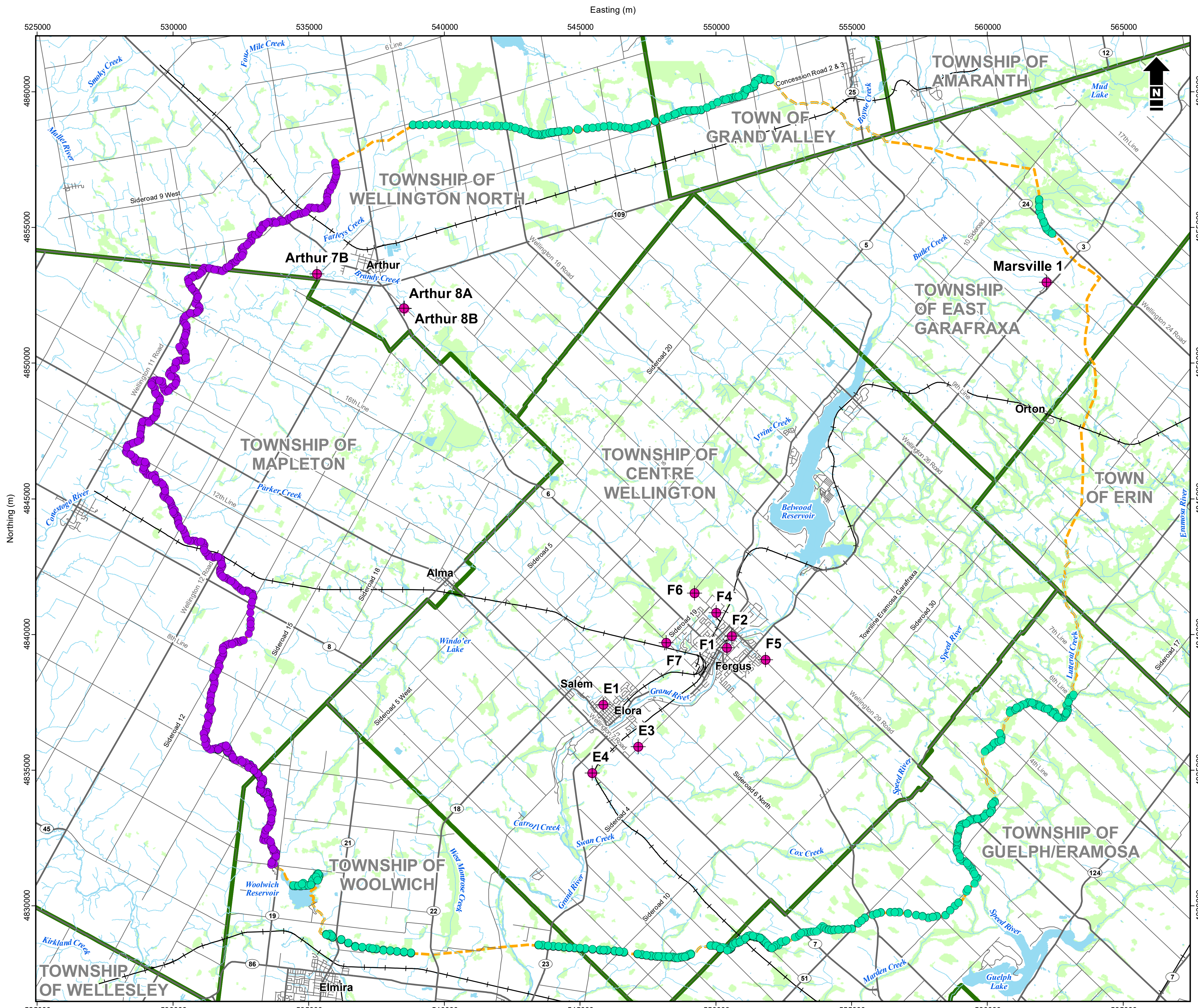
Figure 3



Study Area
Municipal Boundary
Wetland
Water Body
Watercourse
Highway
Road
Railroad Trail
Municipal Well
Lower Bedrock Boundary Condition - Current
Lower Bedrock Boundary Condition - New

1:145,000
1,500 0 1,500 3,000 metres
NAD 1983 UTM Zone 17N

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Additional Model Boundary Conditions

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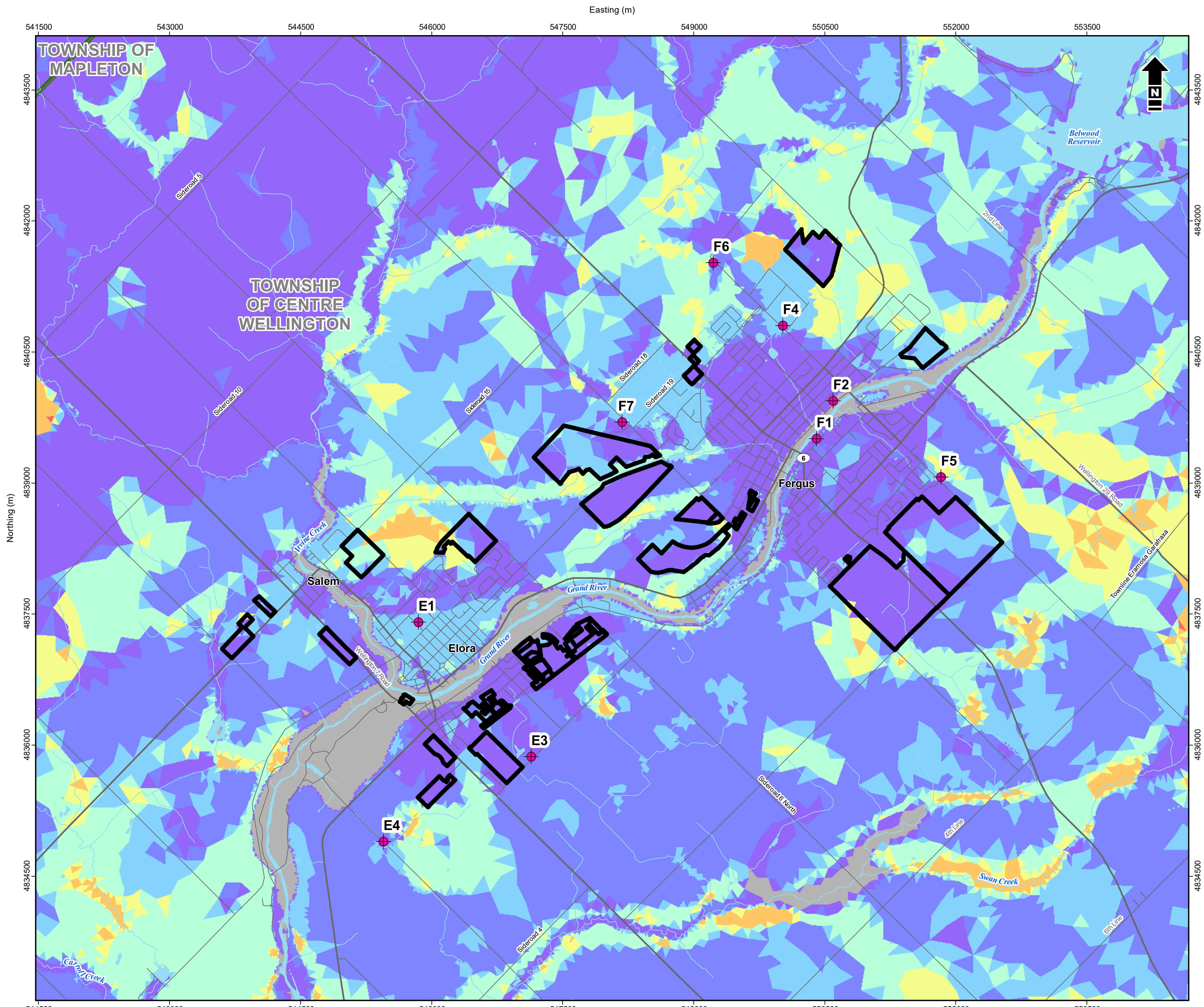
Figure 4



Land Use Change
Municipal Boundary
Water Body
Watercourse
Highway
Road
Municipal Well

Future Groundwater Recharge (mm/yr)

0
0 < ... <= 75
75 <...<= 125
125 < ...<= 200
200 < ... <= 300
300 < ... <= 400
400 < ... <= 500
> 500

1:45,000 metres
500 0 500 1,000
NAD 1983 UTM Zone 17N

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Centre Wellington Tier Three Water Budget Assessment - Risk Assessment Report

Land Use Change and Future Recharge

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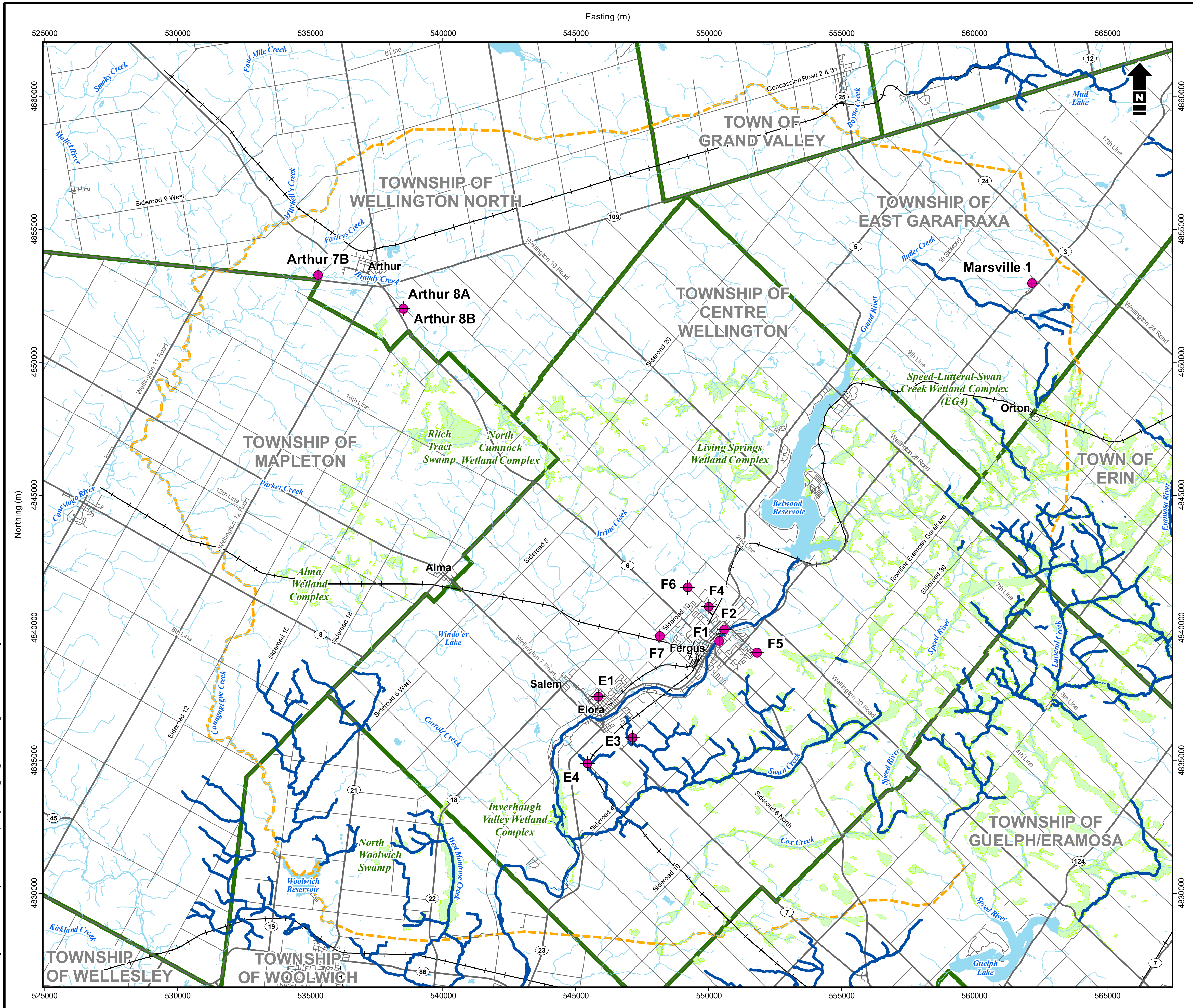
Figure 5



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Centre Wellington Tier Three Water Budget Assessment - Risk Assessment Report

Other Water Uses

Date:	Project:	Submitter:	Reviewer:
October 2019	23876	J. Melchin	D. Van Vliet

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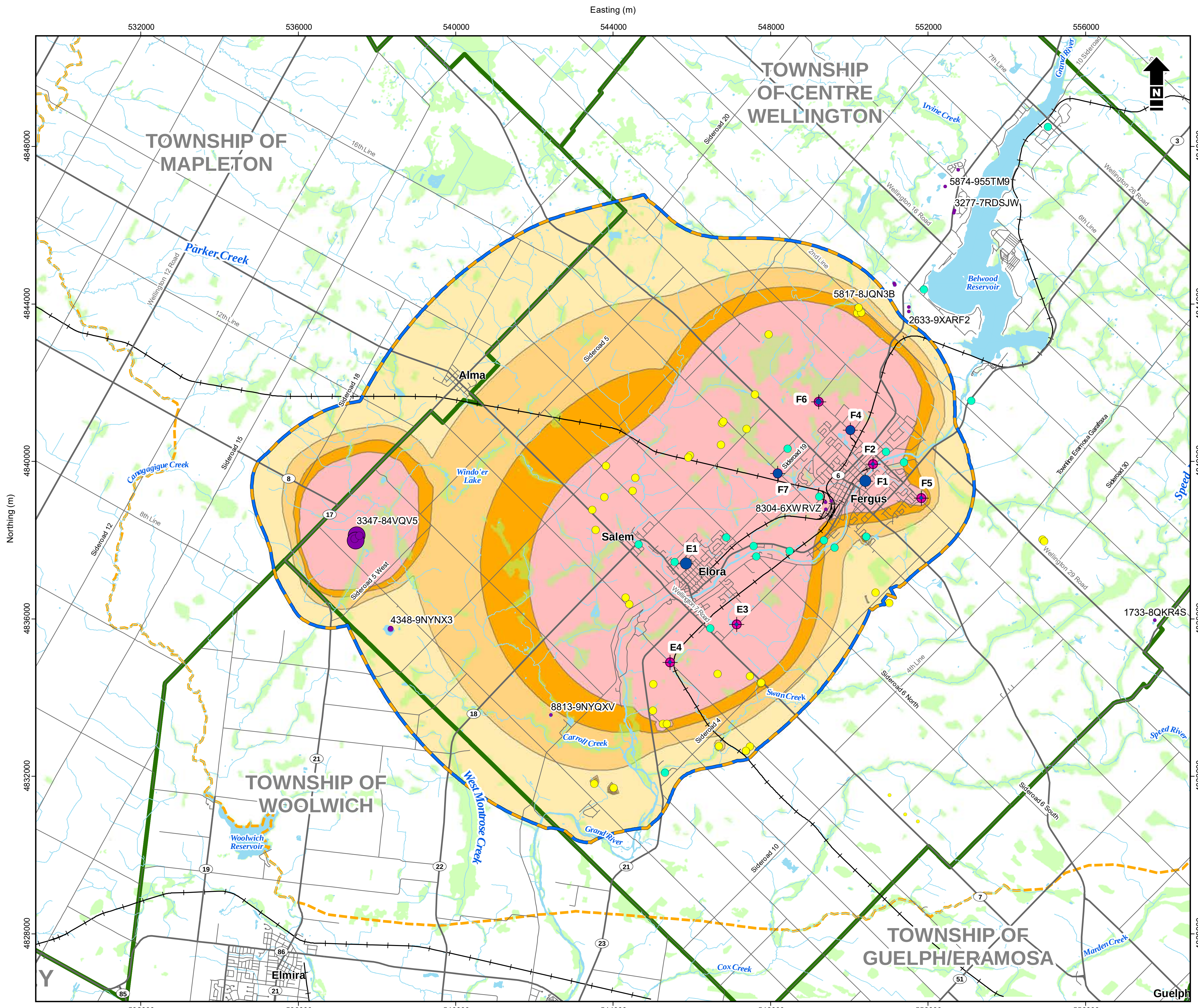
Figure 6



Study Area
WHPA-Q1/WHPA-Q2/Groundwater Vulnerable Area
Municipal Boundary
Water Body
Watercourse
Highway
Road
Railroad Trail
Municipal Well

Drawdown (m)

- 2 - 3
- 3 - 4
- 4 - 5
- > 5

Simulated Municipal and Non-municipal Demands

Type

- Municipal PTTW
- Non-Permitted Agriculture
- Non-Municipal PTTW
- Well Representing a Cluster of Domestic Wells

Average Annual Consumptive Rate (m^3/day)

- < 250
- 250 - 500
- 500 - 750
- 750 - 1000
- 1000 - 1250
- 1250 - 1500
- 1500 - 1750
- > 1750

Note: the Risk Level assignment to the Groundwater Vulnerable Area does not imply that an individual groundwater taking or recharge reduction activity within that area will threaten the reliability of the municipal water supply.

1:100,000 metres
1,000 0 1,000 2,000
NAD 1983 UTM Zone 17N

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Grand River Conservation Authority
Centre Wellington Tier Three Water Budget Assessment - Risk Assessment Report

WHPA-Q1/WHPA-Q2/Groundwater Vulnerable Area

Date:	Project:	Submitter:	Reviewer:
October, 2019	23876	J. Melchin	D. Van Vliet

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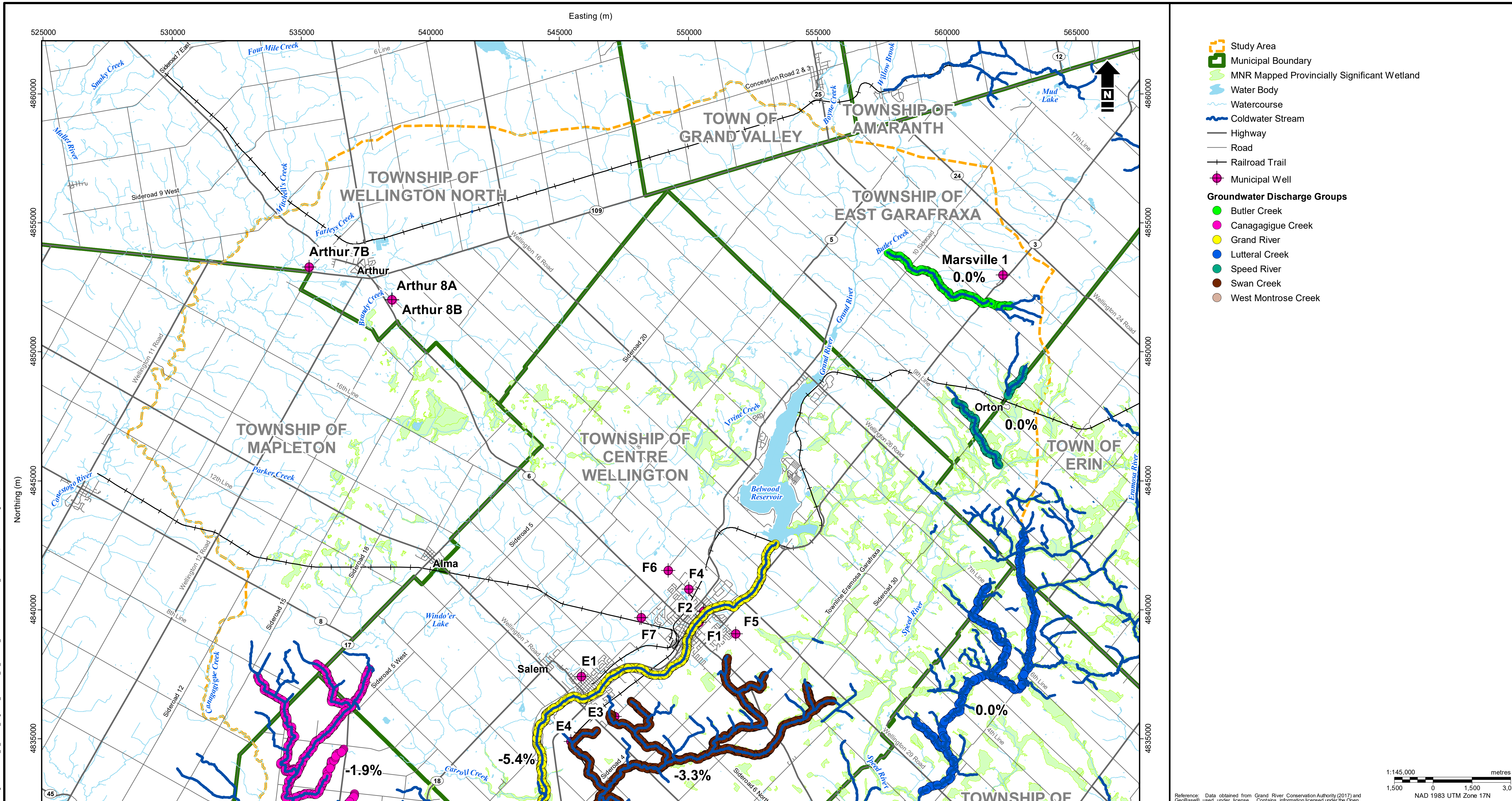
Figure 7



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Grand River Conservation Authority
Centre Wellington Tier Three Water Budget Assessment - Risk Assessment Report

Location of Stream Segments Evaluated for Baseflow Reductions

Date: October 2019	Project: 23876	Submitter: J. Melchin	Reviewer: D. Van Vliet

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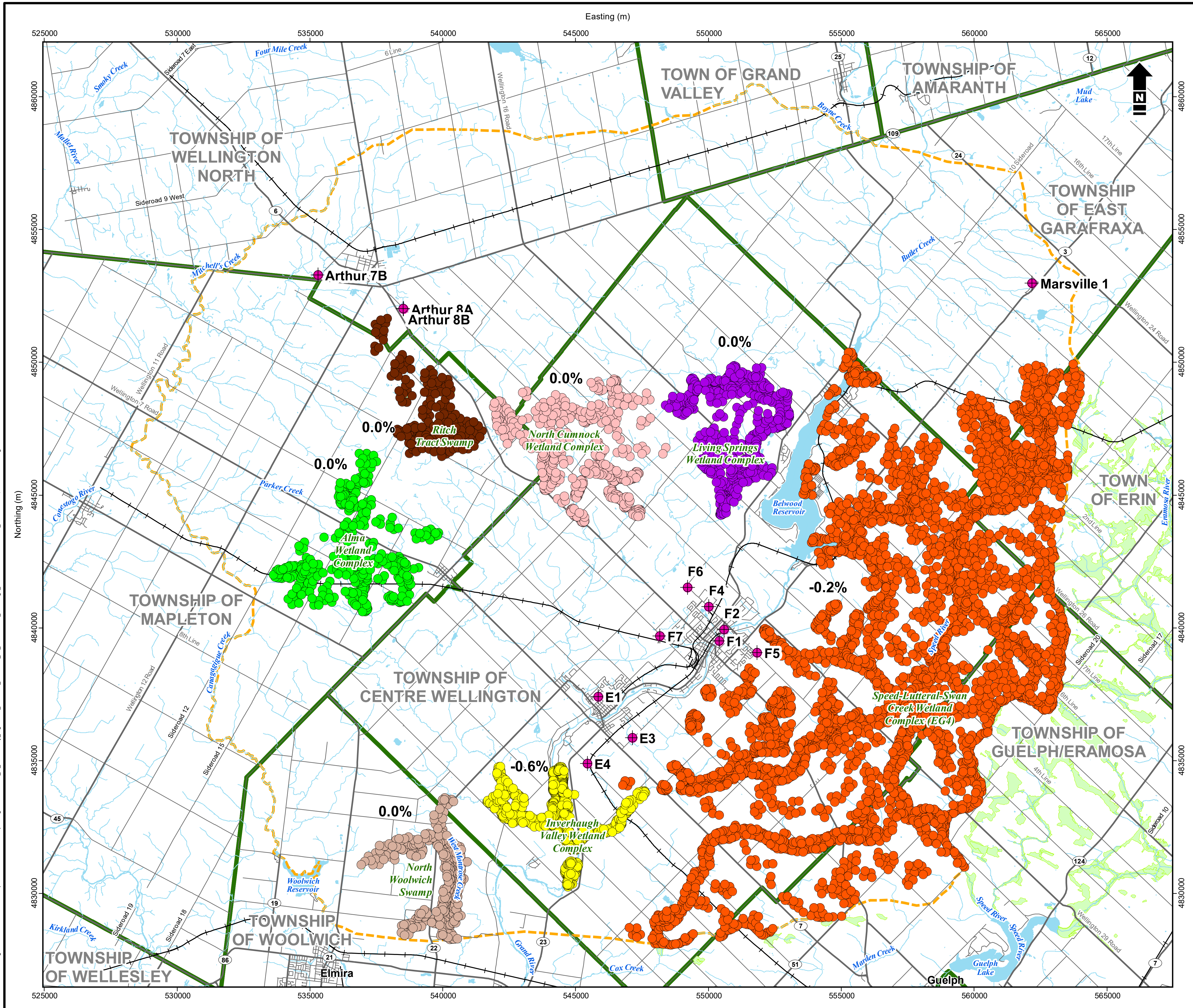
Figure 8



Study Area
Municipal Boundary
MNR Mapped Provincially Significant Wetland
Water Body
Watercourse
Highway
Road
Railroad Trail
Municipal Well

PSW Groundwater Discharge Group
Alma Wetland Complex
Inverhaugh Valley Wetland Complex
Living Springs Wetland Complex
North Cumnock Wetland Complex
North Woolwich Swamp
Ritch Tract Swamp
Speed Lutteral Swan Creek Wetland Complex

1:145,000
metres
1,500 0 1,500 3,000
NAD 1983 UTM Zone 17N

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Centre Wellington Tier Three Water Budget Assessment - Risk Assessment Report

Location of Provincially Significant Wetlands Evaluated for Groundwater Discharge Reductions

Date:	Project:	Submitter:	Reviewer:
February 2020	23876	J. Melchin	D. Van Vliet

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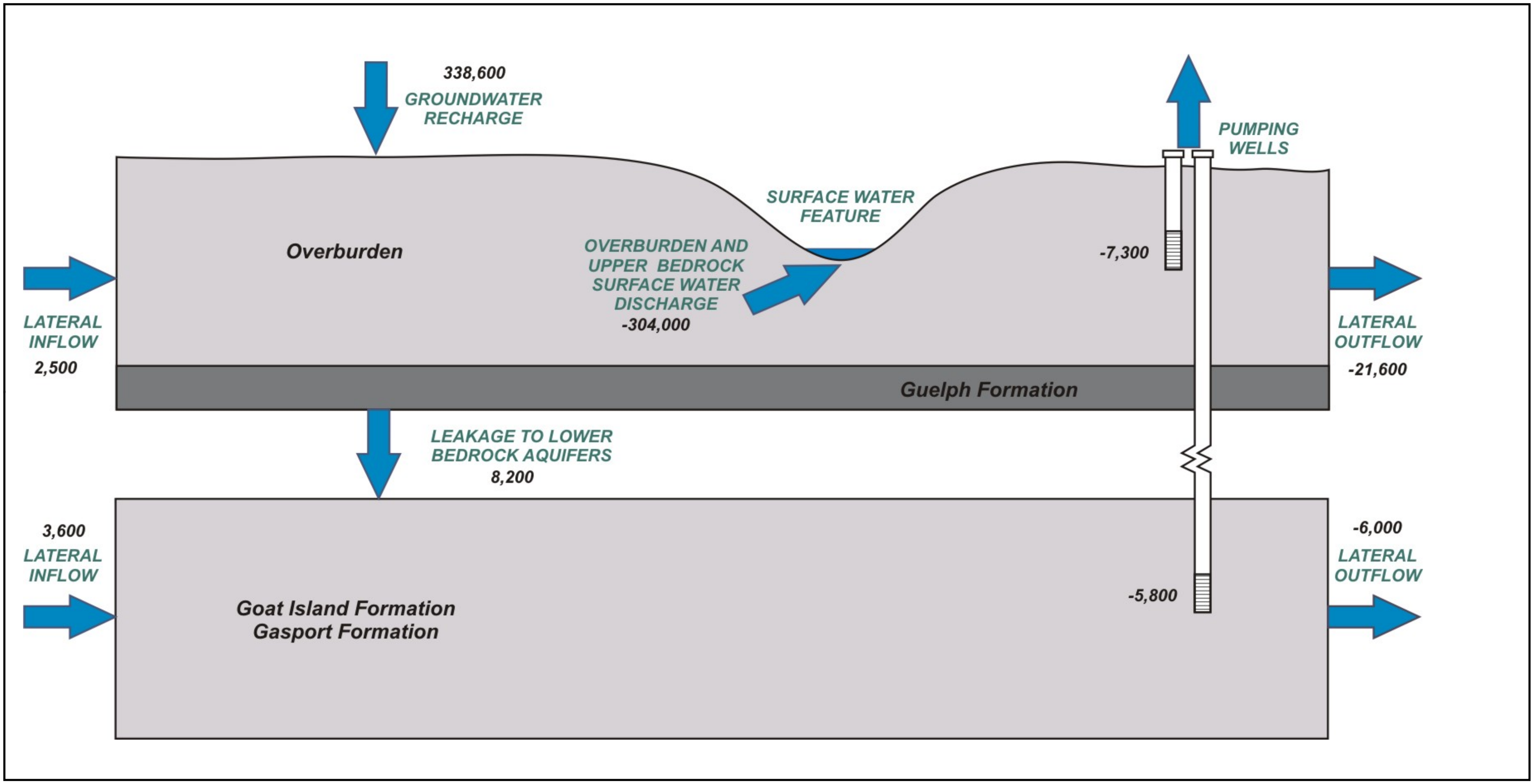
Figure 9

I:\GrandRiverCA\23876\FiguresandTables\T3\2019\Report\RiskAssessmentReport\Figure-10-Water_Budget_Schematic_Scenario_C.mxd - Letter_L - 02-Oct-19, 12:46 PM - lmwright - TID002



Note: all flows are in m ^{3}/day

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Grand River Conservation Authority
Centre Wellington Tier Three Water Budget Assessment - Risk Assessment Report

Water Budget Schematic - Scenario C

Date:	Project:	Submitter:	Reviewer:
October 2019	23876	J. Melchin	D. Van Vliet

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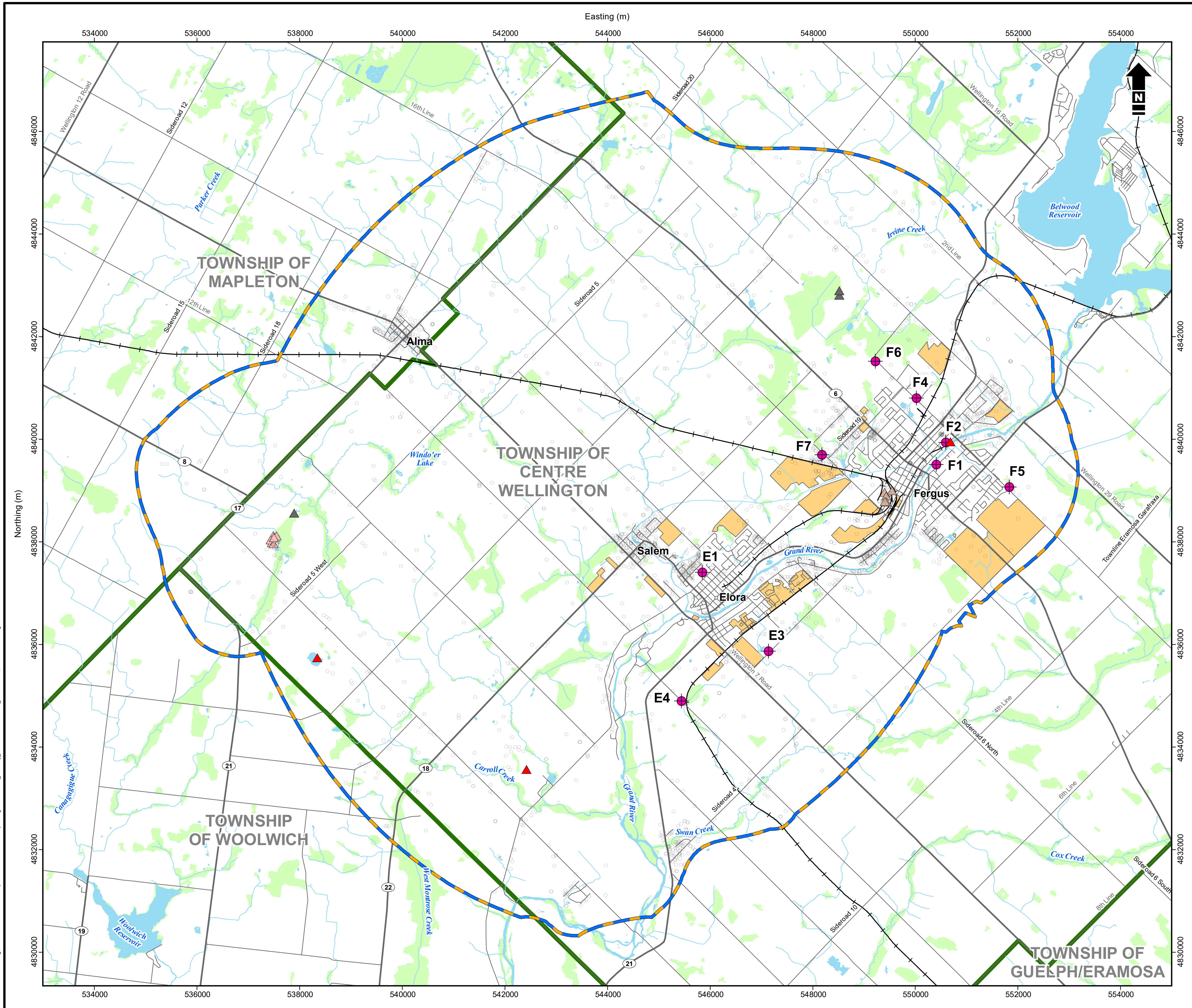
Figure
10



WHPA-Q1/WHPA-Q2/Groundwater Vulnerable Area
Municipal Boundary
Groundwater Recharge Reduction Threat
Wetland
Water Body
Watercourse
Highway
Road
Railroad Trail
Municipal Well
Non-Permitted Consumptive Water Taking Threat

Permitted Consumptive Water Taking Threat

Commercial
Industrial
Miscellaneous
Remediation

Note: the Risk Level assignment to the Groundwater Vulnerable Area does not imply that an individual groundwater taking or recharge reduction activity within that area will threaten the reliability of the municipal water supply.

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

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Centre Wellington Tier Three Water Budget Assessment - Risk Assessment Report

Water Quantity Threats

Date:	Project:	Submitter:	Reviewer:
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Figure 11