REGION OF WATERLOO
TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

Report Prepared for:
REGION OF WATERLOO

Prepared by:
MATRIX SOLUTIONS INC.
AND
S.S. PAPADOPULOS AND ASSOCIATES INC.

Final Report; September 2014
Waterloo, Ontario

31 Beacon Point Court
Breslau, Ontario, Canada N0B 1M0
Phone: 519.772.2777 Fax: 519.648.3168
www.matrix-solutions.com

REGION OF WATERLOO

TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

Report prepared for the Region of Waterloo, September 2014

Patricia Meyer, M.Sc., P.Geo.
Matrix Solutions Inc.
Senior Hydrogeologist

reviewed by
Paul Martin, M.Sc., P.Eng.
Matrix Solutions Inc.
Principal Hydrogeological Engineer

Martinus Brouwers, M.A.Sc.
Matrix Solutions Inc.
Groundwater Modelling Specialist

Chris Neville, M.A.Sc.
S.S. Papadopulos and Associates
Senior Hydrogeologist

Jinhui Zhang, M.A.Sc.
S.S. Papadopulos and Associates,
Groundwater Modelling Specialist

DISCLAIMER

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

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

EXECUTIVE SUMMARY

This report describes a water quantity risk assessment completed as part of the Region of Waterloo Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment). This assessment was completed on a number of municipal drinking water systems located within the Region of Waterloo in the Province of Ontario, Canada. As a requirement under the *Clean Water Act* (MOE 2006), the purpose of this project was to identify water quantity threats to these municipal drinking water systems. The project was also completed as a pilot project to test and refine the approaches and methodologies for conducting a Tier Three Assessment.

The Tier One and Tier Two Water Quantity Stress Assessments required technical studies completed for many subwatersheds across the province. The Water Quantity Stress Assessment compared available groundwater and surface water supply to demand from existing and future drinking water systems. Where the ratio of water demand to water supply was high, subwatersheds were 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 Quantity Stress Assessment completed for the Grand River Watershed (AquaResource 2009a) identified the Central Grand River and Canagagigue subwatersheds as having a Significant and Moderate potential for hydrologic stress for the groundwater sources, respectively. The identification of stress led to the requirement for Tier Three Assessment for the well fields within the Region of Waterloo that are located within these two subwatersheds.

This report details the Tier Three Assessment carried out for the Region of Waterloo. It summarizes the municipal water demands, and the process and results of the Tier Three Assessment. Several companion reports summarize the development of the conceptual hydrogeologic models, as well as the numerical hydrologic and groundwater flow models used to complete the Risk Assessment and the water budget.

Scope of Work

The scope of work completed in this Tier Three Assessment and documented in this report follows the Province’s Technical Rules and Technical Guidance Bulletin (MOE 2009; MOE and MNR 2010).

The following tasks were completed for this study:

- Develop and calibrate a groundwater flow model with sufficient detail to simulate groundwater flow near municipal wells and surface water features.

- Refine an existing hydrologic model to simulate variable stream flow in the area and to estimate groundwater recharge rates in the Study Area.

- Apply the calibrated watershed-based flow generation model and groundwater flow models to assess the water budget components in the Study Area and in the vicinity of municipal wells.

- Complete a Local Area Risk Assessment for the municipal wells located in the Study Area.

- Delineate and map significant groundwater recharge areas (SGRAs).

Water Budget Tools

As part of the Tier Three Assessment, hydrologic and groundwater modelling tools were developed 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, and refined around wells (and intakes) to a level supported by available data. The models were calibrated to represent typical operating conditions under average (steady-state) and variable (transient) pumping and climate conditions.

The groundwater and surface water modelling approach was designed to simulate average and drought conditions, to represent the detailed hydrologic and/or hydrogeologic conceptual model, and to integrate the inputs and outputs of the surface water and groundwater models (e.g., groundwater recharge, baseflow). The groundwater flow model was developed using FEFLOW (DHI-WASY 2011) based on the best geological and hydrogeological data available for the study area (Matrix and SSPA 2012). The Guelph All-Weather Storm-Event Runoff (GAWSER) watershed-based flow generation model, previously developed by Grand River Conservation Authority, was refined, re-calibrated, and validated (AquaResource 2009b). The companion reports describe the development and calibration of the watershed-based flow generation model and groundwater model in greater detail.

Local Area Risk Assessment

Four distinct Local Areas were delineated for the municipal supply wells in the Study Area. These areas were delineated following the Province's Technical Rules (MOE 2009) based on a combination of the cone of influence of each municipal well, as well as land areas where reductions in recharge have the potential to have a measurable impact on the municipal wells. They encompass the Kitchener-Waterloo and Cambridge areas as well individual areas for Conestoga Plains and Blair Road wells.

A set of Risk Assessment scenarios were developed to represent the municipal allocated quantity of water (existing plus committed demands up to the current permitted water takings) and current and planned land uses. The calibrated watershed-based flow generation modeland two groundwater flow models were used to estimate both the changes in groundwater elevations in the municipal supply aquifer and the impacts to groundwater discharge and baseflow under average and drought climate conditions.

Conclusions

Based on the results of the Risk Assessment modelling scenarios, all four of the Local Areas containing municipal supply wells were classified as having a Low Risk Level. This is due to the productive overburden and bedrock aquifers in the area, and also on the large, integrated system of groundwater wells, the Grand River surface water intake and the Aquifer Storage and Recovery System at Mannheim, which increase the management options and increases the tolerance in the municipal supply system. Following the methods laid out in the Technical Rules (MOE 2009), there are no consumptive water users or potential reductions to groundwater recharge within the Local Areas that are classified as Significant water quantity threats.

TABLE OF CONTENTS

FIGURES

LIST OF TABLES

APPENDICES

1 INTRODUCTION

The Province of Ontario introduced the *Clean Water Act* (Bill 43; MOE 2006) to ensure that all residents have access to safe drinking water. Under the *Clean Water Act*, Source Protection Authorities are required to conduct technical studies to identify 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* (MOE 2006), municipalities may be required to complete a Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) to assess the ability of the municipal water sources to meet their Allocated water demands. Tier Three Assessments are required where municipal wells or intakes are located in subwatersheds that were classified as having a Moderate or Significant stress as part of a Tier Two Water Quantity Stress Assessment completed under the requirements of the *Clean Water Act* (MOE 2006). Tier Three Assessments identify municipal wells or intakes that may be unable to meet their allocated water demands under average or drought conditions.

Following the completion of the Grand River Tier Two Water Quantity Stress Assessment (AquaResource 2009a), a Tier Three Assessment was required for several municipal systems within the Region of Waterloo (Region). Some of the Region's municipal wells are located within the Central Grand River and Canagagigue Subwatersheds (Figure 1-1), which were classified as having a Significant and Moderate stress levels, respectively, in the Tier Two Stress Assessment.

This report summarizes the existing and Allocated water demands, the existing and future (Official Plan) land development areas, and the methodology and results of the Local Area Risk Assessment. Several companion reports summarize the development and calibration of the numerical hydrologic and groundwater flow models used to complete this Tier Three Assessment (AquaResource 2009b; Matrix and SSPA 2012).

1.1 The Study Area

The Region lies within southwestern Ontario and includes the cities of Kitchener, Waterloo and Cambridge, as well as several, smaller, rural communities located within the Townships of Wilmot, North Dumfries, Wellesley and Woolwich (Figure 1-1). The population of the Region currently is approximately 550,000, most of whom are reliant on municipal water for their potable water supplies. Within the cities of Cambridge, Kitchener, and Waterloo, municipal water supply is provided through an integrated urban system (IUS) that is 75% derived from groundwater sources, and 25% from a surface water intake on the Grand River, located at Hidden Valley (Kitchener). The Region also provides municipal water through groundwater wells to portions of 16 other smaller communities and settlement areas including Elmira, New Dundee, Conestogo and West Montrose. In general, most of the groundwater production wells in the Cambridge area extract water from bedrock aquifers, and most of the production wells in the Kitchener and Waterloo areas extract water from aquifers associated with the Waterloo Moraine and underlying overburden sediments.

The Tier Three Assessment Study Area (also referred to as the Study Area) is depicted on Figure 1-1 and includes all of the active and inactive municipal wells within the urban areas of Kitchener, Waterloo and Cambridge, as well as four rural well fields (Elmira, West Montrose, Conestogo and New Dundee) that are located in either the Central Grand or Canagagigue Subwatersheds (Figure 1-2). (Note: St. Agatha was included in the Tier Three Assessment at the onset of the study, but the wells were decommissioned in recent years with notification protocols in accordance with the *Clean Water Act* [MOE 2006]. These wells are not discussed at any length in this report).

From a hydrologic perspective, the Region includes several large tributaries of the Grand River, including the Conestogo, Speed and Nith Rivers, as well as numerous smaller tributaries such as Alder Creek, Schneider Creek, Laurel Creek and Hunsberger Creek (Figure 1-1). Land use within the Study Area includes natural heritage features such as wetlands, green-lands and forested areas, as well as urban areas, aggregate extraction areas and rural agricultural.

1.2 Study Team

The Region of Waterloo Tier Three Assessment was initiated by the Region, was directed by a technical Peer Review team, and completed by a consultant project team. The technical Peer Review team was comprised of members of the following organizations:

- Region of Waterloo (the Region)
- Ministry of Natural Resources (MNR)
- Ontario Ministry of the Environment (MOE)
- Grand River Conservation Authority (GRCA) as a partner in the Long Point Region Source Water Protection Region
- Technical advisors to the Long Point Region Source Protection Region

The consultant project team consisted of:

- Matrix Solutions Inc., the primary consultant
- S.S. Papadopulos and Associates Inc.
- Golder Associates Ltd.
- Stantec Consulting Ltd.
- Blackport Hydrogeology Inc.

1.3 *Clean Water Act* Water Budget Framework

The *Clean Water Act* (MOE 2006) requires that each Source Protection Committee prepare an Assessment Report for their Source Protection Area in accordance with Ontario Regulation 287/07 (General Regulation) and the Technical Rules for the Assessment Report. A requirement of the Assessment Report is the development of water budgets to assess water availability to meet municipal water demand within a tiered framework. Tier One and Tier Two Assessments evaluate the level of potential subwatershed hydrologic stress under various climate and water use scenarios. The Tier Three Assessment establishes the risk that a community's sources of water will not be able to meet Allocated water demands, taking into consideration climate and other water uses.

Water Budgets developed under the *Clean Water Act* (MOE 2006) provide a quantitative measure of the hydrologic cycle components and a conceptual understanding of the processes and pathways by which surface water and groundwater flows through a watershed or subwatershed. Key deliverables of the water budget analyses include the watershed based flow generation models and groundwater flow models.

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

The Tier Three Water Budget and Local Area Risk Assessment is completed for two reasons: 1) to estimate the likelihood that a municipality will be able to sustain its Allocated Rates; and 2) to identify threats placed on the drinking water sources that may influence the municipality’s ability to meet their Allocated Rates. A Tier Three Water Budget uses numerical groundwater and/or hydrologic models that are refined to the extent that they have the accuracy needed to evaluate hydrologic or hydrogeologic conditions at a water supply well or surface water intake.

1.3.1 Tier Three Water Budgets and Local Area Risk Assessments

A Tier Three Assessment is undertaken for a municipal supply when it is located within a subwatershed that has been assigned a Moderate or Significant water quantity hydrologic stress level in the Tier Two Water Quantity Stress Assessment. In general, Water Quantity Stress Assessments provide a consistent approach for evaluating the long-term reliability of the Province’s drinking water sources, and they identify drinking water threats located within local vulnerable areas.

The Tier Three Assessment is completed for the “Local Area” and focuses the water budget assessment around municipal drinking water wells or surface water intakes. Local Areas for surface water or groundwater systems are vulnerable areas, and for groundwater wells, the Local Area is the combination of the cone of influence of the municipal wells and other water takings whose cones of influence intersect that of the wells, and areas where reductions in recharge would have a measurable impact on the cone of influence of the wells.

Calibrated Tier Three Assessment models estimate the impact of increased water demand, variations in climate, and land use development on 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 Allocated Rates, the Local Area is assigned a ”Moderate” or ”Significant” water quantity Risk Level. Once the Risk Level is assigned to the Local Area, activities within the Local Area that remove water from an aquifer or surface water body without returning that water to the same aquifer or surface water body (i.e., consumptive water uses) are identified as drinking water threats. Similarly, activities that reduce groundwater recharge to an aquifer within the Local Area are identified as drinking water threats and are classified as Moderate or Significant depending on the Local Area Risk Level. The Risk Assessment modelling scenarios consider the need to meet water demand requirements of other uses, such as wastewater assimilation flows or the ecological flow requirements of a cold water fish habitat.

The MOE Technical Rules (Part IX.1 to Part IX.4; MOE 2009), the MOE and MNR Technical Bulletin (MOE and MNR 2010) and the MNR/MOE water budget guide (MNR and MOE 2011) address the requirements and deliverables for the Local Area Assessment and Risk Level. As most of the guidance manuals were not completed before the initiation of this study, this project was completed as a pilot project to test and refine the approaches and methodologies for conducting Tier Three Assessments.

1.3.2 Tier Three Methodology

Each Tier Three Water Budget and Local Area Risk Assessment is required to complete the following steps:

- Develop the conceptual and numerical Tier Three Assessment models with detailed hydrogeologic and/or hydrologic characterization surrounding municipal wells and intakes. The conceptual models form the basis for the development of numerical models that are calibrated to represent typical 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 Quantity of Water by compiling and describing the existing, and Allocated Rates, for each municipal wells and intake.

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

- Characterize future land uses by evaluating the potential impact of future land use changes on drinking water sources. This task is done 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 (WHPA-Q1 and WHPA-Q2) using the Tier Three Water Budget Model.

- Define the Local Area based on the delineation of the WHPA-Q1 and WHPA-Q2 areas.

- Evaluate the Risk Assessment scenarios, using the Tier Three Water Budget Model 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, Significant) to the Local Area(s) based on the results of the Risk Assessment scenarios. An uncertainty level (e.g., high and low) will accompany each Risk Level ranking.

- Identify drinking water quantity threats such as consumptive water uses or reductions in recharge for Local Areas where the Risk Level is Significant and Moderate.

Details regarding the steps undertaken to complete the Tier Three Assessment for the Region of Waterloo are discussed throughout this document.

1.4 Region of Waterloo Tier Three Assessment

1.4.1 Introduction

In the Tier Two Assessment, the GRCA identified the Canagagigue Creek and the Central Grand Subwatersheds (Figure 1-1) as having a Moderate and Significant potential for hydrologic stress, respectively. This identification of potential stress led to the requirement for a Tier Three Assessment for all of the municipal wells located within these assessment areas. The Canagagigue Creek Assessment Area includes municipal wells within West Montrose, Conestogo (Conestogo Plains) and Elmira (Well E10). The Central Grand Assessment Area contains the New Dundee Well Field, the well fields located within the Cities of Kitchener, Waterloo and Cambridge, as well as those located within Wilmot Township (Erb Street and Mannheim West Well Fields), and the Township of Woolwich (Forwell Well

Field; Figure 1-1). As such, the Tier Three Assessment needed to assess the likelihood that the Region will be able to meet future water quantity requirements for these municipal water supplies.

1.4.2 Well Field Characterization

The first step in the Tier Three Assessment involved detailed characterization of the hydrogeologic conditions within the urban well field areas. Well field characterization reports were drafted for individual well fields or groups of well fields, and these reports set the stage for the groundwater flow modelling portion of the Water Budget and Local Area Risk Assessment. The companion reports are listed in Table 1-1.

TABLE 1-1 Tier Three Assessment Characterization Reports

Report Title	Reference
Tier Three Water Budget and Local Area Risk Assessment: Draft Physical Characterization Summary Report	AquaResource 2009c
Region of Waterloo Tier Three Water Budget and Local Area Risk Assessment Rural Well Fields Characterization Report	AquaResource 2011
Tier Three Water Budget and Local Area Risk Assessment: Waterloo North, William Street and Lancaster Well Fields Characterization Study	Blackport 2012a
Tier Three Water Budget and Local Area Risk Assessment: River Wells; Pompeii, Woolner and Forwell Well Fields Characterization Study	Blackport 2012b
Tier Three Water Budget and Local Area Risk Assessment: Mannheim Well Fields Characterization	Golder 2011a
Tier Three Water Budget and Local Area Risk Assessment: Cambridge East Well Field Characterization	Golder 2011b
Tier Three Water Budget and Local Area Risk Assessment: Fountain Street Well Field Characterization	Golder 2011c
Tier Three Water Budget and Water Quantity Risk Assessment: Strange Street Well Field Characterization Study	Stantec 2009
Tier Three Water Budget and Local Area Risk Assessment: Cambridge Southwest Characterization Study	Stantec 2011a
Tier Three Water Budget and Local Area Risk Assessment: Cambridge Northwest Characterization Study	Stantec 2011b
Tier Three Water Budget and Local Area Risk Assessment: Erb Street Well Field Characterization Study	Stantec 2012a
Tier Three Water Budget and Local Area Risk Assessment: Greenbrook Well Field Characterization Study	Stantec 2012b
Tier Three Water Budget and Local Area Risk Assessment: Parkway and Strasburg Well Fields Characterization Study	Stantec 2012c

1.4.3 Tier Three Assessment Water Budget Tools

Three numerical modelling tools were applied in the Tier Three Assessment; two groundwater flow models and a watershed-based flow generation model. The Guelph All-Weather Storm-Event Runoff (GAWSER) model was used to simulate surface water partitioning and stream flow generation. GAWSER had sufficient spatial discrimination to allow delineation of the variation in recharge volume from the principal soil-profile response units. Although GAWSER represented interflow and baseflow components of streamflow using single units lumped at a subwatershed scale, and could not be used to characterize spatial properties in groundwater flow, the calibration of the GAWSER model to observed streamflow provided confirmation that the spatially-distributed recharge rates were correct on a watershed-averaged basis (AquaResource 2009b).

Two FEFLOW (DHI-WASY 2011) models were used to simulate subsurface (groundwater) flow. One model, the Regional Model, was used to simulate groundwater flow in the Kitchener-Waterloo area, and the second, the Cambridge Model, was used to simulate groundwater flow in the Cambridge area. A combined modelling approach was adopted whereby the recharge estimated by GAWSER (as a simulated output) was used as a boundary condition input (i.e., the driving force) for the groundwater flow models. The GAWSER model was described in an earlier report (AquaResource 2009b), and the FEFLOW (DHI-WASY 2011) groundwater flow model calibration and water budget was described in a companion report (Model Calibration Report and Water Budget Report; Matrix and SSPA 2012). The application of the Tier Three water budget models for the Local Area Risk Assessment is the focus of this report.

1.5 Organization of This Report

This report is organized into the following sections:

Section 1: Introduction. The *Clean Water Act* (MOE 2006) water budget framework and the scope of this project are outlined in this section.

Section 2: Risk Assessment Methodology. This section outlines the Risk Assessment methodology, the delineation of vulnerable areas, as well as the model scenarios and results. The sensitivity analysis methodology and results are also presented.

Section 3: Risk Assessment Data Requirements. This section outlines the land use, water demands and other water uses that were assessed to complete the Local Area Risk Assessment.

Section 4: Risk Assessment Thresholds. This section outlines the establishment of the drawdown thresholds and the ecological thresholds applied in the Local Area Risk Assessment.

Section 5: Vulnerable Area Delineation and Risk Assessment Results. This section describes the delineation of the vulnerable areas (WHPA-Q1, WHPA-Q2 and Local Area), as well as the results of the Risk Assessment scenarios, and the assignment of the Local Area Risk Levels. The uncertainty assessment is applied, and the results are also presented.

Section 6: Significant Groundwater Recharge Areas. The methodology and results of the Significant Groundwater Recharge Areas (SGRAs) are delineated and discussed in this section.

Section 7: Data and Knowledge Gaps. The data and knowledge gaps identified during all levels of the Tier Three Assessment, from the well field characterization to the Risk Assessment scenarios, are outlined in this section.

Section 8: Summary and Conclusions. This section outlines the study conclusions, recommendations, and the limitations and use of the report.

Section 9: Acknowledgements. This section provides a list of individuals and/or organizations whom report authors wish to credit for their contributions to the project.

Section 10: References. This section provides a list of references for citations in the report text.

2 RISK ASSESSMENT METHODS

2.1 Water Quantity Vulnerable Areas

One of the deliverables of the Tier Three Assessment is the delineation of areas that are vulnerable from a municipal drinking water quantity perspective. Similar to the water quality vulnerable areas, the water quantity vulnerable areas (Wellhead Protection Area for Quantity; WHPA-Q1 and WHPA-Q2) are delineated to protect the quantity of water required by a municipality to meet their current or future water supply needs. The Technical Rules (MOE 2009) require that WHPA-Q1 and WHPA-Q2 areas be delineated for all municipal water supply wells that extract water from a subwatershed assigned a groundwater stress level of Moderate or Significant in the Tier Two Assessment.

2.1.1 WHPA-Q1 Delineation

The WHPA-Q1 is delineated as the cone of influence of the municipal well and the whole of the cones of influence of all other wells when the wells are pumped at a rate equivalent to their allocated quantity of water (MOE 2009). The cone of influence for the well(s) was 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 pumping. This simulation establishes groundwater elevations that would exist without municipal or other permitted demands.

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

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

2.1.1.1 Regional Model

The average observed seasonal water level fluctuation in monitoring wells completed in the overburden production aquifers of the Waterloo Moraine is approximately 2 m (see Appendix B for details). Therefore, a 2 m drawdown contour interval was selected for use in delineating the WHPA-Q1 in the Kitchener-Waterloo area. This interval was selected because a variation of at least 2 m in observed groundwater water level elevation would be required before considering whether the change was due to increased pumping or seasonal variability. The Regional Model was used to delineate the WHPA-Q1 for the municipal wells located in Kitchener-Waterloo and the surrounding rural well fields that were part of the Tier Three Assessment.

2.1.1.2 Cambridge Model

The Cambridge Model was set up to simulate the response to municipal pumping within the nearby City of Guelph by applying boundary conditions in the Cambridge Model that are representative of pumping groundwater elevations in the City of Guelph Tier Three Assessment FEFLOW model. Given the interaction between the two cities, the delineation of the WHPA-Q1 needed to consider a non-pumping condition within Guelph as well as Cambridge. The northern and northeastern specified head boundary conditions in the Cambridge Model, that overlapped with the Guelph Tier Three model, were updated using the non-pumping conditions in the Guelph model under the non-pumped scenario (Note: pumping in the Cambridge area was also shut off and existing land use in both models was applied). The Allocated Rates in the Guelph and Cambridge Models were then applied and the northern and northeastern boundary conditions in the Cambridge Model were again updated to simulate the impact of increased pumping in both cities. The difference in groundwater elevations within each of the modelled aquifers was calculated and contoured.

The average observed seasonal water level fluctuation for monitoring wells completed in bedrock and deep overburden production aquifers within the Cambridge area is approximately 2 m (see Appendix B for details). As such, the 2 m drawdown contour interval was selected for use in delineating the WHPA-Q1 area for the Cambridge area. This interval was selected because a variation of at least 2 m in observed groundwater elevation would be required before considering whether the change was due to increased pumping or seasonal variability.

2.1.2 WHPA-Q2 Delineation

The WHPA-Q2 is defined in the MOE Technical Rules (MOE 2009) as the WHPA-Q1 plus any area where a future reduction in recharge would have a measurable impact on the cone of influence of the municipal wells. The cone of influence is the area within the depression created in the water table or potentiometric surface when the wells are pumped at a rate equivalent to their Allocated Rates. Proposed land development areas that had the potential to reduce recharge, and therefore, impact the available drawdown at the municipal wells, were simulated in the groundwater flow models, and are outlined in detail in Section 3.1.3.

2.1.3 Local Area Delineation

The term, "Local Area" is introduced in the MOE Director's Rules (Part III.2) and is defined as the area that combines the cone of influence of the municipal supply wells (WHPA-Q1) and the areas where a reduction in recharge would have a measurable impact on the cone of influence of the wells (WHPA-Q2). The Local Areas for the Region were delineated following review of the WHPA-Q1 and WHPA-Q2 areas delineated in the Regional and Cambridge Models, as well as the Local Area delineated in the nearby City of Guelph Tier Three Assessment.

2.2 Risk Assessment Scenarios

TABLE 2-1 summarizes the groundwater Risk Assessment scenarios listed in the Technical Rules (MOE 2009).

TABLE 2-1 Summary of Groundwater Risk Assessment Scenarios (MOE 2009)

Scenario	Time Period	Data Restrictions
C	The period for which climate and stream flow data are available for the Local Area	Data related to average pumping rates for water takings and land cover reflect conditions during the study year.
D	10-year drought period	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the study year.
G	The period for which climate and stream flow data are available for the Local Area	Data related to average pumping rates for water takings and land cover reflect conditions during the year in which the planned or existing system with a committed demand is operating at its Allocated Rates.
H	10-year drought period	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the year in which the planned or existing system with a committed demand is operating at its Allocated Rates.

In Table 2-1, Scenarios C and D correspond to existing pumping rates and land use under average climate and drought conditions, respectively. Scenarios G and H correspond to future land use development and allocated pumping rates for wells under average climate and drought conditions, respectively. As such, the scenarios were interpreted as follows:

- Scenarios representing average climate (i.e., C and G) were simulated using steady-state conditions.
- Scenarios representing drought conditions (i.e., D and H) were simulated using a transient model for the drought period of the 1960s and 1990s.
- Multiple versions of Scenarios G and H were required to evaluate the impact of allocated pumping rates separate from impacts of land cover and the cumulative impact of both.

- Impacts to other uses (e.g., wetlands and cold water fisheries) were not evaluated for the drought scenarios (i.e., D and H). The drought scenarios identified the potential for groundwater elevations to fall beneath a safe additional drawdown for each municipal well.

Table 2-2 summarizes the groundwater modelling scenarios conducted for the Region of Waterloo Tier Three Assessment. These scenarios were designed to assist in identifying the potential impacts from pumping each of the existing municipal wells, land use, and drought on current hydrogeological conditions. The data required for each of the modelling scenarios are outlined in Section 3.

Table 2-2 Risk Assessment Model Scenarios

Scenario	Time Period	Model Scenario Details			
		Land Cover	Municipal Pumping	Model Simulation	
C	Period for which climate and stream flow data are available for the Local Area (2008)	Existing	Existing	Steady-state, Average Annual Recharge	
D	10-year drought period	Existing	Existing	Transient (1960-2005); Monthly recharge rates (GAWSER)	
G1	Period for which climate and stream flow data are available for the Local Area (2008)	Official Plan	Allocated Rates	Groundwater Recharge Reduction and Increase in Demand	Steady-state, Average Annual Recharge
G2		Existing	Allocated Rates	Increase in Demand	
G3		Official Plan	Existing	Groundwater Recharge Reduction	
H1	10-year drought period	Official Plan	Allocated Rates	Groundwater Recharge Reduction and Increase in Demand	Transient (1960-2005); Monthly recharge rates (GAWSER)
H2		Existing	Allocated Rates	Increase in Demand	
H3		Official Plan	Existing	Groundwater Recharge Reduction	

2.2.1 Scenario C – Existing Conditions, Average Climate

Scenario C evaluated the ability for existing municipal water supply wells to maintain existing average annual pumping rates under average climate conditions. This scenario was simulated in steady-state in the groundwater flow models using 2008 (existing) pumping rates (see Section 3.2.1.1) and the average annual groundwater recharge distribution from the calibrated GAWSER model (1950 to 2005 simulation).

The groundwater flow models were constructed and calibrated to predict groundwater levels in the respective aquifers at the municipal pumping wells, and to predict groundwater levels and/or groundwater discharge rates under existing water demand and average climate conditions.

2.2.2 Scenario D – Existing Conditions, Drought

Scenario D evaluated whether each municipal well is able to pump at their existing rates during an extended drought period. This scenario was simulated using the calibrated groundwater flow models in continuous transient mode (1960 to 2005). Average monthly recharge rates from the GAWSER model were applied in the groundwater flow models throughout the duration of the simulations (1960 to 2005), which included several drought periods (i.e., the late 1960s and late 1990s droughts).

The Technical Rules (MOE 2009) refer to a 10-year period to define drought conditions for the scenarios. However, this assessment went beyond the requirements of the Technical Rules (MOE 2009) and examined two drought periods that occurred within the 45-year climate period examined (i.e., 1960s and 1990s). The 45-year period examined with the transient model included the two drought periods, but also periods where precipitation (and in turn recharge) were above normal.

As outlined in the Technical Rules (MOE 2009), the impacts of municipal pumping on other uses were not considered in this drought scenario. As a result, the main output parameters for this scenario are simulated drawdown or groundwater elevations at each of the municipal wells.

2.2.3 Scenario G – Allocated Rates, Future Land Development, Average Climate

Scenario G evaluated the ability for existing wells to maintain the Allocated pumping rates under average climate conditions and reductions in recharge. This scenario was simulated using the calibrated groundwater flow models in steady-state conditions, using groundwater recharge rates that reflect long-term average climate conditions. Scenario G was subdivided into three scenarios (G1, G2 and G3). The purpose of subdividing into these scenarios was to isolate the impacts of municipal pumping from land developments and assess the cumulative impact of the two stresses. Only the scenario representing increased municipal pumping (G2) was considered when evaluating the impact of the scenarios on wetlands and cold water streams.

2.2.3.1 Scenario G1

This scenario evaluated the cumulative impact of increased municipal pumping rates (Allocated Rates) and reductions in recharge (due to increases in imperviousness) due to future land use changes defined in the Official Plans, on the municipal wells, and other uses. The Allocated Rates applied in this scenario are discussed in Section 3.2.1.2, and the change in land use and interpreted reduction in recharge, are discussed in Section 3.1.

2.2.3.2 Scenario G2

This scenario evaluated only the impact of increased municipal pumping rates (Allocated Rates) on the municipal wells and other water uses. The existing conditions land use was simulated in this scenario to isolate the influence of municipal pumping from land development. Only this scenario is considered when evaluating the impact of the scenarios on wetlands and cold water streams. Baseflow reductions arising from land use development are independent from increased groundwater pumping, and only those impacts associated with groundwater pumping are used to evaluate the Risk Level relating to the impact to other uses.

2.2.3.3 Scenario G3

This scenario evaluated only the impact of reductions in recharge (due to increases in imperviousness) due to future land use changes defined in the Official Plans, on the municipal wells and on other water uses. Existing municipal pumping rates were used in this scenario to isolate the influence of land development from the Allocated Rates.

2.2.4 Scenario H – Allocated Rates, Future Land Development, Drought Conditions

Scenario H evaluated the ability for existing wells to maintain Allocated Rates through a drought period (same temporal period as Scenario D). The groundwater flow model was run transiently to examine the combined impact of drought conditions, land use development and additional municipal pumping on groundwater elevations at the municipal wells. Impacts to other water uses were not considered in Scenario H.

Similar to Scenario G, this scenario was subdivided into Scenario H1, H2 and H3 to evaluate the relative contribution of municipal water takings and land use development at each municipal well under drought conditions.

2.2.4.1 Scenario H1

This scenario evaluated the cumulative impact of increased municipal pumping rates (Allocated Rates), reductions in recharge (due to increases in imperviousness) due to future land use developments defined in the Official Plans, and drought conditions on the municipal wells.

2.2.4.2 Scenario H2

This scenario evaluated only the impact of increased municipal pumping rates (Allocated Rates) on the municipal wells during a drought period. The existing conditions land use was simulated in this scenario.

2.2.4.3 Scenario H3

This scenario evaluated the impact of reductions in recharge (due to increases in imperviousness) due to future land use developments defined in the Official Plans and drought conditions on the municipal wells.

2.3 Uncertainty Evaluation of Risk Assessment Scenarios

The input parameters applied in the Regional and Cambridge Models contain a level of uncertainty, and the numeric models are generalizations of the physical world. There is uncertainty in the subsurface structure (e.g., continuity of till units), parameter values representing material properties (e.g., hydraulic conductivity) and boundary conditions (e.g., recharge and surface water discharge features), and this study acknowledged and quantified the impact of this uncertainty.

Knowledge of model input parameter values is imperfect and incomplete. The values are updated until the model-predicted groundwater elevation values are a good fit to the observed values. The observed values also contain a margin of error (e.g., uncertainty in reference elevations, seasonal water level variability, and varying time periods of the measurements). All of these factors contribute to the non-uniqueness of a model and the input parameter values. As a result, many combinations of parameter values can produce an equally good fit to the observed data. Model predictions depend upon parameter values and therefore, understanding parameter uncertainty can help evaluate the certainty (or uncertainty) in the model predictions.

In the context of a single conceptual model, numeric uncertainty can be analyzed by making small perturbations to parameter values and evaluating the fit to the observed data. Exploring these minor changes provides insight into parameter-specific numeric uncertainty. However, to examine the uncertainty in the overall flow system, alternative conceptual models with various parameter 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 ”realizations”) were created using the software program PEST (Watermark Numerical Computing 2012). Each alternative is considered statistically calibrated to a level that is as good (or better) than the original base case model presented in the companion Model Calibration and Water Budget Report (Matrix and SSPA 2012). Three realizations were developed for the Regional and Cambridge Models to assess the uncertainty in the model parameters, and how that uncertainty may impact the Risk Assessment and the assignment of the Risk Level. The three uncertainty realizations for each the Regional and Cambridge Model were developed for various reasons. The first set of realizations aimed to improve the current calibration under the current conceptual model by using all available average annual and time-varying data available. The second two uncertainty realizations aimed to test two of the key uncertainties identified in the Tier Three Assessment that have the potential to play the greatest role on the model predictions. Specifically, the second uncertainty realization aimed to test the general uncertainty associated with the hydraulic conductivity values of the overburden and bedrock aquifers. The third uncertainty realization was developed to test assumptions regarding the properties of the bedrock aquifers beneath the Waterloo Moraine and the properties of the Guelph Formation in the Cambridge area. The underlying sections and Appendix C outline the set-up of these realizations in more detail.

2.3.1 Regional Model Uncertainty Realizations

Three uncertainty realizations were developed for the Regional Model to test the uncertainties in the conceptual model of the area. The three realizations are outlined below.

Uncertainty Realization 1 is consistent with the conceptual model, maintains a good fit to the steady-state observation dataset, and simulates time-varying trends in groundwater elevations, representative of typical operating conditions (aggregated to a bimonthly period) between 2003 and 2011. The water budget model described in the companion report (Matrix and SSPA 2012) was calibrated to individual, short-or long-term pumping, or shut down tests at each well field. However, Realization 1 involved calibration to the long-term, time-varying records of groundwater elevations with greater spatial coverage, particularly in the areas between well fields. This alternative realization is referred to in this report as the “Optimization to Long-Term Transient Observations” realization.

Uncertainty Realization 2 was designed to examine the impact of modifying the hydraulic conductivity values of the regional till units to the upper range of our conceptual understanding. The hydraulic conductivity values of the till units were started at the upper limits of our conceptual understanding, and PEST adjusted those values, as well as the hydraulic conductivity values of the other input parameters (i.e., the intervening aquifers) to produce a model that was statistically calibrated to the steady-state groundwater elevations in the model. This realization was completed to test the assumption that the regional till units have low hydraulic conductivity values that support groundwater elevations in the overlying aquifers, and act as confining units to the underlying aquifers. This realization aimed to examine the impact of variability in the hydraulic conductivity values of the aquitard units, and this alternative realization is referred to in this document as the “Leaky Aquitards” realization.

Uncertainty Realization 3 was designed to examine the impact of modifying the hydraulic conductivity values of the bedrock (i.e., Salina Formation) beneath the Waterloo Moraine to the upper range of our conceptual understanding. The original conceptual model assumed the hydraulic conductivity values for the Salina Formation were relatively low, based on the water chemistry of the bedrock groundwater sources, which suggested long residence times. However, permits to take water for wells completed in the Salina Formation in the Study Area suggest that potential well yields, and hence aquifer transmissivity and hydraulic conductivity values, are higher than initially conceptualized.

The hydraulic conductivity values of the bedrock were started at the highest limits of our conceptual understanding and PEST adjusted those values, as well as the hydraulic conductivity values of the overlying units, to produce a model that was statistically calibrated to the steady-state groundwater elevations in the model. This realization aimed to examine the impact of variability in the hydraulic conductivity values of the bedrock units underlying the Waterloo Moraine, and this alternative realization is referred to in this document as the “Bedrock Uncertainty” realization.

2.3.2 Cambridge Model Uncertainty Realizations

Three uncertainty realizations were developed for the Cambridge Model to test the uncertainties in the conceptual model of the area. The three realizations are outlined below.

Uncertainty Realization 1 in the Cambridge Model is the same as Uncertainty Realization 1 in the Regional Model (Section 2.3.1). The realization is consistent with the conceptual model, maintains a good fit to the steady-state observation dataset and simulates time-varying trends in groundwater elevations representative of typical operating conditions (aggregated to a bimonthly period) between 2003 and 2011. The water budget model described in the companion report (Matrix and SSPA 2012) was calibrated to individual short or long-term pumping or shut down tests at each well field. However, Realization 1 involved a calibration to the long-term, time-varying records of groundwater elevations with greater spatial coverage, particularly in the areas between well fields. This alternative realization is referred to in this report as the “Optimization to Long-Term Transient Observations” realization.

Similar to the Uncertainty in the Regional Model, Uncertainty Realization 2 in the Cambridge Model was designed to examine the impact of modifying the hydraulic conductivity values of the regional aquitard units to the upper range of our conceptual understanding. The hydraulic conductivity values of the bedrock aquitards were started at the upper limits of our conceptual understanding, and PEST adjusted those values, as well as the hydraulic conductivity values of the other input parameters (i.e., the intervening aquifers) to produce a model that was statistically calibrated to the steady-state groundwater elevations in the model. This realization was completed to test the assumption the aquitard units, such as the Vinemount Member of the Eramosa Formation, have low hydraulic conductivity values that support the groundwater elevations in the overlying aquifers, and act as confining units to the underlying aquifers. This realization aimed to examine the impact of variability in the hydraulic conductivity values of the aquitard units, and this alternative realization is referred to in this document as the “Leaky Aquitards” realization.

Uncertainty Realization 3 simulated additional layers within the Guelph Formation to allow for vertical variability within the formation. The original conceptual model simulated the Guelph Formation as one hydrogeologic unit; however, through the manual calibration it was concluded that additional vertical discretization was desirable within the formation. This realization was completed to test the assumption that additional characterization within the Guelph Formation would aid the model calibration process within the Cambridge Well Field areas.

Additional details regarding the development of these realizations are outlined in Appendix C for the Regional and Cambridge Models.

3 RISK ASSESSMENT DATA REQUIREMENTS

The following sections document the data examined and compiled for the Tier Three Assessment. In particular, the municipal and non-municipal water demands and land use cover that will be represented in the Risk Assessment model scenarios are discussed.

3.1 Land Use

In addition to consumptive water uses, the MOE Technical Rules (MOE 2009) identify reductions in groundwater recharge as potential water quantity threats. As such, the Tier Three Assessment modelling scenarios considered the impact of future land development, via reductions in groundwater recharge, on municipal water sources.

The following steps were undertaken in consultation with Region staff, to identify where potential land use development is expected to occur within the Study Area:

- A map of existing land uses was created.
- A map of future land uses was created using the Official Plan mapping as a guide.
- A map identifying the areas of land use change was created by comparing future land use and existing land uses.
- Areas of future potential change in land development and groundwater recharge, based on imperviousness estimates, was generated across the Study Area.

The data sources and additional details are discussed in the following sections.

3.1.1 Existing Conditions Land Use

The existing land use cover used in this portion of the Tier Three Assessment was very similar to the land uses applied in the Tier Three GAWSER flow generation model (AquaResource 2009b) with minor updates to the land uses in urban areas. The land cover data used in the original Grand River GAWSER model was based on 1992 imagery, and did not reflect current land use practices, particularly within urban areas. Land use mapping for Kitchener, Waterloo, and Cambridge was obtained from the respective cities and compiled into one consolidated land use mapping file, and this file was used to update the land use within the urban boundaries. Municipal land use mapping was checked against 2006 ortho-imagery to ensure urban lands flagged as developed actually were developed. Road lines were buffered by 10 m and assumed to be 100% impervious.

Updates were made to the land use classifications in the rural communities of Elmira, New Dundee and St. Agatha to accurately represent the developed areas in these communities. In addition, the land use classifications in the urban areas of the Region were also revisited to reflect site-specific knowledge.

For example, a large development area classed as commercial was updated to low-density commercial to reflect the knowledge of the existing land use practices in that area.

3.1.2 Future (Official Plan) Land Use

The Risk Assessment scenarios also included an assessment of the impact of future land use development, as specified in the municipality's Official Plan, on municipal water sources. As such, the Regional Municipality of Waterloo Official Plan (digital version) was obtained from the Region on July 4, 2012. This mapping represented the most current and up to date Official Plan and land use mapping within the Region at that time.

Staff at the Region reviewed the Future Land Use mapping and updated the land use classifications in some areas where development had occurred since 2008 (existing conditions). For example, areas where the Official Plan specified a residential area (interpreted by Matrix to be moderate density), but a low density residential subdivision was built in 2010, the Official Plan land use mapping classification was updated to low density residential.

3.1.3 Land Use Change

Changes in land uses from existing to revised Official Plan land uses were created within the GIS. The existing land use polygons were overlain with Official Plan land use polygons and new polygons were created to note where changes in land use from existing to future conditions were expected. Changes in land use that lead to interpreted decreases in groundwater recharge (due to increases in imperviousness) were applied in the Tier Three Assessment scenarios. Figure 3-1 illustrates the land use polygons where reductions in recharge were predicted to occur due to land use development in the Region.

3.1.3.1 Land Use Change and Imperviousness

The groundwater flow model represents the changes in land use development by increasing or decreasing groundwater recharge proportionally to the percentage of impervious area. For the Tier Three Assessment, only areas with a reduction in recharge were carried forward. The Risk Assessment model scenarios assume that mitigation measures such as infiltration ponds or similar best management practices that enhance recharge are not taken into consideration (MOE 2009).

Each of the land use areas were assigned a perviousness value as described in the GAWSER Model Update Report (AquaResource 2009b). Table 3-1 summarizes the perviousness values applied to the land use areas that are expected to change in the future. These imperviousness values estimate the expected 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 50 mm/year after the construction of a medium density residential subdivision (reduction of

50%). This groundwater recharge reduction is attributed to a decrease in infiltration (subsequently, groundwater recharge) and an increase in runoff.

TABLE 3-1 Land Use Impervious Estimates

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%

The polygons where recharge is expected to take place were of different sizes and orientations than the individual FEFLOW model elements. To address this issue, the FEFLOW model mesh was overlain on the change in land use area, and an area weighted average was calculated within the model elements to calculate the revised recharge rate to apply to each model element. The same procedure was completed using the Cambridge Model mesh. Figures 3-2 and 3-3 illustrate the spatial distribution of reductions in groundwater recharge, between existing and future conditions, for the Regional Model and Cambridge Model, respectively. These distributions illustrate the extent that reductions in recharge are predicted to occur on an elemental basis, based on the assumptions used in the modelling analysis.

3.2 Water Demand

Consumptive water demand refers to the amount of water removed from a surface water or groundwater source that is not returned directly to that source. Estimates of consumptive water demand are necessary in water budget assessments to identify subwatersheds that may be under hydrologic stress. This section summarizes the known consumptive water takers identified in the Study Area, separating them into permitted municipal and non-municipal water takings.

All municipal water supply wells within the Region were considered 100% consumptive as water is pumped from groundwater aquifers and discharged to the Grand River via waste water treatment plants. The exception is the Aquifer Storage and Recovery (ASR) wells located in the Mannheim area. These wells were not simulated in the model as water pumped from the Grand River is injected into the groundwater aquifer and then removed a few months later for use. On an average annual basis, this water taking is considered non-consumptive as it is returned to the same source that it was derived.

The evaluation of water demands within the Study Area also considered non-consumptive water uses, such as groundwater discharge for ecological use, to support waste water assimilation, and/or to support recreational water uses. Only groundwater discharge to streams and leakage from streams to aquifers is represented explicitly in the groundwater flow model in the Tier Three Assessment. However, other water uses rely on a minimum flow or minimum variation in groundwater elevations from the groundwater and surface water systems, so they are assessed as part of the Risk Assessment. Other water uses are described in Section 3.3.

Municipal and non-municipal water demands are discussed in the following sections.

3.2.1 Municipal Water Demand

As part of the Local Area Risk Assessment, the allocated quantity of water (Allocated Rates) was estimated for each existing groundwater well. The Allocated Rates for the Local Area were established in accordance with the MOE Technical Rules (MOE 2009) and other provincial guidance (MOE 2013). The Allocated Rates were estimated based on the existing and committed water demand. The definitions of these water demand terms are described below.

- **Existing Demand:** Average annual pumping rates during the study year. Maximum monthly and maximum daily demands should also be estimated for the study year based on historical trends.

- **Committed Demand:** The increase in quantity of water provided by a drinking water system that would be required if the area served by the system were developed in accordance with the Official Plans for the area to an extent that would result in the greatest use of drinking water. For example, a portion of the Official Plan that has been approved for development, such as a subdivision or commercial block, and will be coming online in the near future. The portion of this amount that is within the current lawful PTTW is part of the Allocated Quantity of Water (MOE 2013). Any amount that exceeds the permit, is considered part of the Planned Demand (see below).

- **Planned Demand:** The *Clean Water Act* (MOE 2006) defined a planned drinking water system as one that is established, or will be established if; a) Approval to proceed with the establishment of the system or part has been given under Part II of the Environmental Assessment Act; b) The establishment of the system or part has been identified as the preferred solution within a completed planning process conducted in accordance with an approved class environmental assessment under Part II.1 of the Environmental Assessment Act and no order has been issued under subsection 16 (1) of that Act; or c) The system or part would serve a reserve as defined in the *Indian Act* (Canada 2013; MOE 2006). The Planned Demand for an existing or new planned well or intake is any amount of water that meets the definition of a planned system (as outlined above) and any any amount of water that is needed to meet a committed demand that exceeds the current lawful permit to take water (MOE 2013).

In summary, the Allocated Rates are 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, so there are no Planned Demands in this assessment.

TABLE 3-2 Municipal Pumping Rates Applied in the Water Budget Models

Well	Well Field	PTTW Pumping Rate (m^3/d)	2008 Average Annual Pumping Rate (m^3/d)	2031 Allocated Pumping Rate (m^3/d)
G4	Blair Road	1,901	945	-
G4A	Blair Road	1,901	-	1,728
G16	Clemens Mill	3,283	1,666	2,938
G17	Clemens Mill	4,320	1,997	2,160
G18	Clemens Mill	3,269	1,041	1,296
G6	Clemens Mill	2,160	1,346	864
C3	Conestogo (Plains)	786	70	214
C4	Conestogo (Plains)	786	9	38
P6	Dunbar Rd	Grandfathered	884	0
G9	Elgin Street	Grandfathered	1,002	0
E10	Elmira	6,546	0	0
W6A	Erb Street	5,564	1,614	1,296
W6B	Erb Street	4,582	0	1,296
W7	Erb Street	9,092	6,041	6,048
W8	Erb Street	10,474	3,672	2,592
P16	Fountain Street	1,961	0	0
K1	Greenbrook	Max annual daily average of 17,626 m^3/day	372	0
K1A	Greenbrook		0	1,728
K2	Greenbrook		1,874	0
K2A	Greenbrook		0	1,728
K4B	Greenbrook		3,413	1,728
K5A	Greenbrook		957	1,728
K8	Greenbrook		126	864
H3	Hespeler	1,642	561	864
H4	Hespeler	2,074	0	1,296
H5	Hespeler	1.987	383	864
K41	Lancaster	Grandfathered	0	0

Well	Well Field	PTTW Pumping Rate (m^3/d)	2008 Average Annual Pumping Rate (m^3/d)	2031 Allocated Pumping Rate (m^3/d)
K42A	Lancaster	2,290	0	0
K21	Mannheim East	4,925	2,303	2,592
K25	Mannheim East	6,826	3,813	3,456
K29	Mannheim East	5,210	2,503	2,592
K91	Mannheim East Peaking	3,458	674	2,160
K92	Mannheim East Peaking	4,320	813	2,160
K93	Mannheim East Peaking	4,320	813	2,592
K94	Mannheim East Peaking	4,320	843	2,592
K22A	Mannheim West	6,550	1,252	0
K23	Mannheim West	6,566	2,256	432
K24	Mannheim West	6,566	2,562	2,592
K26	Mannheim West	9,092	6,841	6,048
G1	Middleton	Not Specified	3,491	5,184
G14	Middleton	Not Specified	3,206	2,160
G1A	Middleton	Not Specified	3,994	1,728
G2	Middleton	Not Specified	5,366	6,912
G3	Middleton	Not Specified	3,396	4,752
G15	Middleton (Willard)	6,547	2,143	2,592
ND4	New Dundee	983	2	2
ND5	New Dundee	983	222	222
K31	Parkway	Grandfathered	2,567	2,160
K32	Parkway	Grandfathered	2,270	2,592
K33	Parkway	4,550	2,894	3,024
K70	Forwell/Pompeii	13,700	0	0
K71	Forwell/Pompeii		0	0
K72	Forwell/Pompeii		0	0
K73	Forwell/Pompeii		0	0
K74	Forwell/Pompeii		0	0
K75	Forwell/Pompeii		0	0

Well	Well Field	PTTW Pumping Rate (m^3/d)	2008 Average Annual Pumping Rate (m^3/d)	2031 Allocated Pumping Rate (m^3/d)
G5[1]	Pinebush	4,320	1,641	-
G5A[1]	Pinebush	4,320	0	1,296
P10	Pinebush	Grandfathered	2,945	3,110
P15	Pinebush	5,184	962	1,296
P11	Pinebush	5,184	1,136	1,728
P17	Pinebush	5,184	741	
P9	Pinebush	NS	1,474	1,296
G38	Shades Mill	9,850	0	1,296
G39	Shades Mill	9,850	0	2,592
G7	Shades Mill	Grandfathered	2,306	1,728
G8	Shades Mill	2,292	1,204	864
SA3	St. Agatha	518	8	0 (connected via pipeline to urban systems)
SA4	St. Agatha	691	12	
SA5	St. Agatha	273	52	
SA6	St. Agatha	273	37	
K10A	Strange Street	Not Specified	327	432
K11[1]	Strange Street	Not Specified	199	-
K11A[1]	Strange Street	Not Specified	-	1,728
K13	Strange Street	Not Specified	526	1,296
K18	Strange Street	Not Specified	2,160	1,296
K19	Strange Street	Not Specified	216	1,296
K34	Strasburg	4,582	3,184	2,764
K36	Strasburg	2,290	0	0
W10	Waterloo North	3,142	0	1,296
W1B	William Street	5,237	818	432
W1C	William Street	3,274	14	2,160
W2	William Street	5,246	2,384	1,728
W3	William Street	3,024	0	0
K80	Woolner	11,100	0	0

Well	Well Field	PTTW Pumping Rate (m^3/d)	2008 Average Annual Pumping Rate (m^3/d)	2031 Allocated Pumping Rate (m^3/d)
K81	Woolner	11,100	220	0
K82	Woolner	11,100	1,072	0
WM1 to WM4	West Montrose	238	69	0 (water supplied via pipeline from Conestogo)
		TOTAL	105,904	119,448

Notes: [1] Wells G4A, G5A and K11A were drilled in recent years adjacent to the existing wells to supplement (Wells G4A and G5A) or replace (Well K11A) water demands from Wells G4, G5 and K11.

Not specified: Individual pumping rates for the Strange Street Wells are not specified; however, the PTTW specifies a maximum daily rate from all wells of 16,512 m^3/day and a maximum annual daily average of 10,000 m^3/day. Similarly, for the Middleton Wells individual pumping rates are not specified; however, the PTTW specifies a maximum daily rate from all wells of 24,000 m^3/day and a maximum annual daily average of 24,000 m3/day, with an allowance for increasing the maximum daily rates to 30,000 m^3/day for a maximum of 100 days and 35,000 m^3/day for a maximum of 15 additional days, within a calendar year. Individual pumping rates for the Greenbrook Wells are not specified; however, the PTTW specifies a maximum daily rate from all wells of 37,361 m^3/day and a maximum annual daily average of 17,626 m^3/day.

Grandfathered: These wells have no PTTWs as they were constructed before the implementation of the Ontario Water Resources Act.

3.2.1.1 Existing Municipal Water Demand

As noted above, the existing demand refers to the average annual pumping rates for municipal wells within the Region during the study year (MOE 2009). For the Region of Waterloo Tier Three Assessment, the municipal pumping rates for the 2008 calendar year were selected as the most representative of existing conditions as all well fields were in operation in 2008 and pumping at fairly consistent rates. The year 2008 also represents the calendar year when the well field characterization efforts for the Region of Waterloo Tier Three Assessment were undertaken. The 2008 rates listed in Table 3-2 are the rates that will be used in Scenarios C and G3 (Table 2-2), and the 2008 monthly pumping rates will be used in Scenarios D and H3. Table 3-2 also contains the Allocated Rates, as described in Section 3.2.1.2.

3.2.1.2 Allocated Municipal Water Demand

As part of the Tier Three Assessment, the hydrologic and hydrogeologic responses to increases in municipal pumping associated with the total of the Allocated Rates was assessed. The Region recently initiated a review of its approved 2000 (updated 2007) Long-Term Water Strategy (LTWS) to estimate the demand required from each municipal pressure zone within the Region, and how the existing municipal wells could be utilized to meet that demand. The LTWS considered future environmental, social, economic, technical and political implications for each servicing option. Part of that study included the derivation of municipal well field pumping rates to the year 2031. These pumping rates are listed in Table 3-2 as “Allocated Rates,” and these rates will be used in the Risk Assessment Scenarios G2 and G3.

In addition to the groundwater pumping rates specified in Table 3-2, the Region also extracts water from the Grand River using a surface water intake located at Hidden Valley. Extracted surface water is pumped to the Mannheim Water Treatment Plant where it is treated to drinking water standards and is pumped to the water distribution system. A portion of the treated drinking water is stored in an underground aquifer utilizing the Region’s ASR well system. The ASR system is used to store water when surplus water is available and to recover the stored water from the aquifer when needed to meet water demands and operational requirements. As the withdrawal volume of water does not exceed the injected volume, these takings are considered non-consumptive and were not included in the Tier Three Assessment. The ASR system and the Grand River intake provide additional flexibility and water supply tolerance to the Region during higher demand and/or drought periods.

Variable Climate

As outlined in Table 2-2, Scenarios C and G represent average climatic conditions and therefore, can be simulated using the steady-state groundwater flow model. Scenarios D and H represent variable climatic conditions (including at least one 10-year drought period) and were simulated using transient groundwater flow models. The transient 10-year drought scenarios required realistic estimates of how the Region will vary pumping on a monthly basis over the long-term.

Monthly pumping rates for Scenarios H1 and H2 were estimated by analyzing monthly and annual historic pumping rates for each of the Region's active production well fields from 2005 to 2011. Each well field's average monthly production between 2005 and 2011 was divided by its annual average to yield a monthly pumping rate factor (or multiplier) that is representative of the production patterns of that well field. The Region's water use bylaws, instituted in 2005, reduced the peak water use across the urban area and therefore, the 2005 to 2011 period was selected as it is the most representative of existing and committed seasonal water demands at the well fields across the Region.

Appendix D outlines the monthly pumping rate factors applied to estimate the monthly varying municipal well field pumping rates for two of the transient (drought) scenarios (Scenarios H1 and H2). The pumping rate factors were multiplied by the Allocated Rate at each well to yield the monthly pumping rates for the future pumping scenarios for Scenarios H1 and H2. The monthly pumping rates were repeated each year of the transient simulation (1950 to 2005), using the commensurate monthly recharge estimates from the GAWSER model. The monthly pumping rate factors for the Mannheim Peaking wells were updated to match the peaking factors for the Mannheim West Well Field, as the Region expects the operation of the Mannheim Peaking Well Field to change in the coming years, so the well field operates on a more consistent basis, in a manner similar to Mannheim East and Mannheim West.

Scenario H3 is a transient scenario that simulated existing production conditions. In this case, the actual monthly average pumping rates from 2008 for each well were applied and repeated on a monthly basis throughout the transient scenario.

3.2.2 Non-Municipal Water Demand

3.2.2.1 Permitted Water Uses

In addition to the municipal supply wells, a total of 233 non-municipal permitted groundwater wells (sources) existed within the Regional or Cambridge Model domains in 2008, and these permits were examined in detail as part of the Tier Three Assessment characterization. At that time, the 2008 PTTW database and 2008 Water Taking Reporting System (WTRS) database were the most up–to–date databases containing permit and source names, geographic data, coordinates of permits/sources, period of water taking and daily reported pumping rates. The PTTW database does not contain screened or open hole interval information, so assumptions were made on the elevation of the production aquifer for each of the 233 sources located within, and surrounding the Region.

Several steps were undertaken to develop a dataset of non–municipal permitted water demands within the models. These included review of reported daily and monthly reported takings, or making estimates of consumptive use based on the permitted rates if reported rates were unavailable.

Recognizing the uncertainty associated with the non-reported permitted water takings, the study team examined the MOE WTRS database for 2010 and 2011 to refine the non-municipal water demand estimates. In some instances, water takings were reported in 2008, but not 2010 or 2011, and in others, water takings were reported in 2010 but not 2011. As such, the best available water taking information was carried forward and applied in the groundwater flow models. In all instances, daily reported rates were averaged over the month and the year to obtain average annual pumping rates for the non-municipal permitted water takings. Where data were not available in the WTRS, water demands were estimated using monthly reported water takings collected by the GRCA between 2002 and 2006 (AquaResource 2009a), or consumptive demands were estimated using consumptive use factors (MOE 2007) applied to the maximum permitted rates and maximum allowable days of pumping recorded in the PTTW database.

Ten permits to take water located outside the Region of Waterloo boundary were omitted from the Regional Model, as pumping of these wells caused numerical instability of the model. Within the Region of Waterloo, the overburden layer structure and parameters in the model were based on regional-scale overburden layers, as interpreted by the Ontario Geological Survey (OGS), and local scale updates from the Tier Three Assessment and other Region projects. However, outside the municipal boundary, the local scale hydraulic characterization of individual aquifers and aquitards has not been completed. As a result, the modelled long-term pumping at these wells, which were often simulated to be completed in hydraulic conductivity units that were too low to sustain pumping, caused excessive drawdown at the wells and the model became unstable at these locations.

The hydraulic conductivity values could have been updated in the model; however, as the screened interval or the aquifer where the well is drawing water is unknown, it seemed arbitrary to add zones of higher hydraulic conductivity material around the wells without a geologic foundation. Consequently, the wells associated with these ten permits were removed from the model to improve overall model stability. The total consumptive water taking associated with the wells that were removed from the model was approximately 5,300 m^3/d, which was less than 4% of the total estimated consumptive (municipal and non-municipal) permitted groundwater takings in the Regional Model. The permits are located at a great distance southwest, west, and north of the urban cities of Kitchener and Waterloo, and are 8 to 24 km away from the closest municipal wells. Therefore, these water takings were interpreted to have no impact on the municipal water supply sources within the Region.

Figure 3-4 illustrates the spatial distribution of permits located within the Study Area that were included, and those that were excluded from the modelling exercise due to numerical instability issues. Additional information on the permit to take water analyses undertaken in 2008 is outlined in Matrix and SSPA (2012), and the rates applied in the model are outlined in Appendix E of this report.

3.2.2.2 Non-Permitted Water Uses

The potential impacts of non-permitted groundwater takings on the Region's water supply sources were assessed on a local-scale in the well field characterization reports for each of the urban well field areas (Blackport 2012a, 2012b; Golder 2011a, 2011b and 2011c; Stantec 2009, 2012a, 2012b and 2012c).

Figure 3-5 shows the locations of domestic, agricultural and commercial water wells within the Study Area, as queried from the Region's WRAS+ database. Some wells that are located in serviced areas pre-date the supply of serviced water to the area. Although these well may no longer be used for potable supply, they may be used for lawn watering or similar uses. Domestic water takings were not simulated in the groundwater flow model, as the sum of the volume of their takings is minor (< 2%) as compared to the average annual municipal and non-municipal permitted demands, and much of this water is interpreted to be returned via septic systems to the same source from which it is withdrawn (AquaResource 2009a).

3.3 Other Water Uses

The Tier Three Assessment must identify all other water uses and estimate the water quantity requirements for those uses where possible. Other water uses that are relevant to the Study Area include non-municipal groundwater takings (discussed in Section 3.2.2), and aquatic habitat, Provincially Significant Wetlands (PSWs), waste water assimilation, and recreational uses, which are illustrated on Figure 3-6 and discussed below.

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

- System function is often not well enough understood to generate definitive 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).

- System function is not always tied to a unit flow rate of water (e.g., the health and ecological integrity of a PSW may be dependent on the unit rate of change in the water table elevation).

The Province of Ontario introduced the use of thresholds to evaluate other water uses. Thresholds applied in the Region of Waterloo Tier Three Assessment are discussed in the following sections.

3.3.1 Aquatic Habitat

A Local Area can be designated as having a Significant Risk Level if an adverse impact to cold water fisheries or wetlands is predicted as a result of pumping a supply well at its Allocated Rate. In Ontario, 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.

The Province has prescribed specific baseflow reduction thresholds that should be used when assigning a Risk Level associated with predicted impacts to cold water fish community streams due to municipal pumping at the Allocated Rates. Within the Region, a Moderate Risk Level would be applied if pumping at the Allocated Rates resulted in a reduction in groundwater discharge that is classified as a coldwater stream by an amount that is at least 10 percent of the existing estimated stream flow that is exceeded 80 percent of the time (Qp80), or at least 10 percent of the existing estimated average monthly baseflow of the stream (MOE 2013; MOE and MNR 2010; MNR and MOE 2011).

Figure 3-6 shows fish habitat mapping as mapped by the GRCA and MNR. Streams mapped as cold water communities are subject to the Province's groundwater discharge reduction thresholds. Cold water communities within the Kitchener and Waterloo area include the headwaters of Laurel Creek in northwest Waterloo, Strasburg Creek at the Strasburg Well Field, and the main branch of Alder Creek from the Erb Street Well Field south to New Dundee. Other cold water streams include Airport, Hopewell and Idlewood Creeks, located east of the Grand River and the cities of Kitchener and Waterloo. Within the Cambridge area, cold water streams being examined in the Tier Three Assessment include Mill Creek from the headwaters in the northeast to the Grand River, Moffatt Creek south of the Shades Mill wells, and Blair and Cedar Creeks on the west side of the Grand River.

3.3.2 Provincially Significant Wetlands

The Technical Rules (MOE 2009) also identify PSWs as other water uses that, if significantly impacted by municipal pumping, would result in an elevated Risk Level for the Local Area. The wetland systems within the Study Area include swamps, marshes, fens and bogs. Evaluated wetlands are classified under a standard methodology, taking into account the biological, hydrological, and socio-economic features and functions of a wetland. Based on this system, wetlands can be identified as PSWs and these are protected under the wetland component of the *Provincial Policy Statement* (OMMAH 2005).

The most pertinent wetland features for the Risk Assessment include swamps and fens as they are partially or entirely reliant on groundwater discharge for their ecological health. The most sensitive wetland features, as identified by the GRCA (2008), and the model applied to evaluate the impact, are summarized in Table 3-3.

TABLE 3-3 Summary of Sensitive Wetland Features and Applied Modelling Tool

Complex	Sub-complexes	Wetland Type	Modelling Tool
Laurel Creek Complex	Sunfish Lake	Open Water, Swamp	Regional
Laurel Creek Complex	Sunfish Lake, Optimist Bog	Bog	Regional
Mannheim Area	Laurentian West	Marsh, Swamp	Regional
Mannheim Area	Middle Alder Creek Complexes	Swamp	Regional
Mannheim Area	Upper Alder Creek Complexes	Swamp, Marsh	Regional
Roseville Swamp	Cedar Creek Wetland	Swamp, Marsh	Regional
Roseville Swamp	Roseville Swamp	Swamp (Marsh)	Regional
Spongy Lake		Fen, Bog, Marsh, Swamp	Regional
Strasburg Creek		Swamp, Marsh	Regional
Beverly Swamp	Beverly Swamp	Swamp, Marsh	Cambridge
East side of Cambridge	Mill Creek Wetland	Swamp, Marsh	Cambridge
East side of Cambridge	Moffat Creek	Swamp, (Marsh)	Cambridge
East side of Cambridge	Sheffield Rockton Complex	Fen, Swamp, Marsh	Cambridge
Ellis Creek Wetlands		Swamp, Marsh	Cambridge
Puslinch Lake and Portuguese Bog	Irish Creek Complex	Swamp, Marsh	Cambridge
	Portuguese Swamp	Swamp	Cambridge
Upper Speed River		Swamp, Marsh	Cambridge

4 RISK ASSESSMENT THRESHOLDS

Following delineation of the vulnerable areas (Section 5), a series of Risk Assessment scenarios are run to assess change in groundwater elevations at the municipal wells, and the change in groundwater discharge to specified surface water features. The predicted change in water level and groundwater discharge values are compared to an established set of drawdown and ecological thresholds to determine if the predicted changes are acceptable or not. The following sections outline the thresholds used in the Region of Waterloo Tier Three Assessment.

4.1 Drawdown Thresholds

Safe additional drawdown is defined as the additional depth that the water level within a pumping well could fall and still maintain the well's Allocated Rate. It is calculated as the additional drawdown that is available over and above the drawdown created by the existing conditions (2008) average annual pumping rate. To establish the safe additional available drawdown for each municipal well examined in the Tier Three Assessment, the following components were calculated for each well:

- **Safe Groundwater Level Elevation:** The lowermost water level elevation within a municipal pumping well that an operator can pump a well. This elevation may be related to the well screen elevation, pump intake elevation, top of aquifer, or other operational limitations.

- **Existing Water Level Elevation in the Municipal Pumping Well:** The elevation of the observed average annual pumped water level within the municipal well in 2008.

- **Estimated Non-linear Well Losses at Each Well:** The drawdown within a well in response to well inefficiencies (e.g., entrance losses and turbulent flow around pump fittings) that occurs due to well construction characteristics and well condition.

Each component is discussed in the following sections.

4.1.1 Safe Groundwater Level Elevation

The safe groundwater level elevations for each of the Region's water supply wells examined in the Tier Three Assessment were established and provided by the Region, based on knowledge of well construction, hydraulic characteristics and operational experience. Safe groundwater level elevations were typically determined as follows:

- The current elevation of the pump intake.

- The elevation of the highest water producing feature. For screened wells, that typically draw water from unconsolidated materials, the elevation of the top of the screened interval was considered the highest water producing feature. For open hole wells typically drawing water from bedrock aquifers, the elevation of the highest water producing features was conservatively assumed to be the bottom of the well casing (top of the exposed rock interval), unless relevant available information (e.g., down hole flow profiles, down hole video logs, historical water level data, etc.) indicated that the elevation of the highest water producing feature was below the base of the well casing.

The second case listed above recognizes that regardless of the current pump setting, if required, the pumps can be lowered within respective wells to the limit of the primary water producing features, while still maintaining well capacity and the cooling flow required to prevent pump failure. Based on this approach, the estimated safe water level elevation and the safe available additional drawdown for each municipal well are presented in Table 4-1.

TABLE 4-1 Non-Linear In Well Losses and Safe Additional Available Drawdown

Well	Well Field	2008 Average Annual Pumping Rate (m^3/d)	2031 Allocated Pumping Rate (m^3/d)	2008 Pumped Water Level Elevation (m asl)	Safe Water Level Elevation (m asl)	Drawdown Resulting from In-Well Losses (m)	SAAD (m)[1]
G4	Blair Road	941	1728	260.0	250.5	-0.7	9.5
G4A	Blair Road	0	1728	260.0	250.5	0.0	9.5
G16	Clemens Mill	1664	2938	279.0	259.2	2.4	19.8
G17	Clemens Mill	1995	2160	268.6	261.9	0.1	6.7
G18	Clemens Mill	992	1296	270.0	250.1	0.2	19.9
G6	Clemens Mill	1347	864	274.6	261.1	-0.3	13.6
P6	Dunbar	883	0	267.0	257.4	-0.6	9.6
G9	Elgin Street	1002	0	272.0	266.1	-0.8	5.9
H3	Hespeler	563	864	275.0	257.2	3.5	17.8
H4	Hespeler	0	1296	303.9	295.0	4.7	9.0
H5	Hespeler	383	864	293.7	281.5	0.4	12.2
G1	Middleton Street	3475	5184	244.5	235.0	0.6	9.5
G14	Middleton Street	3206	2160	248.0	225.3	-0.6	22.7
G1A	Middleton Street	3996	1728	246.9	231.9	-1.8	15.1
G2	Middleton Street	5375	6912	248.0	232.9	0.3	15.1
G3	Middleton Street	3407	4752	247.0	228.2	0.6	18.9
G5	Pinebush	1638	0	285.3	283.7	-0.6	1.6
G5A	Pinebush	0	1296	285.3	254.4	0.0	30.9
P10	Pinebush Road	2943	3110	295.0	288.4	0.2	6.6
P11	Pinebush Road	1877	1728	287.3	253.4	1.1	33.9
P15	Pinebush Road	962	1296	285.0	271.2	0.3	13.8
P17	Pinebush Road	741	0	281.0	260.7	-0.2	20.3
P9	Pinebush Road	1474	1296	285.2	269.8	-0.3	15.4
G38	Shades Mill	0	1296	279.4	259.0	0.9	20.4
G39	Shades Mill	0	2592	278.6	256.8	0.8	21.8
G7	Shades Mill	2306	1728	281.0	277.3	-0.1	3.7

Well	Well Field	2008 Average Annual Pumping Rate (m^3/d)	2031 Allocated Pumping Rate (m^3/d)	2008 Pumped Water Level Elevation (m asl)	Safe Water Level Elevation (m asl)	Drawdown Resulting from In-Well Losses (m)	SAAD (m)[1]
G8	Shades Mill	1206	864	280.6	276.7	-0.2	4.0
G15	Willard	2143	2592	252.0	242.2	0.2	9.8
W6A	Erb Street	1614	1296	349.0	335.10	-0.1	13.9
W6B	Erb Street	0	1296	348.0	337.90	0.2	10.1
W7	Erb Street	6041	6048	344.0	338.14	0.0	5.9
W8	Erb Street	3672	2592	342.5	337.29	-0.3	5.2
K1A	Greenbrook	372	1728	305.0	284.03	0.1	21.0
K2A	Greenbrook	1874	1728	303.0	283.47	0.0	19.5
K4B	Greenbrook	3413	1728	300.0	290.59	-0.8	9.4
K5A	Greenbrook	957	1728	305.0	289.83	0.0	15.2
K8	Greenbrook	126	864	305.0	286.19	0.1	18.8
K21	Mannheim East	2303	2592	322.0	317.66	0.0	4.3
K25	Mannheim East	3813	3456	332.0	324.33	0.0	7.7
K29	Mannheim East	2503	2592	330.0	322.79	0.0	7.2
K91	Mannheim Peaking	674	2160	332.0	322.46	0.0	9.5
K92	Mannheim Peaking	813	2160	333.0	323.89	0.0	9.1
K93	Mannheim Peaking	813	2592	331.0	324.42	0.0	6.6
K94	Mannheim Peaking	843	2592	331.0	321.18	0.0	9.8
K22A	Mannheim West	1252	0	331.0	318.90	-0.1	12.1
K23	Mannheim West	2256	432	324.0	315.09	-0.5	8.9
K24	Mannheim West	2562	2592	323.0	310.99	0.1	12.0
K26	Mannheim West	6841	6048	326.0	314.81	0.0	11.2
K31	Parkway	2567	2160	286.0	281.11	0.0	4.9
K32	Parkway	2270	2592	286.0	279.63	0.1	6.4
K33	Parkway	2894	3024	285.0	277.23	0.0	7.8

Well	Well Field	2008 Average Annual Pumping Rate (m^3/d)	2031 Allocated Pumping Rate (m^3/d)	2008 Pumped Water Level Elevation (m asl)	Safe Water Level Elevation (m asl)	Drawdown Resulting from In-Well Losses (m)	SAAD (m)[1]
K10A	Strange Street	327	432	327.9	316.98	0.0	10.9
K11A	Strange Street	199	1728	335.9	315.43	0.0	20.4
K13	Strange Street	526	1296	333.9	315.15	0.0	18.7
K18	Strange Street	2160	1296	336.6	313.71	-0.4	22.9
K19	Strange Street	216	1296	336.6	311.00	0.2	25.6
K34	Strasburg	3184	2765	279.4	274.99	-0.4	4.4
K36	Strasburg	0	0	302.0	266.82	0.0	35.2
W10	Waterloo North	0	1296	341.3	330.57	0.5	10.7
W1B	William Street	818	432	309.9	302.36	0.0	7.5
W1C	William Street	14	2160	315.1	292.89	0.0	22.2
W2	William Street	2384	1728	305.5	293.82	-1.2	11.7
W3	William Street	0	0	312.5	279.17	0.0	33.3
K80	Woolner	1	0	288.2	287.32	0.0	0.9
K81	Woolner	220	0	288.3	287.66	0.0	0.6
K82	Woolner	1,072	0	286.0	283.87	0.0	2.3
P16	Fountain Street	0	0	291.0	276.1	0.0	14.9
K70	Forwell/ Pompeii	0	0	291.0	285.7	0.0	5.3
K71	Forwell/ Pompeii	0	0	291.5	285.7	0.0	5.3
K72	Forwell/ Pompeii	0	0	291.0	287.8	0.0	3.7
K73	Forwell/ Pompeii	0	0	292.0	286.7	0.0	4.3
K74	Forwell/ Pompeii	0	0	292.0	288.8	0.0	3.2
K75	Forwell/ Pompeii	0	0	291.0	290.6	0.0	1.4
K41	Lancaster	0	0	303.5	280.49	23.0	23.0
K42A	Lancaster	0	0	304.5	277.77	26.7	26.7
C3	Conestogo (Plains)	70	214	324.0	306.7	0.0	17.0

Well	Well Field	2008 Average Annual Pumping Rate (m^3/d)	2031 Allocated Pumping Rate (m^3/d)	2008 Pumped Water Level Elevation (m asl)	Safe Water Level Elevation (m asl)	Drawdown Resulting from In-Well Losses (m)	SAAD (m)[1]
C4	Conestogo (Plains)	9	38	324.0	307.1	0.0	17.1
E10	Elmira	0	0	339.0	310.2	0.0	28.8
SA3	St. Agatha	8	0[2]	354.0	346.9	0.0	7.2
SA4	St. Agatha	12		355.0	350.6	0.0	4.4
SA5	St. Agatha	52		357.0	353.6	0.0	3.4
SA6	St. Agatha	37		363.0	354.4	0.0	8.6
ND4	New Dundee	2	2	314.0	308.1	0.0	5.9
ND5	New Dundee	222	222	313.5	308.3	0.0	5.2
WM1	West Montrose	69	0[3]	318.2	318.2	0.0	0.0[3]
WM2	West Montrose						
WM3	West Montrose						
WM4	West Montrose						

[1] SAAD value listed does not take the drawdown associated with in-well losses into account. This was completed when interpreting the Risk Assessment scenario results.

[2] St. Agatha is connected to the integrated urban system via a pipeline and these wells have been abandoned.

[3] The West Montrose system will be decommissioned by the Region in the future, the community will be serviced by groundwater from Conestogo. (NB: this demand was taken into account in the derivation of the Allocated Rates for Conestogo).

asl – above sea level

4.1.1.1 Existing Water Level Elevations in Municipal Pumping Wells

The average pumped water level represents the average water level in the well when it is pumped at rates consistent with normal operational patterns. Water level data measured during uncharacteristically high or low production, as would occur during aquifer testing or well maintenance, was not used to calculate the average pumped water level. Table 4-1 outlines the average pumped groundwater elevations for each of the municipal wells in 2008, and these groundwater elevations are also illustrated on hydrographs in Appendix F.

For some wells that did not have reliable pumping groundwater elevations observed in 2008, the SAAD was estimated using water level elevations from neighbouring observation wells, or from other representative time periods (see Appendix H for details). These SAAD values were taken into account when determining appropriate Allocated Rates for the Risk Assessment.

4.1.1.2 Estimated Non-Linear In-Well Losses

Well losses refer to the difference between the theoretical drawdown in a well and the observed drawdown, and are due to factors such as turbulence in the well itself, and momentum changes as the water flows through the screen and changes direction to flow up the well casing and into the pump intake. These well losses were considered in the Tier Three Assessment, as the additional available drawdown refers specifically to the groundwater elevation in the well (limiting factor for the well to continue pumping water) and not the average groundwater elevation in the aquifer in the vicinity of the well. The in-well losses were calculated as the increased/decreased drawdown that is expected within the pumping well due to the incremental increase/decrease in pumping from the existing to the 2031 Allocated Rates.

Convergent head losses derived from differences in simulating an average water level at a finite element node and the pumping well are negligible due to the small node spacing around the wells in the model and are less important than the in-well losses and were not considered in the analyses.

Changes in drawdown resulting from in-well losses were calculated using 2008 pumping rates, 2031 Allocated Rates, and additional well loss coefficient data provided by the Region of Waterloo. The process used to calculate in-well losses for the Tier Three Assessment is explained in Appendix G, and the calculated values for each well are listed in Table 4-1.

4.1.1.3 Safe Additional Available Drawdown

Table 4-1 lists the safe additional available drawdown (SAAD) value calculated as the difference between the 2008 pumped water level elevation and the safe water level elevation (see Appendix F for municipal well hydrographs). The SAAD provides an indication of a well's ability to sustain pumping in the event of changes in groundwater level elevation in the municipal well. Where the SAAD is low, this indicates that the well may have a higher risk of not being able to meet pumping requirements in the future, if the same or additional pumping volumes are required to be produced by that well.

The SAAD ranges from less than 5 m at Wells G5, G7 and G8, to over 30 m at Well K36 and Well W3 (Table 4-1). These statistics illustrate the range of pumping and SAAD conditions within the Region.

4.2 Ecological Thresholds

As the Tier Three Risk Assessment assesses whether or not municipal groundwater wells can meet their Allocated Rates, while maintaining the requirements of other water uses in the area, the assessment must identify all other water uses and estimate the water quantity requirements for those uses where possible. Establishing the quantity of water required by other water uses is difficult as it is not always a unit flow rate of water. For example, the health and ecological integrity of a PSW may be independent of the water table elevation or the groundwater discharge rate as the health of some wetlands are sustained by precipitation and/or surface water runoff, rather than groundwater discharge. The focus of this study was on assessing potential impacts on cold water streams, swamps and fens as the health of these features are at least partially reliant on groundwater discharge.

4.2.1 Cold Water Fisheries and Provincially Significant Wetlands

Groundwater discharge requirements for cold water aquatic habitat are poorly understood, and the impacts of a reduction in groundwater discharge into the aquatic habitat cannot be definitively predicted using the groundwater flow models. Consequently, the Province introduced the use of thresholds to evaluate the potential for impacts due to reductions in groundwater discharge into cold water streams.

The Province has prescribed specific baseflow reduction thresholds that should be used when assigning a Risk Level associated with predicted impacts to cold water fish community streams due to increased municipal pumping. For cold water streams, a Moderate Risk Level is assigned when groundwater discharge is predicted to be reduced by at least 10% of existing monthly baseflow (as defined by the MOE; MOE 2009, 2013). Baseflow is defined by the MOE (2009) as the monthly Qp80 (the flow that is exceeded 80% of the time) or using another method where gauged stream flow data are unavailable.

Potential baseflow reductions on cold water streams due to changes in land use conditions are not taken into account when assigning the Risk Level through the Tier Three Risk Assessment; such impacts are reviewed for information purposes only. Figure 3-6 illustrates the cold water streams located within the Region that are subject to the Province's groundwater discharge reduction threshold, and the areas of assessment for those reaches.

Assessing the potential ecological impacts that may arise due to reduction in groundwater discharge into wetlands or the lowering of the water table beneath a wetland are similarly poorly understood. The hydrologic functions (i.e., recharging or discharging conditions) within wetland complexes are poorly understood as small fen areas that are fed exclusively by groundwater discharge, may be surrounded by wetlands that lose water to the underlying groundwater flow system on a seasonal or regular basis. The complexity and lack of detailed understanding of the function of many provincially or locally significant wetlands makes it difficult to quantify whether the reduction in groundwater discharge or reduction in water table beneath the wetland will or will not impact the wetland or wetland complex. In this assessment, the largest change in water level at the wetland, and the potential change in predicted function of the wetland or wetland complex (i.e., change from discharging wetland to recharging wetland) were tabulated and used to guide the assessment of impact on other water uses.

5 VULNERABLE AREA DELINEATION AND RISK ASSESSMENT RESULTS

5.1 Vulnerable Area Delineation

The first step in the Local Area Risk Assessment was the delineation of vulnerable areas. Water quantity vulnerable areas were delineated to protect the quantity of water required by the Region's existing and Allocated Rates. The methodology used to delineate the WHPA-Q1 and WHPA-Q2 areas were outlined in Section 2.1, and the results are described in the following sections.

5.1.1 WHPA-Q1

The WHPA-Q1 was delineated as the combined area that is the cone of influence of a well and the whole of the cones of influence of all other wells that intersect that area (MOE 2009). Section 2.1.1 outlines the methodology used, and Appendix B describes the selection of the 2 m contour interval used in the delineation of the WHPA-Q1.

Four WHPA-Q1 areas lie within the Region as illustrated on Figure 5-1. The westernmost is WHPA-Q1A, which underlies the western portions of the Cities of Kitchener and Waterloo. The WHPA-Q1A area extends north to the town of Heidelberg, south to New Dundee, west to St. Agatha and east toward the Grand River.

The WHPA-Q1B underlies the majority of the urban portion of the City of Cambridge, and extends in a northwestward direction toward the City of Guelph (Figure 5-1). The WHPA-Q1B extends into the City of Guelph, as the northern model boundary condition for the Cambridge Model coincides with the pumped water level elevations for the aquifers in the City of Guelph. As a result, the drawdown associated with groundwater pumping in the City of Guelph was simulated in the Cambridge Model. The City of Guelph Tier Three Assessment delineated the WHPA-Q1 for Guelph and it overlaps with the Region's WHPA-Q1B; consequently, a combined WHPA-Q1 area for the two cities was proposed (Figure 5-1).

The WHPA-Q1 for the City of Guelph is considered more representative of the drawdown in the vicinity of the City of Guelph than the drawdown simulated by the Cambridge Model in the Guelph area. Similarly, the drawdown simulated in the Cambridge area by the Cambridge Model is more representative of the drawdown than the drawdown simulated in the City of Guelph model. The Grand River marked the southwestern limit of the Guelph Tier Three Model and as such, the drawdowns associated with the Middleton, Blair Road and Willard Well Fields were not simulated in the Guelph Model. Consequently, the WHPA-Q1B delineated in the Cambridge Model extends further to the south and west as compared to the WHPA-Q1 delineated using the Guelph Model.

Review of the simulated water level contours in both the Cambridge and Guelph Models identifies a groundwater divide within the Gasport Formation between the cities of Cambridge and Guelph. The gradient in this area is shallow and changes in groundwater demand in this area, or within the two cities has the potential to shift the location of this inferred groundwater flow divide. Additional studies may be undertaken to delineate a zone surrounding the groundwater flow divide to ensure future source water protection policies are protective of the Region's and the City of Guelph's water supply sources, as well as other water uses, including coldwater streams and wetlands.

The WHPA-Q1C area is represented by a 100 m buffer surrounding the Conestogo Plains Well Field (Wells C3 and C4). As the Allocated Rates for the wells are low relative to the estimated aquifer transmissivity, the 2 m drawdown cone has a limited spatial extent. As such, a 100 m buffer area was drawn around the municipal wells to delineate the WHPA-Q1C (Conestogo) area. The WHPA-Q1D area is a small drawdown cone located around the Blair Road Wells (Wells G4 and G4A). The drawdown extends approximately 140 m from the Blair Road Well Field Wells on the west side of the Grand River and is masked beneath the well symbols on Figures 5-1.

5.1.2 WHPA-Q2

The WHPA-Q2 is defined in the Technical Rules (MOE 2009) as the WHPA-Q1 area, plus any area where a future reduction in recharge may have a measurable impact on wells located in that area. Proposed land development areas that are predicted to reduce the available drawdown in a municipal well, such that the well may have difficulty pumping at its Allocated Rate, were included within the WHPA-Q2 because they were interpreted to have a measurable impact on the wells. Figure 5-2 illustrates the WHPA-Q2 areas within the Study Area, as well as the proposed land use development areas (as discussed in Section 3.1). The majority of the development that is expected to occur takes place within the WHPA-Q1 areas, with the exception of a few proposed land use development areas that straddle and extend beyond the WHPA-Q1 boundaries as follows:

- **WHPA-Q1A:** Proposed residential development area southeast of the Parkway-Strasburg Well Field in Kitchener
- **WHPA-Q1A:** Proposed residential and industrial development north and south of the Pompeii / Forwell Well Fields (on the east and west sides of the Grand River, respectively)
- **WHPA-Q1B:** Proposed residential development area southeast of the Elgin Well in Cambridge
- **WHPA-Q1A** and **WHPA-Q1B**: Proposed industrial developments in the area surrounding the Fountain Street Well Field between Kitchener and Cambridge

- **WHPA-Q1C:** Proposed residential development area west of the Blair Road Well Field in Cambridge

To assess the impact of land use changes on water quantity for the municipal wells, and to determine if the impact of development is “measureable,” the Cambridge and Regional Models were updated to simulate the land use developments (assuming no best management measures; see Section 3.1.2 and 3.1.3 for additional details). The simulated average annual groundwater recharge distribution from the Regional and Cambridge Models were updated to reflect the future reductions in recharge and the models were re-run. The reductions in groundwater level elevations due to all of the proposed land development areas within the Region (as illustrated on Figure 5-2) were examined.

In the Kitchener area near Parkway-Strasburg, the impact of all proposed land developments was predicted to cause less than 40 cm of additional drawdown in the wells in the Parkway-Strasburg area. This drawdown was compared to the safe additional available drawdown at the wells, which varies from 4.8 m to over 30 m. As the impact of all developments in the area (i.e., those within and just beyond the WHPA-Q1A boundary is less than 10% of the safe additional available drawdown, the reduction in recharge due to the proposed land development was not considered a measureable impact. Consequently, the development that straddles or lies just outside the WHPA-Q1A was not included in the WHPA-Q2A boundary.

In the East Kitchener area, several residential developments are proposed near the Grand River, north and south of the Pompeii/Forwell Well Fields (Figure 5-2). The impact of these proposed land developments was predicted to cause less than 10 cm of additional drawdown at the Pompeii/Forwell Well Fields, which is minor when compared to the safe additional available drawdown at the wells, and considering these wells are hydraulically connected to the Grand River. As the reduction in recharge is not expected to cause a measurable impact, the development that straddles or lies just east of the WHPA-Q1A was not included in the WHPA-Q2A boundary.

In the Elgin Street area, the impact of all proposed land developments was predicted to be 20 cm at the Elgin Street Well. This equates to 3% of the safe additional available drawdown at the well. As the impact of all development is minor compared to the available drawdown, the reduction in recharge occurring outside the WHPA-Q1B area was not included in the WHPA-Q2B.

In the Fountain Street area between Kitchener and Cambridge, several industrial developments are proposed (Figure 5-2). The impact of these proposed land developments was predicted to cause less than 50 cm of additional drawdown at the Fountain Street Well (Well P16), which is minor when compared to the 14.9 m of safe additional available drawdown at the well. The impact due to the reduction in recharge is not considered measurable, so the developments that lie between the WHPA-Q1A and WHPA-Q1B were not included in the WHPA-Q2A or WHPA-Q2B boundaries.

In the Blair Road area, the sum of all proposed land developments in the Cambridge area were predicted to lead to less than 4 cm of additional drawdown at the well. As the safe additional available drawdown at the well is 9.5 m, the impact of the development that lies just outside the WHPA-Q1C boundary is expected to be far less than 1% of the available drawdown. This impact was not considered a measureable impact on the well, and therefore, the land use development area was not included as part of the WHPA-Q2B.

In summary, the seasonal variation in groundwater elevations of approximately 2 m would mask any changes in proposed land use change for the developments lying outside the WHPA-Q1 areas, and the incremental additional drawdown at the municipal wells is much smaller than the available drawdown. Therefore, the reduction in recharge due to land development taking place outside the WHPA-Q1 areas were not considered to cause a measurable impact on the wells, and were not included in the WHPA-Q2 areas. The WHPA-Q2 areas are therefore coincident with their respective WHPA-Q1 areas.

5.1.3 Local Areas

The Local Areas for this study are also illustrated on Figure 5-2. The Local Areas by definition are delineated by combining the cone of influence of the municipal supply wells (WHPA-Q1; Figure 5-1) and the areas where a reduction in recharge would have a measurable impact on the cone of influence of the wells (WHPA-Q2; Figure 5-2). As noted in Section 5.1.2, the WHPA-Q1 and WHPA-Q2 areas are coincident, reflecting low potential for measureable impact on groundwater elevations at the municipal wells under proposed changes in land use outside the WHPA-Q1 areas. Local Area A includes many of the municipal wells in the Kitchener and Waterloo areas, Local Area B includes many of the wells in the Cambridge area, Local Area C includes the Conestogo Plains wells and Local Area D includes the Blair Road wells.

5.2 Risk Assessment Scenario Results

Depending on the scenario, the model results were evaluated with respect to the estimated drawdown at each municipal well, and the predicted impact on groundwater discharge to cold water streams and PSWs.

The additional drawdown predicted in each of the Risk Assessment model scenarios was estimated and compared to the estimated safe additional drawdown at each municipal well. The drawdown values for each scenario are additional, or incremental drawdown values relative to the drawdown already experienced within the well in 2008.

In the steady-state scenarios (Scenarios G1, G2 and G3), the difference between the groundwater elevations at the well in the existing conditions scenario (Scenario C) and the groundwater elevations at the end of each model scenario were recorded as the additional predicted drawdown (Table 5-1). For the transient scenarios, the lowest simulated water level elevation in the aquifer at each municipal pumping well was compared to the water level in Scenario C, and this value was recorded in Table 5-1. The model simulated drawdowns in each scenario were then compared to the field-based safe additional drawdown values to identify municipal wells that may be unable to pump at their Allocated

Rates. The Risk Assessment scenario results for the Regional and Cambridge Models are presented in Sections 5.2.1 and 5.2.2, respectively.

The Risk Assessment scenarios run using the Cambridge and Regional Models provide insight into the cumulative impacts associated with pumping the municipal wells at higher rates. The models provide insight into the potential cumulative drawdown experienced in the municipal wells, and the potential interaction between the groundwater and surface water systems. However, the operations of the municipal wells are much more complex than the scenarios depict. The Region operates an integrated urban system whereby water from various distribution system pressure zones can be distributed as required to meet demands. Wells or entire well fields may be shut down for days, weeks or months, with the other well fields in the area compensating for the shut down. This inherent tolerance in the system is not simulated by the models in the Risk Assessment scenarios. Further, in situations where wells or well fields are shut down, the compensating wells could be pumped at rates approaching those on the individual permits to take water, which are based on long-term sustainability tests undertaken during an environmental assessment. The average pumping rates used in the Tier Three Assessment should not be viewed to constrain the sustainable pumping rates calculated through the environmental assessment process.

Similarly, the Region also operates an ASR system at Mannheim, whereby water is pumped from the Grand River, is treated and injected into underground aquifers for storage and is used when the Region needs the water. On an average annual basis, there is no net consumptive use at these wells as the volume injected is the same as the volume withdrawn. As a result, the ASR system was not included in the Regional Model. This system is designed to provide additional water supplies during periods of peak demand and/or when other systems are offline for maintenance, which provides another level of tolerance for the integrated urban system.

Municipal water is also derived from the Grand River. The Tier Three Assessment assumed that no additional water would be taken from the Grand River, although it is possible that additional supplies could be obtained from the river in the future.

5.2.1 Drawdown at Municipal Wells – Regional Model

Table 5-1 summarizes the model-predicted drawdown in the municipal wells under each of the Risk Assessment scenarios using the Regional Model. In all instances, the predicted drawdown was less than the safe additional drawdown at each of the wells, which indicated the wells are able to pump at their current and Allocated Rates over the long-term (including drought conditions) under existing and future land use development conditions. In Table 5-1, the in-well losses needed to be subtracted from the safe additional available drawdown values for the scenarios with the Allocated Rates (i.e., Scenarios G1, G2, H1 and H2) and then compared to the modelled drawdown values. In Table 5-1, negative in-well losses or modelled drawdown values correspond to water level recovery or increases, due to reductions in municipal pumping from the existing to the Allocated Rates.

To visualize the extent of the drawdown within the Kitchener and Waterloo areas, the model-predicted groundwater elevations in each production aquifer were exported from the model at the end of the average climatic conditions (steady-state) scenarios (i.e., Scenarios G1, G2 and G3; Table 2-2). These were then compared to the groundwater elevations under existing (2008) conditions (Scenario C) to produce maps of the spatial extent of additional drawdown relative to 2008 groundwater elevations. Figures 5-3 to 5-5 illustrate the spatial extent of the 2 m additional drawdown contour for Scenarios G1, G2 and G3, respectively (Note: this is additional drawdown relative to the drawdown experienced in 2008). Model predicted drawdown (2 m contour) due to reductions in recharge due to land use development (Scenario G3) are illustrated on Figure 5-5. This figure shows that the reductions in recharge have the potential to cause drawdown in the water table that exceeds 2 m in several areas, including the area between the Mannheim and Parkway / Strasburg Well Fields, and between the Strange Street and Erb Street Well Fields.

Figure 5-4 illustrates the 2 m additional drawdown contour predicted when the municipal wells are pumped at their Allocated Rates, as compared to the existing (2008) rates. Well W6B in Erb Street is one example of a well where the predicted drawdown at the well has a limited lateral extent and as such, the drawdown contour is concealed beneath the well symbol on Figures 5-3 and 5-4. The impact of pumping at the Allocated Rates (Scenario G2; Figure 5-4) is predicted to cause drawdown across much of the western reaches of the City of Kitchener and southern reaches of the City of Waterloo. Figure 5-4 highlights the need to manage the water resources in all of the urban well fields holistically, rather than on an individual well field basis as most of the urban well fields are hydraulically connected to one another. For example, increasing the water demands at the Strange Street Well Field may cause water level reductions at the nearby Greenbrook Well Field. The results for each of the base case Risk Assessment scenarios are discussed on a well field basis in the following sections. However, changes in groundwater demand and recharge reductions across the entire Waterloo Moraine area need to be considered when interpreting the drawdown results at individual municipal wells.

TABLE 5-1 Risk Assessment Drawdown Results – Regional Model

Well Field	Well Name	Safe Additional Aquifer Drawdown (2008)	Additional In-Well Losses (m)	Drawdown (m): Average Climate Scenarios			Drawdown (m): Drought Scenarios			
				G1	G2	G3	D	H1	H2	H3
				Allocated Rates, Future Land Use	Allocated Rates	Future Land Use	Existing Recharge, Demand	Allocated Rates, Future Land Use	Allocated Rates	Future Land Use
Erb Street	W6A	13.9	-0.1	2.2	1.9	0.3	1.4	3.1	2.8	1.7
	W6B	10.1	0.2	3.6	3.3	0.3	1.2	4.5	4.3	1.5
	W7	5.9	0.0	0.2	-0.3	0.5	1.8	1.3	0.9	2.2
	W8	5.2	-0.3	-0.1	-0.6	0.5	1.7	0.9	0.5	2.1
Waterloo North	W10	10.7	0.5	4.8	4.7	0.2	0.7	6.6	6.4	0.8
William Street	W1B	7.5	0.0	2.4	2.2	0.2	1.3	3.6	3.5	1.5
	W1C	22.2	0.0	4.9	4.7	0.2	1.1	6.1	6.0	1.3
	W2	11.7	-1.2	2.2	2.0	0.2	1.3	3.7	3.5	1.5
	W3	33.3	0.0	3.0	2.8	0.2	1.1	3.9	3.7	1.2
Mannheim East	K21	4.3	0.0	2.6	1.4	1.2	1.6	3.8	2.8	2.6
	K25	7.7	0.0	2.1	0.8	1.2	1.7	3.4	2.3	2.8
	K29	7.2	0.0	2.1	0.9	1.2	1.7	3.5	2.3	2.7
Mannheim Peaking	K91	9.5	0.0	2.9	1.7	1.1	1.6	4.1	3.1	2.6
	K92	9.1	0.0	3.0	1.8	1.1	1.6	4.2	3.1	2.6
	K93	6.6	0.0	3.6	2.5	1.1	1.6	4.5	3.5	2.5
	K94	9.8	0.0	3.3	2.2	1.1	1.7	4.5	3.5	2.6
Mannheim West	K22A	12.1	-0.1	-0.4	-1.2	0.9	1.6	0.8	0.0	2.3
	K23	8.9	-0.5	-1.0	-1.9	0.9	1.4	0.2	-0.6	2.2
	K24	12.0	0.1	1.2	0.2	1.0	1.6	2.6	1.7	2.5
	K26	11.2	0.0	0.9	-0.1	1.1	1.7	2.5	1.5	2.7
Strange Street	K10A	10.9	0.0	5.6	5.3	0.3	2.1	7.2	6.9	2.4
	K11A	20.4	0.0	8.2	7.9	0.4	2.1	10.6	10.2	2.4
	K13	18.7	0.0	11.7	11.3	0.4	3.0	16.8	16.5	3.3
	K18	22.9	-0.4	4.4	4.1	0.4	4.0	7.3	6.9	4.3

Well Field	Well Name	Safe Additional Aquifer Drawdown (2008)	Additional In-Well Losses (m)	Drawdown (m): Average Climate Scenarios			Drawdown (m): Drought Scenarios			
				G1	G2	G3	D	H1	H2	H3
				Allocated Rates, Future Land Use	Allocated Rates	Future Land Use	Existing Recharge, Demand	Allocated Rates, Future Land Use	Allocated Rates	Future Land Use
	K19	25.6	0.2	7.8	7.4	0.4	2.8	10.7	10.3	3.2
Greenbrook	K1A	21.0	0.1	5.0	4.5	0.6	2.5	6.5	5.8	3.1
	K2A	19.5	0.0	3.3	2.8	0.6	1.8	4.7	4.1	2.4
	K4B	9.4	-0.8	-2.1	-2.6	0.5	5.3	-0.5	-1.0	5.8
	K5A	15.2	0.0	5.4	5.0	0.5	6.0	7.1	6.6	6.6
	K8	18.8	0.1	4.7	4.1	0.6	1.7	6.0	5.4	2.2
Parkway	K31	4.9	0.0	0.3	0.0	0.4	1.1	1.1	0.8	1.4
	K32	6.3	0.1	0.5	0.1	0.4	1.1	1.3	1.0	1.4
	K33	7.8	0.0	0.4	0.0	0.4	1.1	1.2	0.9	1.5
Strasburg	K34	4.8	-0.4	-2.1	-2.5	0.4	1.7	-0.7	-1.1	2.1
	K36	35.2	0.0	-0.1	-0.5	0.4	1.1	0.7	0.3	1.4
Lancaster	K41	23.0	0.0	1.0	0.8	0.2	0.6	1.7	1.5	0.8
	K42A	26.7	0.0	1.1	1.0	0.2	0.6	1.8	1.7	0.8
Pompeii / Forwell	K70	5.3	0.0	0.1	0.0	0.1	0.2	0.2	0.2	0.2
	K71	5.3	0.0	0.1	0.0	0.1	0.1	0.2	0.1	0.2
	K72	3.7	0.0	0.1	0.0	0.1	0.2	0.2	0.2	0.2
	K73	4.3	0.0	0.1	0.0	0.1	0.2	0.2	0.2	0.2
	K74	3.2	0.0	0.1	0.0	0.1	0.2	0.2	0.2	0.2
	K75	1.4	0.0	0.1	0.0	0.1	0.1	0.2	0.1	0.2
Woolner	K80	0.9	0.0	0.0	-0.1	0.1	0.1	0.1	0.0	0.2
	K81	0.6	0.0	-0.7	-0.7	0.1	0.1	-0.6	-0.6	0.1
	K82	2.2	0.0	-2.1	-2.2	0.1	0.1	-2.0	-2.0	0.2
Fountain Street	P16	14.9	0.0	0.5	0.1	0.5	0.6	1.0	0.7	0.9
Conestogo	C3	17.0	0.0	2.2	2.1	0.0	0.3	3.0	3.0	0.3
	C4	17.1	0.0	1.1	1.1	0.0	0.3	1.6	1.5	0.3

Well Field	Well Name	Safe Additional Aquifer Drawdown (2008)	Additional In-Well Losses (m)	Drawdown (m): Average Climate Scenarios			Drawdown (m): Drought Scenarios			
				G1	G2	G3	D	H1	H2	H3
				Allocated Rates, Future Land Use	Allocated Rates	Future Land Use	Existing Recharge, Demand	Allocated Rates, Future Land Use	Allocated Rates	Future Land Use
New Dundee	ND4	5.9	0.0	0.2	0.0	0.2	1.9	2.0	1.8	2.0
	ND5	5.2	0.0	0.2	0.0	0.2	1.9	2.0	1.8	2.0
Elmira	E10	28.8	0.0	0.1	0.0	0.1	0.7	0.7	0.7	0.7

5.2.1.1 Erb Street

The Allocated Rates for the Erb Street Well Field were similar to the existing conditions (2008) pumping rates. Wells W6A and W7 were expected to pump at rates similar to 2008, whereas under the Allocated Rates, some of the existing (2008) pumping was shifted from Well W8 to Well W6B (see Table 3-2).

Scenario G1 assessed the drawdown impacts on the municipal wells from future changes in land use that cause reductions in recharge due to land development specified in the Official Plan (subsequently referred to as recharge reductions), and changes in average annual municipal pumping from existing (2008) to the Allocated Rates (subsequently referred to as pumping at the Allocated Rates). For this scenario, the greatest predicted additional drawdown (3.6 m) occurred at Well W6B (Table 5-1), but this value is well below the safe additional available drawdown at the well (10.1 m). Under this scenario, the water level in Well W8 was predicted to recover by 0.1 m (Table 5-1).

Scenario G2 assessed the impact of pumping at the Allocated Rates on groundwater elevations in the wells, and also on other water uses such as cold water streams and wetlands (see Section 5.2.3 below for discussion on surface water impacts). For this scenario, groundwater elevations were predicted to decline by approximately 3.3 m at Well W6B due to increased pumping, and to increase 0.6 m at Well W8 (Table 5-1).

Scenario G3 assessed changes in groundwater elevations in the wells solely due recharge reductions. Several new development areas are proposed east of the Erb Street Well Field, including a group of residential and industrial developments north of Erb Street between Wilmot Line and Ira Needles Boulevard, and another development area south of Erb Street along the west side of Ira Needles Blvd (Figure 3-1). The additional drawdown predicted due to recharge reductions varied from 0.3 to 0.5 m (Scenario G3; Table 5-1).

Scenario D assessed the impacts of existing (2008) monthly (seasonal) pumping rates (subsequently referred to as 2008 monthly pumping rates), existing land use cover and drought climatic conditions (subsequently referred to as drought climate). The maximum additional drawdown due to monthly variability in pumping and drought climate was predicted to range from 1.2 m at Well W6B to 1.8 m at Well W7 (Table 5-1).

Scenario H1 assessed changes in groundwater elevations in the wells resulting from drought climate, monthly future pumping at the Allocated Rates, and recharge reductions. The maximum additional drawdown predicted in this scenario was 4.5 m at Well W6B (Scenario H1; Table 5-1), which is well below the safe additional available drawdown at the well (10.1 m). Scenario H2 assessed the impact of monthly pumping at the Allocated Rates under drought climate. The drawdown in the wells was comparable to the Scenario H1 results (Table 5-1). The drawdown due to recharge reductions under drought climate (Scenario H3) was predicted to vary from 1.5 m at Well W6B to 2.2 m at Well W7 (Table 5-1).

Under all scenarios, the predicted drawdown at the Erb Street Well Field remained within the safe additional available drawdown values for the wells.

5.2.1.2 Waterloo North

Well W10 was not pumping in 2008; however, the Allocated Rate was estimated to be 1,296 m^3/d.

Under average climatic conditions, 4.8 m of additional drawdown was predicted at Well W10 due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1). Similarly, 4.7 m of drawdown was predicted at Well W10 due to pumping at the Allocated Rates (Scenario G2), and only 0.2 m of drawdown was predicted due to recharge reductions, primarily associated with the residential development located upgradient (west and north) of the well (Scenario G3; Figure 3-1; Table 5-1).

Approximately 0.7 m of additional drawdown was predicted at Well W10 due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1). As Well W10 was not pumping in 2008, this drawdown is reflective of the impact of drought and climatic variability and not seasonal variations in pumping.

Under drought climate conditions, additional drawdown of 6.6 m was predicted at Well W10 due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). This value was well below the safe available additional drawdown at the well (10.2 m; Table 5-1). Similarly, 6.4 m of additional drawdown was predicted due to pumping at the Allocated Rates (Scenario H2; Table 5-1), and approximately 0.8 m of drawdown was predicted at the well due to recharge reductions (Scenario H3; Table 5-1).

Under all scenarios, the predicted drawdown at the Waterloo North Well Field remained within the safe additional available drawdown value for Well W10.

5.2.1.3 William Street

At the William Street Well Field, the municipal pumping rates were forecast to increase from 3,217 m^3/d in 2008 to 4,320 m^3/d under the future Allocated Rates. Allocated Rates at Wells W1B and W2 were reduced relative to the 2008 rates, while the pumping rate at Well W1C increased (Table 3-2).

Under average climatic conditions, 4.9 m of additional drawdown was predicted at Well W1C, and 2.4 and 2.2 m was predicted at Wells W1B and W1C, respectively due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1). Drawdown was predicted at Wells W1B and W1C despite their reductions in pumping at the Allocated Rates because of the increase in pumping at Well W1C and possibly also due to increased taking under the Allocated Rates at the nearby Strange Street Well Field (Figure 5-3; Table 3-2). Drawdown predicted due to pumping at the Allocated Rates (Scenario G2) was comparable to the aforementioned results, suggesting the majority of the drawdown predicted in Scenario G1 was due to pumping at the Allocated Rates, and not recharge reductions.

Only 0.2 m of drawdown was predicted at each well due to recharge reductions, as there is little undeveloped land near the well field (Scenario G3; Figure 3-1; Table 5-1).

Maximum drawdown of 1.3 m was predicted at Wells W1B and W2 due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1). This predicted drawdown is less than the safe additional available drawdown values of 7.5 and 11.7 m, respectively.

Under drought climate conditions, maximum additional drawdown of 6.1 m was predicted at Well W1C due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). This value is well below the safe additional available drawdown value (22.2 m; Table 5-1) at the well. Similarly, a maximum drawdown of 6.0 m was predicted at Well W1C due to pumping at the Allocated Rates (Scenario H2; Table 5-1). Approximately 1.2 m (Well W3) to 1.5 m (Well W1B) of additional drawdown was predicted due to recharge reductions (Scenario H3; Table 5-1). These values are well below the safe additional drawdown values at the wells, which vary from 7.5 to 33.3 m (Table 5-1).

Under all scenarios, the predicted drawdown at the William Street Well Field remained within the safe additional available drawdown values at each well.

5.2.1.4 Mannheim East

The Allocated Rates at the Mannheim East Well Field were similar to the 2008 pumping rates (Table 3-2).

Under average climatic conditions, 2.1 to 2.6 m of additional drawdown was predicted at the wells in the well field due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1). Drawdown predicted due to pumping at the Allocated Rates ranged from 0.8 to 1.4 m (Scenario G2; Table 5-1), and drawdown due recharge reductions was predicted to be 1.2 m at each of the wells (Scenario G3; Table 5-1). Several land use developments were identified within 1 km of the municipal wells, including a residential development north of Bleams Road between Fisher-Hallman and Trussler Road (Figure 3-1). In addition, extensive land development is planned south of Bleams Road and east of Trussler Road. The 1.2 m of drawdown predicted under the recharge reduction scenario (Scenario G3) represented more than one-quarter of the safe additional available drawdown at Well K21 (4.3 m). The areas where the developments are slated to take place contain coarse-grained sediments at surface and as such, convey significant volumes of recharge to the unconfined (AFB2) Mannheim Aquifer.

Drawdown ranged from 1.6 to 1.7 m at the wells due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1), which is below the safe additional drawdown values of 4.3 to 7.7 m at the wells.

Under drought climate conditions, maximum additional drawdown of 3.8 m was predicted at Well K21 due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1), and this value was less than, but close to, the safe additional available drawdown at the well (4.3 m; Table 5-1).

Wells K25 and K29 are in close proximity to Well K21 and all three wells draw water from the same aquifer. Predicted additional drawdown was 3.4 and 3.5 m at Wells K25 and K29, respectively, which represented less than half of the safe additional available drawdown at these wells (7.7 and 7.2 m at Wells K25 and K29, respectively). As the additional predicted drawdown at Well K21 approached its safe additional available drawdown, pumping could be readily shifted to Wells K25 and/or K29 if required, which have additional available drawdown.

Additional drawdown due to pumping at the Allocated Rates under drought climate was predicted to range from 2.3 m at Wells K35 and K29, to 2.8 m at Well K21 (Scenario H2; Table 5-1). Approximately 2.6 m (Well K21) to 2.8 m (Well K25) of additional drawdown was predicted due to recharge reductions under drought climate (Scenario H3; Table 5-1). These values are well below the safe additional drawdown values at the wells, which vary from 4.3 m (Well K21) to 7.7 m (Well K25; Table 5-1).

Under all scenarios, the predicted drawdown at the Mannheim East Well Field remained within the safe additional available drawdown values at each well.

5.2.1.5 Mannheim Peaking

The Mannheim Peaking Well Field is currently pumped primarily during the summer months to meet peak water demands. The pumping rates used for the Allocated Rates at this well field represent year-round pumping and some of the wells in the Mannheim West Well Field (i.e., Wells K22A and/or K23) represent pumping to meet peak demands. As such, the cumulative Allocated Rates for this well field were increased from 3,142 m^3/d (in 2008) to 9,504 m^3/d (Table 3-2). Allocated Rates of 2,160 m^3/d were assigned to Wells K91 and K92, and 2,592 m^3/d to Wells K93 and K94. While these rates were increased, there was a commensurate decrease in pumping at the neighboring Mannheim West Well Field.

Under average climate conditions, a maximum of 3.6 m of additional drawdown was predicted at Well K93 due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1) and this value is well below the safe additional available drawdown for the well (6.6 m). Drawdown predicted due to pumping at the Allocated Rates ranged from 1.7 to 2.5 m (Scenario G2; Table 5-1), and drawdown due recharge reductions was predicted to be 1.1 m at each of the wells (Scenario G3; Table 5-1).

Maximum drawdown of 1.7 m was predicted at Well K94 and 1.6 m was predicted at the remaining wells due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1).

Under drought climate conditions, a maximum of 4.5 m of additional drawdown was predicted at Wells K93 and K94 due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). This value is well below the safe additional available drawdown value for these wells (6.6 and 9.8 m, respectively; Table 5-1). Similarly, drawdown due to pumping at the Allocated Rates was predicted to range from 3.1 to 3.5 m (Scenario H2; Table 5-1). Approximately 2.5 to 2.6 m of additional drawdown was predicted due to recharge reductions (Scenario H3; Table 5-1). These values are well below the safe additional drawdown values at the wells, which vary from 6.6 to 9.8 m (Table 5-1).

Under all scenarios, the predicted drawdown at the Mannheim Peaking Well Field remained within the safe additional available drawdown values for each well.

5.2.1.6 Mannheim West

At the Mannheim West Well Field, the Allocated Rates total 9,072 m^3/d, which represents an approximate 30% reduction in pumping relative to 2008 rates. Under the Allocated Rates, Well K22A was not pumping and Well K23 was reduced by 80%. The Allocated Rates for Wells K24 and K26 were similar to 2008 pumping rates (Table 3-2).

Under average climatic conditions, a maximum of 1.2 m of additional drawdown was predicted at Well K24, and water level recovery of 0.4 and 1.0 m was predicted at Wells K22A and K23 due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1). Drawdown predicted due to pumping at the Allocated Rates ranged from 0.2 m at Well K24 to a water level recovery in Wells K22A, K23 and K26 due to decreases in demand from 2008 to the Allocated Rates (Scenario G2; Table 5-1). A range of 0.9 to 1.1 m of drawdown was predicted at the wells in the well field due recharge reductions, highlighting the importance of management of the groundwater recharge at this well field (Scenario G3; Table 5-1).

Maximum drawdown of 1.7 m was predicted at Wells K26 due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1).

Under drought climatic conditions, a maximum of 2.6 m of additional drawdown was predicted at Well K24 due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). This value is well below the safe additional available drawdown value (12.0 m; Table 5-1) at the well. Similarly, a maximum drawdown of 1.7 m (Well K24) and a recovery of 0.6 m (K23) was predicted due to pumping at the Allocated Rates (Scenario H2; Table 5-1). Approximately 2.2 m (Well K23) to 2.7 m (Well K26) of additional drawdown was predicted due to recharge reductions (Scenario H3; Table 5-1). These values are well below the safe additional drawdown values at the wells, which vary from 9.4 to 12.2 m (Table 5-1).

Under all scenarios, the predicted drawdown at the Mannheim West Well Field remained within the safe additional available drawdown values for each well.

5.2.1.7 Strange Street

The Allocated Rates for the Strange Street Well Field totaled 6,048 m^3/d, which was nearly double the 2008 average annual rate (Table 3-2). Under the Allocated Rates, the wells were predicted to pump at rates of 1,296 to 1,728 m^3/d, with the exception of Well K10A, which was predicted to pump at 432 m^3/d.

Under average climatic conditions, a maximum of 11.7 m of additional drawdown was predicted at Well K13 due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1). This value is below the safe additional available drawdown at the well (18.7 m; Table 5-1). Approximately 4.4 m of additional drawdown was predicted at Well K18, despite the decrease in pumping from existing to Allocated Rates, and this was attributed to the increase in pumping from Well K19, which lies adjacent to Well K18, and the overall increase in pumping at the well field.

Under average climatic conditions, drawdown predicted due to pumping at the Allocated Rates ranged from 4.1 m (Well K18) to 11.3 m (Well K13; Scenario G2; Table 5-1) and drawdown was predicted to range from 0.3 to 0.4 m due to recharge reductions (Scenario G3; Figure 3-1; Table 5-1). Proposed land use development within 1 km of the municipal wells is limited but several land use developments are proposed to occur along Ira Needles Boulevard and Wilmot Line (see Figure 3-1) upgradient of the well field.

Maximum drawdown of 3.0 m was predicted at Well K13 due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1) and this is attributed to the seasonal pumping variations whereby the summer pumping rates in 2008 were 15% higher than the pumping rates in the fall and winter. This trend was present in the 2004 to 2011 period (used to characterize the transient pumping rates for Scenarios H1 and H2 discussed below).

Under drought climatic conditions, a maximum of 16.8 m additional drawdown was predicted at Well K13 due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). This value is below the safe additional available drawdown value at the well (18.7 m; Table 5-1). Similarly, drawdown ranging from 6.9 m (Wells K10A and K18) to 16.5 m (Well K13) was predicted due to pumping at the Allocated Rates (Scenario H2; Table 5-1).

Approximately 2.4 m (Wells K10A and K11) to 4.3 m (Well K18) of additional drawdown was predicted due to recharge reductions under drought climate (Scenario H3; Table 5-1). Relative to historic well field pumping rates, the Allocated Rates proposed for the Strange Street Well Field were higher, and as such, additional drawdown values were predicted to be significant (> 7 m). The seasonal pumping factors applied were considered conservative as they were based on historic well field operations when the wells pumped at lower average annual rates. The transient rates assumed the Region would continue to pump larger volumes from the well field during the summer months. However, the Region plans to operate the Strange Street Well Field at a more uniform rate throughout the year in the future, with the exception of Wells K18 and K19, which supply a portion of their water to the nearby golf course during the summer months.

Despite the significant increase in pumping from 2008 to Allocated Rates, under all scenarios, the predicted drawdown at the Strange Street Well Field remained within the safe additional available drawdown values for each well.

5.2.1.8 Greenbrook

The Allocated Rates at the Greenbrook Well Field totaled 7,776 m^3/d, and represent a modest increase (15%) over the 2008 pumping rates (Table 3-2). The Allocated Rates were distributed more evenly amongst the wells (as compared to the 2008 rates), with four wells producing at 1,728 m^3/d and Well K8 producing at 864 m^3/d.

Under average climatic conditions, a maximum of 5.4 m of additional drawdown was predicted at Well K5A due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1). Drawdown predicted due to pumping at the Allocated Rates ranged from a maximum additional drawdown of 5.0 m at Well K5A, to a water level recovery of 2.6 m at Well K4B (Scenario G2; Table 5-1). Drawdown of 0.5 to 0.6 m was predicted at the well field due recharge reductions (Scenario G3; Figure 3-1; Table 5-1). Land use development is not expected in the vicinity of the Greenbrook Well Field. However, land use developments in the upgradient area (west of the well field along Ira Needles Boulevard and Wilmot Line), as well as those along Bleams Road (near the Mannheim Well Fields; Figure 3-1), were interpreted to cause the drawdown at the wells.

Maximum drawdown of 6.0 m was predicted at Well K5A due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1). This high drawdown is attributed to the (monthly) pumping rates of the well field during 2008 (see Appendix D for 2008 monthly pumping rates applied in Scenario D), which were much higher in some months than others. The predicted drawdown at Well K5A is still well below the safe additional drawdown value of 15.2 m.

Under drought climatic conditions, a maximum of 7.1 m of additional drawdown was predicted at Well K5A due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). This value is well below the safe additional available drawdown value at the well (15.2 m; Table 5-1). A maximum drawdown of 6.6 m was predicted at Well K5A due to pumping at the Allocated Rates (Scenario H2; Table 5-1). Approximately 2.2 m (Well K8) to 6.6 m (Well K5A) of additional drawdown was predicted due to recharge reductions (Scenario H3; Table 5-1). As noted earlier, the large drawdown predicted in Scenario H3 is attributed to the high monthly pumping rates applied in this scenario (and Scenario D) as opposed to an overall susceptibility to recharge reductions or drought climate.

Under all scenarios, the predicted drawdown at the Greenbrook Well Field remained within the safe additional available drawdown values for each well.

5.2.1.9 Parkway and Strasburg

The Allocated Rates at the Parkway Well Field remained fairly consistent with 2008 rates, whereas the Allocated Rate at Well K34 at the Strasburg Well Field decreased (Table 3-2). Well K36 in the Strasburg Well Field was not pumping in 2008, and is not expected to pump under the Allocated Rates.

Under average climatic conditions, recharge reductions and pumping at the Allocated Rates predicted an additional drawdown of 0.4 to 0.5 m at the Parkway Well Field and a 2.1 m recovery at Well K34 (Scenario G1; Table 5-1). Drawdown predicted due to pumping at the Allocated Rates was minor with only 0.1 m of drawdown predicted at Well K32 and water level recovery was predicted in both wells in the Strasburg Well Field (Scenario G2; Table 5-1). Approximately 0.4 m of drawdown was predicted at all wells in the Parkway and Strasburg Well Fields due recharge reductions in the Strasburg Well Field area along Homer Watson Boulevard to the east, toward New Dundee Road in the south, and west to Fischer-Hallman Road (Scenario G3; Figure 3-1; Table 5-1).

Drawdown of 1.1 m at all wells in the Parkway Well Field, and 1.7 m at Well K34 in the Strasburg Well Field was predicted due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1).

Under drought climatic conditions, maximum additional drawdown of 1.3 m was predicted at Well K32 due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). Similarly, a maximum drawdown of 1.0 m at Well K32 was predicted due to pumping at the Allocated Rates under drought climate (Scenario H2; Table 5-1). Approximately 1.4 m (Well K31, K32, K36) to 2.1 m (Well K34) of additional drawdown was predicted due to recharge reductions under drought climate (Scenario H3; Table 5-1). These values are well below the safe additional drawdown values at the wells, which vary from 4.8 to 35.2 m (Table 5-1).

Under all scenarios, the predicted drawdown at the Parkway and Strasburg Well Field remained within the safe additional available drawdown values for each well.

5.2.1.10 Lancaster

The Lancaster well field was not pumping during 2008 and is not expected to pump in the Allocated Rates scenarios. Predicted groundwater elevations within these wells were monitored during the Risk Assessment scenarios (Table 5-1) to examine the impact of the cumulative increase in urban pumping and recharge reduction.

Under average climatic conditions, 1.0 m (Well K41) and 1.1 m (Well K42A) of additional drawdown was predicted due to recharge reductions and pumping at the nearby well fields at the Allocated Rates (Scenario G1; Table 5-1). Drawdown due to pumping at the Allocated Rates produced similar results of 0.8 m (Well K41) and 1.0 m (Well K42A) at the wells (Scenario G2; Table 5-1) and 0.2 m of drawdown was predicted at both wells due recharge reductions (Scenario G3; Figure 3-1; Table 5-1).

Under drought climatic conditions, drawdown of 0.6 m was predicted at the two wells due to 2008 monthly pumping rates at the nearby urban well fields, existing land use cover and drought climate (Scenario D; Table 5-1). Additional drawdown of 1.7 m (Well K41) and 1.8 m (Well K42A) was predicted due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). This is well below the safe additional available drawdown values for the wells (23.0 to 26.7 m; Table 5-1). Similarly, a maximum drawdown of 1.5 m (Well K41) and 1.7 m (Well K42A) was predicted due to pumping at the Allocated Rates under drought climate (Scenario H2; Table 5-1). Approximately 0.8 m of additional drawdown was predicted at both wells due to recharge reductions under drought climate (Scenario H3; Table 5-1).

Under all scenarios, the predicted drawdown at the Lancaster Well Field remained within the safe additional available drawdown values for each well.

5.2.1.11 River Wells

The River Wells are located adjacent to the Grand River and include the Pompeii/Forwell and Woolner Well Fields. The Pompeii/Forwell Well Fields were not pumping during 2008 and were not expected to pump under the Allocated Rates. The Woolner Well Field pumped at nearly 1,300 m^3/d in 2008, and was not expected to pump under the Allocated Rates. Predicted groundwater elevations within these well fields were monitored during the Risk Assessment scenarios (Table 5-1), and the results suggested these wells would largely be unaffected by increases in municipal pumping at the nearby well fields, or by reductions in recharge due to land use development.

Under average climatic conditions, 0.1 m of additional drawdown was predicted at the five wells in the Forwell/Pompeii Well field and groundwater elevations in the Woolner Well Field were expected to recover by up to 2.4 m due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1). Drawdown predicted due to pumping at the Allocated Rates produced results that were very similar to Scenario G1 (Scenario G2; Table 5-1) and a maximum of 0.1 m of drawdown was predicted at all wells in all three well fields due recharge reductions (Scenario G3; Figure 3-1; Table 5-1).

Maximum drawdown of 0.2 m was predicted at Wells K70, K72, K73 and K74 due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1). As the wells are completed in an aquifer that is hydraulically connected to the Grand River, the predicted impacts of land use changes were likely muted by the influence of the Grand River.

Under drought climatic conditions, maximum additional drawdown of 0.2 m was predicted at Wells K70 to K75 due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). Similarly, a maximum drawdown of 0.2 m was predicted at Wells K70, K72, K73 and K74 due to pumping at the Allocated Rates under drought climate (Scenario H2; Table 5-1). Approximately 0.2 m of additional drawdown was predicted in all wells except Well K75, where 0.1 m of drawdown was predicted due to recharge reductions under drought climate (Scenario H3; Table 5-1). These values are well below the safe additional drawdown values at the wells, which vary from 1.4 to 5.3 m (Table 5-1).

Under all scenarios, the predicted drawdown at the River Wells remained within the safe additional available drawdown values for each well.

5.2.1.12 Fountain Street

The Fountain Street Well Field (Well P16) was not pumping in 2008, and is not forecast to pump under the Allocated Rates scenarios. As such, the water level changes at this well represent impacts from nearby well fields, recharge reductions due to land use development, and fluctuations in groundwater elevations due to drought. Predicted groundwater elevations within these wells were monitored during the Risk Assessment scenarios (Table 5-1) to examine the impact of the cumulative increase in municipal pumping and recharge reduction.

Under average climatic conditions, 0.5 m of additional drawdown was predicted at Well P16 due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1). Similarly, 0.1 m of drawdown was predicted at Well P16 due to pumping at the Allocated Rates (Scenario G2), and 0.5 m of drawdown was predicted due recharge reductions, primarily associated with land use development east of the well field at Maple Grove and Speedsville Roads (Scenario G3; Figure 3-1; Table 5-1).

Approximately 0.6 m of additional drawdown was predicted at the well due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1). As Well P16 was not pumping in 2008, this drawdown reflects impacts of drought and climatic variability and not seasonal variations in pumping.

Under drought climatic conditions, additional drawdown of 1.0 m was predicted at Well P16 due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). This value was well below the safe additional available drawdown at the well (14.9 m; Table 5-1). Similarly, 0.7 m of additional drawdown was predicted due to pumping at the Allocated Rates under drought climate (Scenario H2; Table 5-1), and approximately 0.9 m of drawdown was predicted at the well due to recharge reductions under drought climate (Scenario H3; Table 5-1).

Under all scenarios the predicted drawdown at Well P16 remained within its safe additional available drawdown value.

5.2.1.13 Conestogo Plains

The 2008 pumping rates at the Conestogo Plains Well Field were approximately 80 m^3/d. These rates are expected to increase to 252 m^3/d under the Allocated Rates, as the well field is planned to supply water for Conestogo as well as West Montrose (Table 3-2).

Under average climatic conditions, 2.2 m (Well C3) and 1.1 m (Well C4) of additional drawdown was predicted due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1). As there are no changes in land use specified in the area, the drawdown predicted due to pumping at the Allocated Rates (Scenario G2) was the same as Scenario G1, with 0 m of drawdown predicted due to recharge reductions (Scenario G3; Figure 3-1; Table 5-1).

Approximately 0.3 m of additional drawdown was predicted at the wells due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1), which is negligible compared to the safe additional available drawdown at the wells, which exceeds 17.0 m.

Under drought climatic conditions, additional drawdown of 3.0 m (Well C3) and 1.6 m (Well C4) was predicted due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). These values are well below the safe available additional drawdown values of 17.0 (Well C3) and 17.1 m (Well C4; Table 5-1). Similarly, 3.0 m (Well C3) and 1.6 m (Well C4) of additional drawdown was predicted due to pumping at the Allocated Rates under drought climate (Scenario H2; Table 5-1), and approximately 0.3 m of drawdown was predicted at the well due to recharge reductions under drought climate (Scenario H3; Table 5-1).

Under all scenarios, the predicted drawdown at the Conestogo Well Field remained within the safe additional available drawdown values for each well.

5.2.1.14 New Dundee

There is no change expected in the pumping rates for the New Dundee Well Field between the 2008 rates and the Allocated Rates. As such, Wells ND4 and ND5 were pumped at 2.1 and 222 m^3/d, respectively, in all Risk Assessment scenarios (Table 3-2).

Under average climatic conditions, 0.2 m of additional drawdown was predicted at Wells ND4 and ND5 due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1). As the municipal demand is not increasing from 2008 to the Allocated Rates, there was no change in groundwater elevations due to pumping at the Allocated Rates (Scenario G2), and only 0.2 m of drawdown was predicted due recharge reductions, primarily associated with land use development immediately east of Alder Lake and north of Bridge Street (Scenario G3; Figure 3-1; Table 5-1).

Under drought climatic conditions, a maximum of 1.9 m of additional drawdown was predicted at the two wells due to the seasonality of the 2008 monthly pumping rates and existing land use cover (Scenario D; Table 5-1). Additional drawdown of 2.0 m was predicted at the wells due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). This value was well below the safe available additional drawdown values at the wells of 5.2 m (Well ND5) and 5.9 m (Well ND4; Table 5-1). Similarly, 1.8 m of additional drawdown at the wells due to pumping at the Allocated Rates (Scenario H2; Table 5-1), and approximately 2.0 m of drawdown was predicted at the well due to recharge reductions (Scenario H3; Table 5-1). The majority of the drawdown predicted under Scenario H3 is attributed to the 2008 seasonal pumping rates at the well field (see Appendix D) rather than recharge reductions or an overall susceptibility to drought.

Under all scenarios, the predicted drawdown at the New Dundee Well Field remained within the safe additional available drawdown values.

5.2.1.15 Elmira

Well E10 in Elmira was not pumping in 2008 and is not forecast to pump under the Allocated Rates; however, the groundwater elevations in the well were recorded throughout the Risk Assessment.

Under average climatic conditions, 0.1 m of additional drawdown was predicted at Well E10 due to recharge reductions (Scenario G1; Table 5-1). As the municipal demand is not changing from 2008 to the Allocated Rates, there was no change in groundwater elevations due to pumping at the Allocated Rates (Scenario G2), and only 0.1 m of drawdown was predicted due recharge reductions, primarily associated with land use development in the Elmira area (Scenario G3; Figure 3-1; Table 5-1).

Under drought climatic conditions, 0.7 m of additional drawdown was predicted at Well E10 due to climate variability (Scenario D; Table 5-1) and due to recharge reductions (Scenarios H1 and H2; Table 5-1). This value was well below the safe available additional drawdown value of 28.8 m at the well (Table 5-1). Approximately 0.7 m of drawdown was also predicted at the well due to recharge reductions (Scenario H3; Table 5-1).

Under all scenarios, the predicted drawdown at Elmira Well E10 remained within the safe additional available drawdown value.

5.2.2 Drawdown at Municipal Wells – Cambridge Model

Table 5-2 summarizes the model-predicted drawdown in the municipal wells under each of the Risk Assessment scenarios using the Cambridge Model. In all instances, the predicted drawdown was less than the safe additional drawdown at each of the wells, which indicated the wells are able to pump at their current and Allocated Rates over the long-term (including drought conditions) under existing and future land use development conditions. In Table 5-2, the in-well losses need to be subtracted from the safe additional available drawdown values for the scenarios with the Allocated Rates (i.e., Scenarios G1, G2, H1 and H2) and then compared to the modelled drawdown values. In Table 5-2, negative in-well losses or modelled drawdown values correspond to water level recovery or increases, due to reductions in municipal pumping from the existing to the Allocated Rates.

To visualize the extent of the drawdown in the Cambridge area, the model-predicted groundwater elevations in each production aquifer were exported from the model at the end of the average climatic conditions (steady-state) scenarios (i.e., Scenarios G1, G2 and G3; Table 2-2). These were then compared to the groundwater elevations under existing (2008) conditions (Scenario C) to produce maps of the spatial extent of additional drawdown relative to 2008 groundwater elevations. Figures 5-6 to 5-8 illustrate the spatial extent of the 2 m additional drawdown contour for Scenarios G1, G2 and G3, respectively (Note: this is additional drawdown relative to the drawdown experienced in 2008). Model predicted drawdown (2 m contour) due to reductions in recharge due to land use development (Scenario G3) are illustrated on Figure 5-8. This figure shows that the reductions in recharge have the potential to cause drawdown in the water table that exceeds 2 m in several areas, including the area north of Fountain Street and near the Pinebush Well Field.

Figure 5-7 illustrates the 2 m additional drawdown contour predicted when the municipal wells are pumped at their Allocated Rates, as compared to the existing (2008) rates. The Blair Road well is one example of a well where the predicted drawdown at the well has a limited lateral extent and as such, the drawdown contour is concealed beneath the well symbol on Figures 5-6 and 5-7. The impact of pumping at the Allocated Rates (Scenario G2; Figure 5-7) is predicted to cause drawdown in the area west of Middleton, and also between the Shades Mill and Clemens Mill Well Fields. Figure 5-4 highlights the need to manage the water resources in several of the urban well fields holistically, rather than on an individual well field basis as some of the urban well fields (i.e., Shades Mill, Clemens Mill and Pinebush) are hydraulically connected to one another. For example, increasing the water demands at the Clemens Mill Well Field may cause water level reductions at the nearby Shades Mill Well Field. The results for each of the base case Risk Assessment scenarios are discussed on a well field basis in the following sections.

TABLE 5-2 Risk Assessment Drawdown Results – Cambridge Model

Well Field	Well Name	Safe Additional Aquifer Drawdown (2008)[1]	Drawdown from In-Well Losses (m)	Drawdown (m): Average Climate Scenarios			Drawdown (m): Drought Scenarios			
				G1	G2	G3	D	H1	H2	H3
				Allocated Rates, Future Land Use	Allocated Rates	Future Land Use	Existing Recharge, Demand	Allocated Rates, Future Land Use	Allocated Rates	Future Land Use
Blair Rd	G4	9.5	1.6	3.6	3.5	0.1	0.8	4.1	4.0	0.8
Blair Rd	G4A	16.0[2]	0.0							
Clemens Mill	G16	19.8	2.4	5.4	5.1	0.3	1.2	6.7	6.5	1.4
	G17	6.7	0.1	2.1	1.8	0.3	2.0	3.8	3.5	2.3
	G18	19.9	0.2	5.0	4.7	0.3	3.1	6.9	6.6	3.3
	G6	13.6	-0.2	-2.3	-2.7	0.3	1.2	-1.0	-1.4	1.6
Dunbar Road	P6	9.6	-0.6	-5.4	-5.5	0.1	1.0	-4.9	-4.9	1.1
Elgin Street	G9	5.9	-0.8	-5.0	-5.2	0.2	2.6	-4.2	-4.4	2.8
Hespeler	H3	17.8	3.5	4.1	3.9	0.2	2.8	6.3	6.2	3.1
	H4	9.0	4.6	2.4	2.2	0.2	0.6	3.2	3.1	0.7
	H5	12.2	0.4	6.8	6.7	0.1	6.3	9.0	8.8	6.4
Middleton St	G1	9.5	0.6	0.8	0.7	0.0	0.5	1.6	1.7	0.6
	G14	22.7	-0.6	0.1	0.1	0.0	0.4	0.9	0.9	0.4
	G1A	15.1	-1.8	0.2	0.2	0.0	0.4	1.0	1.1	0.4
	G2	15.1	0.2	1.4	1.4	0.0	1.2	2.4	2.4	1.2
	G3	18.9	0.6	1.3	1.3	0.0	0.6	2.2	2.2	0.6
Pinebush	G5	1.6	0.0	0.2	-0.1	0.3	1.4	1.0	0.7	1.7
	G5A	30.9	0.0							
	P10	6.6	0.2	1.2	0.8	0.4	1.0	2.3	1.9	1.3
	P11	33.9	1.1	1.4	1.0	0.4	1.3	2.4	2.1	1.7
	P15	13.8	0.3	1.6	1.3	0.3	1.3	2.7	2.3	1.6
	P17	20.3	0.7	-2.4	-2.7	0.4	2.6	-1.4	-1.7	2.9
	P9	15.4	-0.3	0.7	0.4	0.3	1.0	1.7	1.4	1.3

Well Field	Well Name	Safe Additional Aquifer Drawdown (2008)[1]	Drawdown from In-Well Losses (m)	Drawdown (m): Average Climate Scenarios			Drawdown (m): Drought Scenarios			
				G1	G2	G3	D	H1	H2	H3
				Allocated Rates, Future Land Use	Allocated Rates	Future Land Use	Existing Recharge, Demand	Allocated Rates, Future Land Use	Allocated Rates	Future Land Use
Shades Mill	G38	20.4	0.9	8.4	8.1	0.3	1.2	10.2	9.9	1.4
	G39	21.8	0.8	12.8	12.5	0.3	1.2	15.0	14.7	1.4
	G7	3.7	-0.1	1.3	0.9	0.4	1.5	2.9	2.6	1.8
	G8	4.0	-0.2	1.1	0.7	0.4	1.6	2.8	2.5	1.9
Willard	G15	9.8	0.4	0.4	0.4	0.0	0.5	1.1	1.2	0.5

[1] Safe additional aquifer drawdown (2008) value does not include the drawdown due to in-well losses experienced when pumping wells at the Allocated Rates.

[2] Well G4A did not exist in 2008 to obtain a pumped water level elevation, so the elevation in Well G4 was conservatively used to calculate the SAAD.

5.2.2.1 Blair Road

The Blair Road Well Field includes Well G4 and recently constructed Well G4A. These wells currently operate in an alternating fashion, with Well G4A typically operating as the lead well. The combined Allocated Rate for the two wells is 1,728 m^3/d, which represents an increase relative to the 2008 average rate of 945 m^3/d. Well G4A was drilled following the characterization and calibration of the Cambridge Model, so the well was not simulated. In the Risk Assessment scenarios, all of the well field pumping was simulated in Well G4, and the drawdown was compared to the safe additional available drawdown for Well G4, recognizing that additional drawdown is also available in Well G4A.

Under average climatic conditions, 3.6 m of additional drawdown was predicted at Well G4 due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-2). Similarly, 3.5 m of drawdown was predicted at Well G4 due to pumping at the Allocated Rates (Scenario G2), and only 0.1 m of drawdown was predicted due recharge reductions, primarily associated with development located west and north of the well (Scenario G3; Figure 3-1; Table 5-2).

Under drought climatic conditions, 0.8 m of additional drawdown was predicted at Well G4 due to 2008 monthly pumping rates and existing land use cover (Scenario D; Table 5-2). Additional drawdown of 4.1 m was predicted at Well G4 due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-2). This value was well below the safe available additional drawdown at the well (9.5 m; Table 5-2). Similarly, 4.0 m of additional drawdown was predicted due to pumping at the Allocated Rates (Scenario H2; Table 5-2), and 0.8 m of drawdown was predicted at the well due to recharge reductions (Scenario H3; Table 5-2).

Under all scenarios, the predicted drawdown at the Blair Road Well Field remained within the safe additional available drawdown value for Well G4.

5.2.2.2 Dunbar Road

The 2008 pumping rate for Well P6 was 884 m^3/d; however, there was no pumping assigned to the wells under the Allocated Rates.

Under average climatic conditions, a water level recovery of 5.4 m was predicted at Well P6 due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-2). Similarly, a water level recovery of 5.5 m was predicted at the well due to the reduction in pumping under the Allocated Rates (Scenario G2), and only 0.1 m of drawdown was predicted due to recharge reductions (Scenario G3; Figure 3-1; Table 5-2).

Under drought climatic conditions, 1.0 m of additional drawdown was predicted at Well P6 due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-2). Water level recovery of 4.9 m was predicted due to pumping at the Allocated Rates and recharge reductions

(Scenario H1; Table 5-2). A recovery of 4.9 m was also predicted due to pumping at the Allocated Rates (Scenario H2; Table 5-2). Approximately 1.1 m of drawdown was predicted at the well due to recharge reductions using the 2008 monthly pumping (Scenario H3; Table 5-2). The 1.1 m of drawdown predicted under Scenario H3 is interpreted to be due to the seasonal water demands in 2008 (see Appendix D), and not due to a sensitivity to drought conditions or recharge reductions.

Under all scenarios, the predicted drawdown at the Dunbar Road Well Field remained within the safe additional available drawdown value for Well P6.

5.2.2.3 Hespeler

The Hespeler Well Field lies in the northern reaches of the City of Cambridge and consists of six municipal wells; Wells H3, H3A, H4, H4A, H5 and H5A. In 2008, Wells H3 and H5 served as peaking wells that pumped during the summer months in periods of peak demand (Well H4 was off). Since 2008, three additional wells (Wells H3A, H4A and H5A) were drilled into the deeper bedrock formations at the existing well sites. The new wells were drilled and tested after the characterization of the well field, and as such were not included in the groundwater flow model and were not predicted in the Risk Assessment.

Well H3 was pumped at an annual average rate of 563 m^3/d in 2008, and was predicted to pump at 864 m^3/d under the Allocated Rates scenarios. Well H4 did not pump in 2008, and Well H5 was pumped at a rate of 383 m^3/d in 2008. Wells H4 and H5 are forecast to pump at 1,296 and 864 m^3/d, respectively, under the Allocated Rates scenarios.

Under average climatic conditions, 4.1 m (Well H3), 2.4 m (Well H4) and 6.8 m (Well H5) of additional drawdown was predicted due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-2). Similarly, 3.9 m (Well H3), 2.2 m (Well H4) and 6.7 m (Well H5) of drawdown was predicted due to pumping at the Allocated Rates (Scenario G2), and only 0.1 to 0.2 m of drawdown was predicted due to recharge reductions (Scenario G3; Figure 3-1; Table 5-2).

A maximum of 6.3 m of additional drawdown was predicted at Well H5 due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-2). This drawdown is primarily due to the seasonal pumping at the well in 2008 as it was only turned on in the summer months to offset peak demands.

Under drought climatic conditions, additional maximum drawdown of 9.0 m was predicted at Well H5 due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-2). This value was well below the safe available additional drawdown at the well (10.2 m; Table 5-2). Similarly, 8.8 m of additional drawdown was predicted at Well H5 due to pumping at the Allocated Rates (Scenario H2; Table 5-2), and approximately 6.4 m of drawdown was predicted at the well due to recharge reductions (Scenario H3; Table 5-2). As noted above, a large component of the drawdown predicted is due to the seasonal water demands at the well field.

Under all scenarios, despite the large predicted drawdown and in-well losses at Wells H3, H4 and H5, the predicted drawdown at the Hespeler Well Field remained within the safe additional available drawdown value for the wells.

5.2.2.4 Pinebush

The 2008 pumping rates for the Pinebush Well Field were approximately 8,900 m^3/d. Municipal pumping for the well field under the Allocated Rates is expected to be very similar at 8,726 m^3/d (Table 3-2).

Under average climatic conditions, 1.6 m of additional drawdown was predicted at Well P15 due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-2). Similarly, a maximum drawdown of 1.3 m was predicted at Well P15 due to pumping at the Allocated Rates (Scenario G2). Recharge reductions associated primarily with the planned industrial and residential developments near the well field on the north and south sides of the 401 predicted 0.3 to 0.4 m of drawdown at the wells in the well field (Scenario G3; Figure 3-1; Table 5-2).

Under drought climatic conditions, additional drawdown was predicted to vary from 1.0 m (Wells P9 and P10) to 2.6 m (Well P17) due to 2008 monthly pumping rates and existing land use cover (Scenario D; Table 5-2). A maximum additional drawdown of 2.7 m was predicted at Well P15 due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-2). This value was well below the safe available additional drawdown at the well (13.8 m; Table 5-2). Similarly, a maximum additional drawdown of 2.3 m was predicted at Well P15 due to pumping at the Allocated Rates (Scenario H2; Table 5-2). Additional drawdown ranging from 1.3 m (Well P9 and Well P10) to 2.9 m (Well P17) was predicted due to recharge reductions and 2008 monthly pumping rates (Scenario H3; Table 5-2). The drawdown predicted under Scenario H3 was interpreted to be due to the seasonal water demands in 2008 (see Appendix D), and not due to a sensitivity to drought conditions or recharge reductions.

Under all scenarios, the predicted drawdown at the Pinebush Well Field remained within the safe additional available drawdown values for all wells.

5.2.2.5 Clemens Mill

The 2008 pumping rates for the Clemens Mill Well Field were approximately 6,000 m^3/d, and the Allocated Rates for this well field were expected to be 7,300 m^3/d (Table 3-2). The largest increase in pumping rate was expected at Well G16, increasing from 1,664 m^3/d in 2008 to 2,938 m^3/d in the Allocated Rates.

Under average climatic conditions, a maximum of 5.4 m of additional drawdown was predicted at Well G16 due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-2). Similarly, a maximum of 5.1 m of drawdown was predicted at Well G16 due to pumping at the Allocated Rates (Scenario G2), and only 0.3 m of drawdown was predicted due to recharge reductions (Scenario G3;

Figure 3-1; Table 5-2). These values are all within the safe additional available drawdown value for Well G16 of 17.4 m (Table 5-2).

Under drought climatic conditions, 1.2 m (Wells G16 and G6) to 3.1 m (Well G18) of additional drawdown was predicted due to 2008 monthly pumping rates and existing land use cover (Scenario D; Table 5-2). Additional drawdown of 6.7 m (Well G16) and 6.9 m (well G18) was predicted due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-2). These values are both well below the safe available additional drawdown at Wells G16 and G18 of 19.8 and 19.9 m, respectively (Table 5-2). A maximum additional drawdown of 6.9 m was predicted at Well G18 due to pumping at the Allocated Rates (Scenario H2; Table 5-2), and a maximum of 3.3 m of drawdown was predicted at Well G18 due to recharge reductions and 2008 monthly pumping rates (Scenario H3; Table 5-2). The drawdown predicted in Scenario H3 for Wells G17 and G18 is interpreted to be due to the seasonal water demands in 2008 (see Appendix D), and not due to a sensitivity to drought conditions or recharge reductions.

Under all scenarios, the predicted drawdown at the Clemens Mill Well Field remained within the safe additional available drawdown value for all wells.

5.2.2.6 Shades Mill

At the Shades Mill Well Field, the forecast Allocated Rates were 6,480 m^3/d, nearly double the average annual pumping rates from 2008. The 2008 calendar year was an anomalous year for the Shades Mill Well Field as Wells G38 and G39 were shut down. Under the Allocated Rates, the pumping rates for Wells G7 and G8 were expected to be reduced relative to 2008 conditions, while Wells G38 and G39 were expected to pump at rates that are comparable to the past 5 years (Table 3-2).

Under average climatic conditions, additional drawdown of 8.4 m (Well G38) and 12.8 m (Well G39) was predicted due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1). Similarly, 8.1 m (Well G38) and 12.5 m (Well G39) of drawdown was predicted due to pumping at the Allocated Rates (Scenario G2), and a maximum of 0.4 m of drawdown was predicted at Wells G7 and G8 due to recharge reductions (Scenario G3; Figure 3-1; Table 5-1).

Under drought climatic conditions, 1.2 m (Wells G38 and G3) to 1.6 m (Well G8) of additional drawdown was predicted due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1). Additional drawdown of 10.2 and 15.0 m was predicted at Wells G38 and G39, respectively, due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). These values are well below the safe available additional drawdown at the wells of 20.4 m (Well G38) and 21.8 m (Well G39; Table 5-1). Similarly, 9.9 and 14.7 m of additional drawdown was predicted at Wells G38 and G39 due to pumping at the Allocated Rates (Scenario H2; Table 5-1), and a maximum of 1.9 m of drawdown was predicted at Well G8 due to recharge reductions (Scenario H3; Table 5-1).

Under all scenarios, the predicted drawdown at the Clemens Mill Well Field remained within the safe additional available drawdown values for each of the wells.

5.2.2.7 Elgin Street

Well G9 had an average annual 2008 pumping rate of 1,001 m^3/d; however, the well is expected to be abandoned and no pumping was assigned to Well G9 under the Allocated Rates.

Under average climatic conditions, 5.0 m of water level recovery was predicted due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1), and recovery of 5.2 m was predicted due to pumping at the Allocated Rates (Scenario G2). Recharge reductions due to planned residential and industrial developments east and south of the well field are predicted to cause 0.2 m of drawdown at Well G9 (Scenario G3; Figure 3-1; Table 5-1).

Under drought climatic conditions, 2.6 m of additional drawdown was predicted at the well due to 2008 monthly pumping rates, existing land use cover and drought climate (Scenario D; Table 5-1). Water level recovery of 4.2 m was predicted due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). Similarly, 4.4 m of water level recovery was predicted due to pumping at the Allocated Rates (Scenario H2; Table 5-1), and 2.8 m of drawdown was predicted due to recharge reductions (Scenario H3; Table 5-1).

Under all scenarios, the predicted drawdown at the Elgin Street Well remained within the safe additional available drawdown values for the well.

5.2.2.8 Middleton Street (and Willard)

At the Middleton Street Well Field, the 2008 rates were 19,400 m^3/d and these rates were expected to increase to 20,700 m^3/d in the Allocated Rates (see Table 3-2). The increased pumping was partitioned primarily between Wells G1, G2 and G3, while pumping at Well G1A decreased by approximately 1,200 m^3/d. The average annual pumping rate in the Willard Well Field in 2008 was 2,143 m^3/d and were expected to increase to 2,592 m^3/d under the future Allocated Rate scenarios.

Under average climatic conditions, a maximum additional drawdown value of 1.4 m (Well G2) was predicted due to recharge reductions and pumping at the Allocated Rates (Scenario G1; Table 5-1). Similarly, 1.4 m of drawdown (Well G2) was also predicted due to pumping at the Allocated Rates (Scenario G2). No changes in groundwater elevations were noted at any of the wells in the Middleton Well Field due to recharge reductions (Scenario G3; Figure 3-1; Table 5-1).

Under drought climatic conditions, 0.4 m (Wells G1A and G14) to 1.2 m (Well G2) of additional drawdown was predicted due to 2008 monthly pumping rates and existing land use cover (Scenario D; Table 5-1). Additional drawdown of 0.9 to 2.4 m was predicted due to pumping at the Allocated Rates and recharge reductions (Scenario H1; Table 5-1). These values are well below the safe available additional drawdown at the wells, which all exceed 8.9 m (Table 5-1). As there was no change in groundwater elevations due to recharge reduction, the same range of additional drawdown (0.9 to 2.4 m) was predicted due to pumping at the Allocated Rates (Scenario H2; Table 5-1). A maximum of 1.2 m of drawdown was predicted at Well G2 due to recharge reductions and the bulk of this drawdown was attributed to the 2008 seasonal variability in well field pumping (Scenario H3; Table 5-1).

Under all scenarios, the predicted drawdown at the wells in the Middleton Street and Willard Well Fields remained within the safe additional available drawdown values for each of the wells.

5.2.2.9 Impacts to Groundwater Discharge

The predicted increase or reduction in groundwater discharge to rivers, streams and wetlands was assessed in the steady-state scenarios (Scenarios G1, G2 and G3). The Technical Rules (MOE 2009) specify that streams and creeks hosting cold water fish communities, and PSWs cannot be negatively impacted by increases in municipal pumping. As such, the analysis presented in this document focuses on impacts of increased municipal pumping (Scenario G2), and the results of the other scenarios are provided for completeness.

In Scenario G3, where future land development was predicted, the influence of best management practices was not simulated as directed in the Technical Rules (MOE 2009), and groundwater recharge was reduced proportionally to the imperviousness assumed for areas where land use changes might occur. These scenarios are conservative as the Region has policies in place to ensure reductions in recharge due to land use development are mitigated. However, the scenarios identify areas where groundwater discharge is most sensitive to land use changes and where efforts to maintain groundwater recharge will be most critical in the future.

5.2.2.10 Streams or Creeks Hosting Cold Water Fish Communities

Groundwater flow models are better able to predict relative changes as opposed to absolute changes under a variety of scenarios. As models are simplifications of very complex subsurface conditions, and as there are uncertainties in the model input parameter values, the model may not accurately simulate a single measured value such as baseflow. However, the model’s parameters are physically-based and so groundwater flow models are well-suited to evaluate how the model predictions may change under various stressors.

The predicted impacts on groundwater discharge to rivers and streams was assessed for Scenario G2 (existing land use, and Allocated Rates) by comparing the predicted groundwater discharge under Scenario G2 to the groundwater discharge predicted under Scenario C (Existing Conditions). The difference in these groundwater discharge values was then normalized by the observed baseflow value to estimate the percent groundwater reduction (or increase).

Table 5-3 summarizes the steady-state model scenario results with respect to predicted reduction in groundwater discharge, for the Regional Model. The reaches hosting cold water fish communities are listed at the top of the table, and the warm water streams are italicized and listed in the lower half of the table.

Under Scenario G2, the predicted reductions in groundwater discharge, relative to current conditions, to reaches hosting cold water fish communities, were less than 10%. Figure 5-9 illustrates the predicted reductions to groundwater discharge for cold water streams in the Regional Model. In this figure, the reaches were themed according to percent reduction in discharge to cold water streams (i.e. less than 10%).

The percent reduction in groundwater discharge was greater than 10% for Shoemaker Creek and Clair Creek under Scenario G2. However, both of these creeks are located in heavily urbanized portions of the cities and sections of these creeks are channelized with a number of culverts. As such, the predicted groundwater discharge reduction on Clair Creek and Shoemaker Creek were not interpreted to be significant from a fisheries or ecological standpoint. They are presented as water is simulated to flow out of these surface water features into the underlying groundwater flow system in the groundwater flow model, so the results are important from an overall water budget perspective.

Greater impacts were observed on cold water streams where reductions in recharge due to land use development were assessed. Specifically under Scenario G3 (change in land use only), reductions in groundwater discharge of 19% and 13% were predicted for Strasburg Creek and the middle portion of Alder Creek just west of the Mannheim West Well Field, respectively. As noted previously, these results suggested the greatest impact that may be realised if land use development were to take place without any mitigating factors.

TABLE 5-3 Impacts to Groundwater Discharge - Regional Model

Reach	Thermal Regime	Simulated Discharge (% Reduction)		
		Scenario G1	Scenario G2	Scenario G3
Airport Creek	Cold water	7%	0%	7%
Alder Creek Headwaters	Cold water	11%	4%	7%
Alder Creek Middle	Cold water	15%	1%	13%
Alder Creek Lower	Cold water	1%	0%	1%
Hopewell Creek	Cold water	2%	0%	2%
Idlewood Creek	Cold water	4%	-2%	6%
Strasburg Creek	Cold water	20%	1%	19%
Laurel/ Beaver Headwaters	Cold water	11%	6%	6%
Clair Creek	*Warm water*	*32%*	*26%*	*6%*
Freeport Creek	*Warm water*	*10%*	*0%*	*10%*
Laurel Creek	*Warm water*	*8%*	*8%*	*1%*

Reach	Thermal Regime	Simulated Discharge (% Reduction)		
		Scenario G1	Scenario G2	Scenario G3
Schneider Creek	*Warm water*	*3%*	*1%*	*2%*
Shoemaker Creek	*Warm water*	*19%*	*17%*	*4%*

Table 5-4 summarizes the reductions in groundwater discharge to all stream reaches in the Cambridge area. The reaches hosting cold water fish communities are listed at the top of the table, and the warm water streams are italicized and listed in the lower portions of the table.

Under Scenario G2, the predicted reductions in groundwater discharge, relative to current conditions, to reaches hosting cold water fish communities, were less than 10%. Figure 5-10 illustrates the predicted reductions to groundwater discharge for cold water streams in the Cambridge Model. In this figure, the reaches were themed according to percent reduction in discharge to cold water streams (i.e. less than 10%).

Greater impacts were observed on reaches where the reductions in recharge due to land use development were assessed. Specifically under Scenario G3 (change in land use only), Moffatt Creek was predicted to have a 13% reduction in groundwater discharge due to recharge reduction (Table 5-4).

TABLE 5-4 Impacts to Groundwater Discharge - Cambridge Model

Reach	Thermal Regime	Simulated Discharge (% Reduction)		
		G1 Base	G2 Base	G3 Base
Blair Creek		0%	0%	1%
Mill Creek Headwaters (Aberfoyle Creek)	Cold water	0%	0%	0%
Mill Creek upstream (downstream of Aberfoyle gauge)	Cold water	0%	0%	0%
Mill Creek (Gauge to Shades Mill Reservoir)	Cold water	6%	5%	2%
Mill Creek Reservoir to the Grand River	Cold water	4%	3%	0%
Ellis Creek	*Warm water*	*5%*	*-1%*	*5%*
Irish Creek	*Warm water*	*12%*	*7%*	*5%*
Moffat Creek	*Warm water /Cold water*	*18%*	*5%*	*13%*

5.2.2.11 Provincially Significant Wetlands

The Technical Rules (MOE 2009) specify that municipal water takings (Allocated Rates) cannot cause a detrimental impact to other water users, which include PSWs. In this assessment, the predicted changes in groundwater elevations beneath wetland complexes (see Table 3-3), in each of the Risk Assessment scenarios, were noted and tabulated. The companion Model Calibration and Water Budget Report (Matrix and SSPA 2012) provides additional information on the wetland features of interest listed in Table 3-3.

In general, it is difficult to calibrate a groundwater flow model at large wetland features because often there are few data points such as observed water level elevations at surface or beneath the surface with which to calibrate the model. However, examining the relative changes in groundwater elevations provides a quantitative measure of how the function of wetlands may potentially change.

The changes in groundwater elevations between the model simulated groundwater elevations under Scenario C (existing land use and municipal pumping) and Scenario G2 (existing land use and Allocated Rates) was evaluated and is summarized in Table 5-5. The average change in groundwater elevation within each wetland complex was tabulated (with negative values indicating a rise in elevation relative to Scenario C). The predicted direction of vertical hydraulic gradients (recharge or discharge) is also summarized in Table 5-5. In all steady-state scenarios, no changes in gradients were predicted at any of the wetland complexes.

The Technical Rules (MOE 2009) specify that municipal water takings (Allocated Rates) cannot cause a detrimental impact to PSWs. As such, the results for Scenario G2 are of primary importance when assigning the Risk Level to the Local Areas. The results of Scenario G1 and G3 are provided for context, to highlight those wetlands that are influenced to a greater degree to changes in municipal pumping or by reductions in recharge due to proposed land use development.

In general, municipal pumping was simulated to reduce the water level elevation on average less than 10 cm at 14 of the 18 wetlands assessed (Scenario G2; Table 5-5; Figures 5-9 and 5-10). The four wetlands that were predicted to decline by more than 10 cm due to increased municipal pumping include the Laurentian West Wetland, Mill Creek Wetland (0.9 m reduction), Spongy Lake, and Portuguese Swamp (Scenario G2; Table 5-5; Figures 5-9 and 5-10). The Mill Creek Wetland in Cambridge was simulated as a discharge feature. However, under Scenario G2, the overall gradient in the wetland was still predicted to be discharging, despite the average decline in groundwater elevation beneath the wetland of approximately 0.9 m (Table 5-5; Figure 5-10). The Laurentian Wetland in Kitchener was simulated in the model as a perched wetland that lies above the regional water table. The temporal variation in the perched water table is independent of the water level variations of the underlying regional water table. As such, lowering of the regional water table beneath the wetland is not expected to cause a detrimental impact on the overlying perched wetland. A 0.2 m reduction in water level was simulated beneath Spongy Lake and Portuguese Swamp, and both of these features were simulated in the model as recharging features, so the change in water level beneath these features was also not expected to impact the form or function of those wetlands.

Wetlands that are predicted to be more influenced by changes to recharge (via land use change; Scenario G3; Table 5-5) include the Laurentian West Wetland near Mannheim, and the Mill Creek Wetland in Cambridge (Figures 5-9 and 5-10). If development were to occur without mitigative measures, such as the requirement for pre-development flows to equal post-development flows, low impact development techniques, or stormwater management controls, reductions in groundwater elevations of approximately 2 m were predicted beneath the Mill Creek and Laurentian West Wetlands

(Scenario G3; Table 5-5). The same impacts due to land use development were noted in several other areas of the Region, stressing the importance of mitigative measures.

TABLE 5-5 Summary of Wetland Impacts for Steady-State Risk Assessment Scenarios

GRCA Complex	GRCA Sub-Complex	Reduction in Water Level Elevation (m)			Gradient
		Scenario G1	Scenario G2	Scenario G3	Wetland Recharge or Discharge to Groundwater
Laurel Creek Complex	Sunfish Lake	0.1	0.0	0.0	Recharge
	Sunfish Lake, Optimist Bog	0.2	0.1	0.1	Discharge
Mannheim Area	Laurentian West	3.0	0.9	2.0	Recharge
	Middle Alder Creek Complex	0.5	0.1	0.4	Recharge
	Upper Alder Creek Complex	0.5	-0.1	0.6	Recharge
Roseville Swamp	Cedar Creek Wetland	0.1	0.0	0.1	Discharge
	Roseville Swamp	0.1	0.0	0.1	Discharge
Spongy Lake		0.4	0.2	0.1	Recharge
Strasburg Creek		0.4	0.0	0.5	Discharge
Beverly Swamp		0.1	0.0	0.0	Recharge
Cheese Factory Rd/ Sudden Bog		0.2	0.1	0.1	Recharge
East of Cambridge	Mill Creek Wetland	3.0	0.9	2.0	Discharge
	Moffat Creek	0.5	0.1	0.4	Recharge
	Sheffield Rockton Complex	0.5	-0.1	0.6	Discharge
Ellis Creek Wetlands		0.1	0.0	0.1	Discharge
Puslinch Lake/ Portuguese Bog	Irish Creek Complex	0.1	0.0	0.1	Recharge
	Portuguese Swamp	0.4	0.2	0.1	Recharge
Upper Speed		0.4	0.0	0.5	Discharge

5.3 Local Area Risk Level

The Local Areas for the Region of Waterloo are illustrated on Figure 5-2. The Risk Level classification applied to the Local Area is based on the ability of the wells to meet their peak demand ("Tolerance") as well as the results of the Risk Assessment scenarios outlined previously.

5.3.1 Tolerance

Municipalities typically 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. 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. The Region of Waterloo does not have water shortage issues as the water supply system for the Tri-Cities is fully integrated, with significant inherent redundancy, a capacity that exceeds current and projected future demands, and storage systems (reservoirs, elevated tanks and ASR) in place to meet peak demands. Therefore, the tolerance of the Region of Waterloo water supply system is high. The surface water intake from the Grand River also adds significant supply tolerance to the water supply system.

5.3.2 Risk Level Circumstances

The Technical Bulletin: Part IX Local Area Risk Level (MOE and MNR 2010) and the recent MOE Technical Memorandum (MOE 2013) lists a series of circumstances, where if one of these circumstances is present, the Local Area is assigned a Significant or Moderate Risk Level.

The Local Area for a groundwater system is assigned a Significant Risk Level if either of the following circumstance are present:

- The wells are not able to meet their existing, or existing plus committed demands, determined when the drawdown at a municipal well exceeds the safe additional available drawdown.

- The Tolerance is "low" and the drinking water system is not able to meet peak water demands in the drought scenario. This may be identified where an existing municipal system has had historical issues meeting peak demands.

The Local Area for a groundwater system is assigned a Moderate Risk Level if municipal pumping in Scenario G results in measurable and potentially unacceptable impacts to other uses. For cold water streams, this circumstance occurs when groundwater discharge is reduced by 10% or more of existing monthly baseflow (MOE 2013).

The results of the Risk Assessment scenarios for the Region showed that the drawdown predicted under all scenarios was less than the Safe Additional Available Drawdown for the wells. This suggested the wells are able to pump sustainably at their Allocated Rates into the future.

With respect to other water uses, the reductions in groundwater discharge to sensitive cold water streams were less than 10% of the baseflow value, and the reductions in groundwater elevations beneath the PSWs was considered low enough that a Moderate Risk Level was not warranted.

Consequently, the four Local Areas delineated in the Region of Waterloo were assigned a Low Risk Level, based on circumstances that all of the wells were predicted to be able to meet their Allocated Quantity of Water, without affecting other uses. The assignment of a Low Risk Level is further supported by the tolerance provided by the integrated urban system of groundwater wells, the ASR system, and the surface water intake on the Grand River.

5.4 Uncertainty Assessment

The uncertainty analysis evaluated alternative conceptual models that contain different hydraulic conductivity values and recharge distributions than those present in the base case. These alternative models were considered to be as well calibrated as the base case model presented in the Model Calibration and Water Budget Report (Matrix and SSPA 2012) and are referred to as alternative "realizations".

While the different realizations have varying parameter values with an equivalent degree of calibration, the predictive results may be different. As such, these realizations were used to assess the range of uncertainty values that stem from the uncertainty in the parameter values. As each realization was as equally well calibrated as the base case, the Risk Assessment scenario results were equally plausible. In general, the predictions made by these realizations were consistent with those made by the base case and did not result in elevating the Risk Level of the Local Areas.

The uncertainty with respect to drawdown at the municipal wells, and changes to baseflow, are presented in Sections 5.4.1 and 5.4.2 for the Regional and Cambridge Models, respectively. The development and details regarding the alternative realizations for the Regional and Cambridge Models are presented in Appendix C.

5.4.1 Uncertainty Realizations – Regional Model Results

Three realizations were developed for the Regional Model to assess the impact on the predictive Risk Assessment scenarios due to uncertainty in the model input parameters. As noted previously, the three model realizations were statistically as well calibrated to groundwater elevations and baseflow observations as the base case model. However, the base case model included the detailed calibration to the well field scale pumping and shut down tests, and the three alternative realizations have not been tested in those transient tests. The three uncertainty realizations performed in the Regional Model are described in Section 2.3.2 and summarized below.

- **Uncertainty Realization 1 (R1):** Transient calibration that emphasized the match to time-varying long-term hydraulic responses of the flow system under typical operating conditions from 2003 to 2011. This alternative realization is referred to as the "Transient" realization.

- **Uncertainty Realization 2 (R2):** Calibration to a conceptualization whereby the overburden aquitards such as the Upper, Middle and Lower Maryhill Tills have greater leakage (i.e., higher hydraulic conductivity values) than the values applied in the base case model. The other parameters in the model were adjusted by PEST to maintain a calibrated condition. This alternative realization is referred to as the "Leaky Aquitard" realization.

- **Uncertainty Realization 3 (R3):** Calibration to a conceptualization whereby the (Salina Formation) bedrock formation underlying the Waterloo Moraine has an increased transmissivity. This alternative realization is referred to as the "Bedrock" realization.

5.4.1.1 Uncertainty Realizations - Well Field Results

All of the Risk Assessment scenarios (see Table 2-) were evaluated for each of the three realizations (requiring 24 simulations in total). The predicted drawdown in the municipal wells for the steady-state model (i.e., Scenarios G1, G2 and G3) are presented in Table 5-6. Table 5-7 presents the results for the variable climate (transient) scenarios (i.e., Scenario D, H1, H2, H3). In these tables, values where the predicted additional drawdown exceeded the safe additional available drawdown have been highlighted, and are discussed in the following subsections. The "R" headings in Tables 5-6 and 5-7 refer to Uncertainty Realizations 1, 2 and 3.

The following sections discuss the specific well fields where one, or more, of the uncertainty realizations have predicted additional drawdown values that exceed the respective safe additional drawdown thresholds. The well fields that are not discussed below were consistent with the results provided in the base case, or the predicted heads did not exceed the safe additional available drawdown values.

TABLE 5-6 Risk Assessment Drawdown Results for Uncertainty Realizations (Average Climate)– Regional Model

Well Field	Well Name	SAAD (2008)	G1 Allocated Rates, Future Land Use			G2 Allocated Rates			G3 Future Land Use		
			R1	R2	R3	R1	R2	R3	R1	R2	R3
Erb Street	W6A	13.9	1.6	2.7	1.2	1.2	2.2	0.8	0.3	0.5	0.4
	W6B	10.1	2.1	4.3	1.4	1.7	3.9	1.0	0.3	0.5	0.4
	W7	5.9	1.0	0.3	0.9	0.5	-0.3	0.4	0.4	0.6	0.5
	W8	5.2	0.9	-0.1	0.6	0.5	-0.7	0.1	0.4	0.6	0.5
Waterloo North	W10	10.7	5.1	6.6	4.0	4.9	6.4	3.8	0.2	0.3	0.2
William Street	W1B	7.5	0.9	2.2	1.6	0.7	2.0	1.4	0.2	0.2	0.2
	W1C	22.2	4.2	5.4	3.9	4.0	5.2	3.7	0.2	0.2	0.2
	W2	11.7	-1.1	2.2	1.5	-1.2	2.0	1.3	0.2	0.2	0.2
	W3	33.3	2.5	2.8	2.2	2.3	2.6	2.0	0.2	0.2	0.3
Mannheim East	K21	4.3	3.0	4.0	2.9	1.7	2.3	1.5	1.3	1.6	1.4
	K25	7.7	2.4	2.9	2.4	1.0	1.2	0.9	1.4	1.7	1.5
	K29	7.2	2.5	3.0	2.5	1.1	1.3	1.0	1.4	1.8	1.5
Mannheim Peaking	K91	9.5	3.1	4.1	3.1	1.8	2.6	1.7	1.3	1.5	1.3
	K92	9.1	3.2	4.2	3.2	1.9	4.9	1.9	1.3	1.5	1.3
	K93	6.6	3.9	6.3	3.9	2.7	5.0	2.6	1.2	1.5	1.3
	K94	9.8	3.5	4.8	3.7	2.3	3.2	2.4	1.3	1.5	1.3
Mannheim West	K22A	12.1	-0.9	-1.9	-0.6	-1.8	-3.0	-1.7	1.0	1.1	1.1
	K23	8.9	-3.4	-2.0	-0.5	-4.4	-3.1	-1.6	1.0	1.1	1.1
	K24	12.0	1.6	1.3	1.4	0.4	0.1	0.2	1.2	1.2	1.2
	K26	11.2	1.2	0.8	1.0	0.0	-0.5	-0.3	1.2	1.3	1.3
Strange Street	K10A	10.9	4.5	6.5	4.1	4.2	6.2	3.9	0.3	0.4	0.3
	K11A	20.4	12.0	12.0	7.9	11.7	11.5	7.5	0.4	0.5	0.5
	K13	18.7	12.4	**	9.1	12.1	**	8.6	0.4	0.5	0.5
	K18	22.9	5.3	4.6	5.1	4.9	4.1	4.6	0.4	0.5	0.5
	K19	25.6	6.8	11.1	7.1	6.4	10.6	6.6	0.4	0.5	0.5
Greenbrook	K1A	21.0	5.4	6.3	6.1	4.8	5.8	5.6	0.6	0.6	0.5
	K2A	19.5	3.3	3.6	2.9	2.7	3.0	2.4	0.6	0.6	0.5
	K4B	9.4	-2.3	-2.4	-0.9	-2.9	-3.0	-1.4	0.6	0.5	0.5
	K5A	15.2	5.2	5.7	4.2	4.7	5.2	3.7	0.6	0.5	0.5
	K8	18.8	5.1	5.9	5.5	4.4	5.2	5.0	0.6	0.6	0.6
Parkway	K31	4.9	0.4	0.2	0.5	-0.1	-0.1	0.0	0.4	0.4	0.4
	K32	6.4	0.5	0.5	0.7	0.1	0.1	0.3	0.4	0.4	0.4
	K33	7.8	0.4	0.4	0.6	0.0	0.0	0.1	0.4	0.4	0.4
Strasburg	K34	4.4	-1.8	-2.7	-3.8	-2.2	-3.1	-4.3	0.4	0.5	0.4
	K36	35.2	-0.1	-0.1	-0.2	-0.6	-0.6	-0.6	0.5	0.5	0.4
Lancaster	K41	23.0	0.6	0.7	0.5	0.5	0.5	0.3	0.1	0.1	0.2
	K42A	26.7	0.7	0.8	0.6	0.6	0.6	0.4	0.1	0.2	0.2
Pompeii/Forwell	K70	5.3	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0
	K71	5.3	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1
	K72	3.7	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0
	K73	4.3	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0

Well Field	Well Name	SAAD (2008)	G1 Allocated Rates, Future Land Use			G2 Allocated Rates			G3 Future Land Use		
			R1	R2	R3	R1	R2	R3	R1	R2	R3
Woolner	K74	3.2	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1
	K75	1.4	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1
	K80	0.9	0.0	0.0	-0.1	-0.1	-0.1	-0.1	0.1	0.1	0.1
	K81	0.6	-0.4	-0.8	-0.3	-0.4	-0.9	-0.4	0.0	0.1	0.0
	K82	2.1	-2.2	-3.0	-1.5	-2.2	-3.0	-1.6	0.0	0.1	0.0
Fountain Street	P16	14.9	0.4	0.6	0.5	-0.1	0.0	0.1	0.3	0.7	0.5
Conestogo	C3	17.0	5.8	3.5	**18.4**	5.7	3.5	**18.3**	0.0	0.0	0.0
	C4	17.1	2.8	1.8	7.4	2.8	1.8	7.4	0.0	0.0	0.0
New Dundee	ND4	5.9	0.2	0.2	0.2	0.0	0.0	0.0	0.2	0.2	0.1
	ND5	5.2	0.2	0.2	0.2	0.0	0.0	0.0	0.2	0.2	0.1
Elmira	E10	28.8	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

*Model stability issue; the water level at the well cannot be reliably simulated

R1 is the Long-Term Transient; R2 is the Leaky Aquitards and R3 is the Bedrock realization

TABLE 5-7 Risk Assessment Drawdown Results for Uncertainty Realizations (Drought Climate)–Regional Model

Well Field	Well Name	SAAD (2008)	D Existing Recharge, Demand			H1 Recharge Reduction, Allocated Rates			H2 Allocated Rates			H3 Recharge Reduction		
			R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
Erb Street	W6A	13.9	1.3	1.7	1.3	2.5	3.8	2.0	2.1	3.6	1.7	1.6	2.2	1.6
	W6B	10.1	1.3	1.5	1.3	3.0	5.5	2.2	2.7	5.3	1.8	1.6	1.9	1.6
	W7	5.9	2.0	2.1	1.9	2.1	1.7	1.9	1.7	1.3	1.5	2.3	2.6	2.4
	W8	5.2	2.0	1.9	1.8	2.1	1.2	1.5	1.7	0.8	1.1	2.3	2.4	2.2
Waterloo North	W10	10.7	0.9	0.8	0.8	6.9	9.1	5.4	6.7	8.9	5.2	1.0	1.0	1.0
William Street	W1B	7.5	1.6	1.5	1.4	2.6	3.8	3.1	2.4	3.6	3.0	1.8	1.6	1.7
	W1C	22.2	1.1	1.1	1.1	5.5	6.8	5.4	5.4	6.6	5.2	1.3	1.2	1.3
	W2	11.7	1.8	1.4	1.3	1.3	4.0	3.2	1.2	3.8	3.1	1.9	1.6	1.6
	W3	33.3	1.1	0.9	1.1	3.7	3.7	3.3	3.5	3.5	3.1	1.3	1.1	1.4
Mannheim East	K21	4.3	2.2	2.0	2.2	**4.6**	**5.6**	**4.4**	3.5	4.1	3.3	3.2	3.4	3.3
	K25	7.7	2.2	2.0	2.3	4.0	4.6	4.0	2.9	3.1	2.8	3.3	3.5	3.5
	K29	7.2	2.2	2.0	2.2	4.1	4.7	4.0	2.9	3.1	2.9	3.3	3.5	3.5
Mannheim Peaking	K91	9.5	2.1	1.8	2.1	4.6	5.6	4.5	3.6	4.2	3.5	3.1	3.1	3.2
	K92	9.1	2.1	1.9	2.1	4.7	5.7	4.6	3.6	4.3	3.6	3.1	3.2	3.2
	K93	6.6	2.0	1.8	2.0	5.1	**6.9**	5.0	4.0	5.5	3.9	3.1	3.1	3.1
	K94	9.8	2.1	1.9	2.1	5.0	6.2	5.1	4.0	4.8	4.1	3.2	3.2	3.3
Mannheim West	K22A	12.1	2.0	1.9	2.1	0.6	-0.5	0.8	-0.2	-1.4	-0.1	2.8	2.8	3.0
	K23	8.9	1.9	1.6	1.9	-2.0	-0.6	0.9	-2.9	-1.5	0.0	2.7	2.5	2.8
	K24	12.0	2.1	1.9	2.1	3.2	3.0	3.0	2.2	2.0	2.1	3.0	3.0	3.1
	K26	11.2	2.2	2.1	2.3	3.0	2.6	2.7	2.0	1.6	1.7	3.2	3.2	3.3
Strange Street	K10A	10.9	3.4	2.8	3.6	6.8	8.3	6.5	6.6	7.9	6.3	3.6	3.1	3.8
	K11A	20.4	2.6	2.4	2.5	16.0	14.7	10.5	15.7	14.1	10.2	2.9	2.8	2.9
	K13	18.7	3.6	6.5	2.6	**20.3**	**	12.2	**20.3**	**	11.9	4.0	11.5	3.0
	K18	22.9	3.5	6.0	3.6	8.0	8.7	7.8	7.7	8.0	7.5	3.8	6.5	4.0

Well Field	Well Name	SAAD (2008)	D			H1			H2			H3		
			Existing Recharge, Demand			Recharge Reduction, Allocated Rates			Allocated Rates			Recharge Reduction		
			R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
	K19	25.6	3.0	3.8	3.0	9.5	15.2	9.8	9.2	14.5	9.5	3.3	4.2	3.4
Greenbrook	K1A	21.0	3.4	3.5	3.8	7.3	8.0	8.1	6.9	7.3	7.6	3.8	3.9	4.2
	K2A	19.5	2.6	2.4	2.7	5.2	5.3	4.9	4.7	4.5	4.5	3.1	2.9	3.2
	K4B	9.4	5.9	5.9	4.7	-0.3	-0.7	0.9	-0.7	-1.4	0.5	6.3	6.4	5.1
	K5A	15.2	6.6	6.8	5.0	7.4	7.5	6.0	6.9	6.8	5.6	7.0	7.1	5.6
	K8	18.8	2.4	2.1	2.4	6.9	7.4	7.3	6.4	6.6	6.9	2.9	2.6	2.9
Parkway	K31	4.9	1.6	1.3	1.8	1.6	1.2	1.7	1.2	0.6	1.4	1.9	1.6	2.2
	K32	6.4	1.5	1.2	1.8	1.7	1.4	2.0	1.3	0.8	1.6	1.9	1.5	2.1
	K33	7.8	1.6	1.3	1.9	1.6	1.3	1.9	1.3	0.7	1.6	2.0	1.6	2.2
Strasburg	K34	4.4	1.9	2.0	2.8	-0.4	-1.0	-2.0	-0.8	-1.6	-2.3	2.2	2.4	3.3
	K36	35.2	1.3	1.2	1.3	0.8	0.8	0.7	0.4	0.1	0.4	1.6	1.5	1.6
Lancaster	K41	23.0	0.6	0.9	0.8	1.2	1.5	1.2	1.1	1.3	1.1	0.7	1.1	0.9
	K42A	26.7	0.7	0.9	0.8	1.4	1.7	1.3	1.3	1.4	1.2	0.8	1.1	1.0
Pompeii/Forwell	K70	5.3	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.3
	K71	5.3	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2
	K72	3.7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2
	K73	4.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2
	K74	3.2	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2
	K75	1.4	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2
Woolner	K80	0.9	0.1	0.2	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.2	0.2
	K81	0.6	0.1	0.1	0.1	-0.3	-0.7	-0.3	-0.3	-0.8	-0.3	0.1	0.1	0.1
	K82	2.2	0.1	0.2	0.1	-2.1	-2.8	-1.5	-2.1	-2.9	-1.5	0.1	0.2	0.1
Fountain Street	P16	14.9	0.4	0.7	0.6	0.8	1.3	1.0	0.6	0.7	0.7	0.8	1.2	0.9
Conestogo	C3	17.0	0.7	0.4	1.9	7.8	4.8	**	7.8	4.8	**	0.7	0.4	1.9
	C4	17.1	0.6	0.4	1.6	3.7	2.4	9.9	3.7	2.4	9.9	0.6	0.4	1.6
New Dundee	ND4	5.9	1.5	1.6	2.6	1.7	1.8	2.5	1.5	1.6	2.3	1.7	1.8	2.7
	ND5	5.2	1.6	1.6	**8.6**	1.6	1.7	**9.0**	1.5	1.6	**8.8**	1.7	1.8	**8.7**

*Model stability issue; the water level at the well cannot be reliably simulated

R1 is the Long-Term Transient; R2 is the Leaky Aquitards and R3 is the Bedrock realization

Mannheim East

The predicted additional drawdown at Well K21 exceeded the safe additional available drawdown under the drought Scenario H1 under all three uncertainty realizations (Table 5-7), albeit only slightly exceeded in Scenarios R1 and R3. However, under average annual (steady-state) climatic conditions, the predicted additional drawdown for this well did not exceed the safe additional available drawdown for the well (Table 5-6). Under average climate conditions (Scenarios G1, G2 and G3), the well would be able to sustain pumping, but the well failed under the drought condition. As noted earlier, the uncertainty assessment was not calibrated to the transient well field scale pumping and shut down tests which may have contributed to the threshold exceedence under Scenario H1 at this well field.

Wells K25 and K29 are completed in the same unconfined aquifer as Well K21. Over 3 m of additional available drawdown were predicted to remain at these wells during Scenario H1 (Table 5-7). As these wells have available drawdown, and are connected to the same integrated distribution system, Wells

K25 and K29 could be pumped harder during a prolonged drought to reduce the water level impacts at Well K21. In addition, the wells in the nearby Mannheim West Well Field have 5 to 10 m of additional available drawdown that could also be used in a long-term drought situation, to offset potential impacts at Well K21 (Table 5-7).

Although the predicted additional drawdown at Well K21 was greater than the safe additional available drawdown threshold in Scenario H1 for the three realizations, it was not necessary to elevate the Risk Level for Local Area A given the tolerance and redundancy within the Mannheim East and West Well Fields , and the lack of calibration to well field pumping and shut down tests. Additional supplies would be available in this area during a drought to manage the water quantity stress; however, the results of the uncertainty assessment highlight the sensitivity of the well to drought, nearby land use development, and increases in municipal pumping.

Mannheim Peaking

The additional drawdown simulated in the Leaky Aquitards realization (uncertainty realization 2) for Scenario H1 exceeded the safe additional available drawdown at Well K93 by 0.3 m (Table 5-7). In this uncertainty realization, the hydraulic conductivity values representing the aquitard units were increased, so to maintain the groundwater elevations in the aquifer units, the hydraulic conductivity values for the aquifers were decreased.

In the area immediately surrounding Well K93, the hydraulic conductivity value was simulated as 5×10^{-4} m/s, which was considerably lower than the calibrated value and conceptual understanding of the aquifer (1.3×10^{-3} m/s). Reducing the hydraulic conductivity value in the Mannheim Aquifer at this location led to simulated drawdown that violated the safe additional available drawdown threshold. In this case, the optimized value was likely hindered by the few number of water level observation targets in the area, to adequately constrain the hydraulic conductivity value.

Although the predicted additional drawdown at Well K93 for Scenario H1 was greater than the safe additional available drawdown threshold, it was not necessary to elevate the Risk Level for Local Area A given the tolerance and redundancy within the Mannheim East and West Well Fields. Additional supplies would be available in this area during a drought to manage the water quantity stress; however, the results of the uncertainty assessment highlight the sensitivity of the well to drought, nearby land use development, and increases in municipal pumping.

Strange Street

Similar to the two previous cases, only one well in the Strange Street Well Field (Well K13) was predicted to have drawdown values in the uncertainty realizations that exceeded the safe additional available drawdown threshold. The threshold was violated in the Transient uncertainty realization in two of the drought scenarios (Scenarios H1 and H2; Table 5-7), and also in the Leaky Aquitards realization 2 in Scenarios G1, G2, H1 and H2 (Tables 5-6 and 5-7).

The simulated hydraulic conductivity surrounding Well K13 in the Transient uncertainty realizations was 2.2×10^{-4} m/s, which is similar to the calibrated value in the base case model (3.0×10^{-4} m/s). However, updates made by PEST in this scenario resulted in the reduction of groundwater recharge from shallow sources to the municipal supply aquifer, which led to greater drawdown at the well under long-term drought conditions.

The simulated hydraulic conductivity surrounding Well K13 (7.9×10^{-5} m/s) in the Leaky Aquitards realization was approximately half an order of magnitude lower than the base case calibrated hydraulic conductivity value (3.0×10^{-4} m/s). While this uncertainty realization allowed source water to reach the municipal wells through increased vertical leakage, the decrease in transmissivity in the production aquifer caused drawdown in excess of the safe additional available drawdown.

While the predicted additional drawdown at Well K13 was greater than the safe additional available drawdown threshold in both the Transient and Leaky Aquitards realizations, it is not necessary to elevate the Risk Level for Local Area A given the tolerance and redundancy within the Strange Street Well Field and other nearby well fields in the integrated system. The pumping rates in the Strange Street Well Field could be re-partitioned to manage the water quantity stress. For example, Wells K18 and K19 have nearly 10 m of additional available drawdown under the drought scenarios (Scenarios H1, H2 and H3) and as such, the pumping could be readily re-partitioned to reduce predicted impacts at Well K13.

Conestogo

Predicted drawdown in Well C3 in the Conestogo Plains Well Field exceeded the safe additional available drawdown in several scenarios in the Bedrock uncertainty realization (Tables 5-6 and 5-7). This was because during the PEST optimization of the Bedrock uncertainty realization, the observed water level elevations at Well C3 were accidentally excluded as PEST observation targets. Consequently, there were an insufficient number of observation points near Wells C3 and C4 to properly constrain the properties of the local aquifer at the well field.

In the Bedrock uncertainty realization, the hydraulic conductivity value at Well C3 was decreased by more than an order of magnitude relative to the hydraulic conductivity value applied in the base case model. This led to predicted drawdown at the well that was inconsistent with the observed well field data. As such, the results of this bedrock uncertainty case should be disregarded as the hydraulic conductivity values applied were inconsistent with the conceptual understanding at the well.

The groundwater elevations in Well C3 were included, as intended, in the PEST optimization set-up for the other two uncertainty cases (Transient and Leaky Aquitards), and the results for those scenarios were consistent with the conceptual understanding at the well field. Given the understanding of the Conestogo Plains Well Field, an elevated Risk Level for Local Area D is not warranted.

New Dundee

Predicted drawdown in Well ND5 in the New Dundee Well Field exceeded the safe additional available drawdown values in several scenarios in the Bedrock uncertainty realization (Tables 5-6 and 5-7). The hydraulic conductivity value applied for the production aquifer was over an order of magnitude lower than the conceptual understanding and the value applied in the base case calibrated model. This led to predicted drawdown at the well that was inconsistent with the observed well field data. As such, this bedrock uncertainty case should be disregarded as the hydraulic conductivity values applied were inconsistent with the conceptual understanding at the well.

The groundwater elevations in Well ND5 in the Transient and Leaky Aquitards scenarios were consistent with the conceptual understanding at the well field. Given the understanding of the New Dundee Well Field, an elevated Risk Level for Local Area A is not warranted.

5.4.1.2 Uncertainty Realizations – Baseflow Impacts

The changes in groundwater discharge, in each of the steady-state Risk Assessment scenarios, in each of the three uncertainty realizations, were evaluated and are summarized in Table 5-8. The results were comparable in magnitude to the predicted reductions in groundwater discharge under the base case (Table 5-3). In some instances, the percentage of baseflow reduction in the uncertainty realizations was greater than that of the base case, and in other instances, the base case model-predicted greater baseflow impacts.

As noted previously, the predicted reductions in groundwater discharge in Scenario G2 is of particular interest, as discharge reductions that exceeded 10% of the existing measured baseflow could result in the classification of a Moderate Risk Level for the Local Area. Predicted reductions in groundwater discharge to cold water streams was less than 10% at all reaches under Scenario G2. The Alder Creek Headwaters approached the 10% threshold (9.7%) in Scenario G2 in the Long-Term Transient uncertainty realization. In general, the changes in groundwater discharge/ baseflow for the Risk Assessment scenarios, in the three uncertainty realizations (Table 5-8), were comparable to the results predicted in the base case (Table 5-3).

TABLE 5-8 Risk Assessment Baseflow Results for Uncertainty Realizations– Regional Model

Stream / Reach	Thermal Regime	Scenario G1 Allocated Rates, Future Land Use		Scenario G2 Allocated Rates		Scenario G3 Future Land Use	
		Min Percent Reduction	Max Percent Reduction	Min Percent Reduction	Max Percent Reduction	Min Percent Reduction	Max Percent Reduction
Airport Creek	Cold water	4.4%	6.9%	-0.4%	0.0%	4.9%	7.0%
Alder Creek Headwaters	Cold water	14.8%	19.1%	5.7%	9.7%	7.7%	10.6%
Alder Creek at Mannheim	Cold water	16.2%	17.7%	-1.5%	1.7%	15.0%	17.0%

Stream / Reach	Thermal Regime	Scenario G1 Allocated Rates, Future Land Use		Scenario G2 Allocated Rates		Scenario G3 Future Land Use	
		Min Percent Reduction	Max Percent Reduction	Min Percent Reduction	Max Percent Reduction	Min Percent Reduction	Max Percent Reduction
West							
Alder Creek at New Dundee	Cold water	0.9%	1.3%	0.1%	0.2%	0.8%	1.2%
Hopewell Creek	Cold water	1.5%	1.8%	0.0%	0.1%	1.4%	1.8%
Idlewood Creek	Cold water	7.1%	9.1%	-1.7%	-1.2%	8.4%	11.1%
Laurel/ Beaver Headwaters	Cold water	9.7%	15.8%	4.0%	7.9%	5.7%	7.9%
Strasburg Creek	Cold water	18.5%	26.2%	0.4%	2.3%	18.1%	24.2%
Clair Creek	*Warm water*	*36.9%*	*39.6%*	*29.6%*	*30.5%*	*7.2%*	*9.5%*
Freeport Creek	*Warm water*	*8.9%*	*9.4%*	*0.0%*	*0.0%*	*9.0%*	*9.4%*
Laurel Creek	*Warm water*	*8.6%*	*9.9%*	*7.7%*	*8.6%*	*0.9%*	*1.3%*
Schneider Creek	*Warm water*	*3.0%*	*5.4%*	*1.1%*	*1.8%*	*1.8%*	*3.6%*
Shoemaker Creek	*Warm water*	*19.4%*	*22.4%*	*14.7%*	*17.9%*	*4.5%*	*4.7%*

5.4.2 Uncertainty Realizations – Cambridge Model

Three different realizations of the Cambridge Model were developed to understand the potential range of results that may be observed using equally well calibrated model realizations. The three realizations developed were as well calibrated to groundwater elevations and baseflow observations as the base case mode. However, the base case model included detailed calibration to the well field scale pumping and shut down tests, and these realizations may not perform as well to those shorter term hydraulic tests as the base case. The three uncertainty realizations performed in the Cambridge Model are described in Section 2.3.2 and summarized below.

- Uncertainty Realization 1: Transient calibration that emphasized the match to time-varying long-term hydraulic responses of the flow system under typical operating conditions from 2003 to 2011. This alternative realization is referred to as the “Transient” realization.
- Uncertainty Realization 2: Steady-state calibration whereby the hydraulic conductivity values of the bedrock aquitards (i.e., Vinemount Member of the Eramosa Formation and others) were started at the upper limits of our conceptual understanding, and PEST adjusted all hydraulic conductivity

values to produce a statistically well calibrated model. This realization aimed to examine the impact of the uncertainty in the hydraulic conductivity values of the aquitard units, and similar to the Regional Model, this realization is referred to as the "Leaky Aquitards" realization.

- Uncertainty Realization 3: Steady-state calibration that simulated additional layers within the Guelph Formation to allow for vertical variability within the formation. The calibrated base case model simulated the Guelph Formation as one hydrogeologic unit; however, through the manual calibration it was concluded that additional vertical discretization was desirable within the formation. This realization was completed to test the assumption that additional characterization within the Guelph Formation would aid the model calibration process within the Cambridge Well Field areas.

5.4.2.1 Uncertainty Realizations - Well Field Results

The following sections outline the specific well fields where one or more of the uncertainty realizations have predicted additional drawdown values that exceeded the respective safe additional available drawdown threshold. The well fields that are not discussed below were consistent with the results provided in the base case, or the predicted heads did not exceed the available additional drawdown values.

All eight of the Risk Assessment scenarios (see Table 2-) were evaluated for each of the three realizations (requiring 24 model scenario runs). The predicted additional drawdown at the municipal wells for steady-state Scenarios G1, G2 and G3 are presented in Table 5-9. The predicted additional drawdown for the transient Scenarios D, H1, H2 and H3 are presented in Table 5-10. If the predicted additional drawdown in the scenario exceeded the safe additional available drawdown, the cells in Tables 5-9 and 5-10 are highlighted and discussed in the following sections. The "R" headings in Tables 5-9 and 5-10 refer to Uncertainty Realizations 1, 2 and 3.

TABLE 5-9 Risk Assessment Drawdown Results for Uncertainty Realizations (Average Climate)– Cambridge Model

Well Field	Well Name	SAAD (2008)	In-Well Losses (m)	G1			G2			G3		
				Allocated Rates, Future Land Use			Allocated Rates			Future Land Use		
				R1	R2	R3	R1	R2	R3	R1	R2	R3
Blair Road	G4A	9.5	0.0	1.8	1.3	1.4	1.8	1.3	1.4	0.0	0.0	0.0
Dunbar	P6	9.6	-0.6	-0.5	-4.9	-4.9	-0.6	-4.9	-5.0	0.0	-0.1	0.0
Hespeler	H3	17.8	3.5	3.2	4.2	6.9	3.0	3.8	6.4	0.2	0.3	0.3
	H4	9.0	4.7	2.9	**4.7**	3.6	2.6	**4.4**	3.3	0.2	0.3	0.3
	H5	12.2	0.4	5.9	5.1	9.8	5.7	5.1	9.7	0.1	0.1	0.1
Pinebush	G5A	30.9	0.0	-0.2	7.0	-0.8	-0.5	-4.1	-1.3	0.3	0.8	0.5
	P10	6.6	0.2	1.3	1.5	1.7	0.9	0.7	1.0	0.4	0.8	0.7
	P11	33.9	1.1	1.6	2.2	2.5	1.2	1.7	1.9	0.4	0.6	0.7
	P15	13.8	0.3	1.8	2.5	3.2	1.5	2.0	2.7	0.3	0.5	0.5
	P17	20.3	-0.2	-3.7	-3.7	-6.4	-4.0	-4.2	-6.9	0.3	0.5	0.5
	P9	15.7	-0.3	0.7	0.4	0.9	0.4	-0.1	0.5	0.3	0.5	0.5

Well Field	Well Name	SAAD (2008)	In-Well Losses (m)	G1 Allocated Rates, Future Land Use			G2 Allocated Rates			G3 Future Land Use		
				R1	R2	R3	R1	R2	R3	R1	R2	R3
Clemens Mill	G16	19.8	2.4	8.1	6.9	10.3	7.9	6.7	9.9	0.2	0.3	0.3
	G17	6.7	0.1	2.1	2.3	2.8	1.9	1.9	2.4	0.2	0.3	0.4
	G18	19.9	0.2	4.9	6.7	7.8	4.7	6.3	7.4	0.2	0.3	0.3
	G6	13.6	-0.3	-2.6	-4.4	-5.0	-2.8	-4.8	-5.5	0.3	0.4	0.4
Shades Mill	G38	20.4	0.9	8.2	11.1	9.4	8.0	10.8	9.1	0.2	0.2	0.3
	G39	21.8	0.8	12.7	15.0	13.6	12.5	14.7	13.3	0.2	0.2	0.3
	G7	3.7	-0.1	0.9	1.2	1.7	0.7	0.8	1.3	0.3	0.3	0.4
	G8	4.0	-0.2	0.2	0.9	1.3	-0.1	0.5	0.9	0.3	0.4	0.4
Elgin Street	G9	5.9	-0.8	-4.4	-6.1	-5.5	-4.6	-6.4	-5.7	0.2	0.2	0.2
Middleton Street	G1	9.5	0.6	1.4	1.5	1.3	1.4	1.5	1.3	0.0	0.0	0.0
	G14	22.7	-0.6	0.2	-0.1	-0.3	0.2	-0.2	-0.3	0.0	0.0	0.0
	G1A	15.1	-1.8	0.1	-0.5	-0.3	0.1	-0.5	-0.4	0.0	0.0	0.0
	G2	15.1	0.3	2.5	3.9	1.2	2.5	3.9	1.2	0.0	0.0	0.0
	G3	18.9	0.6	2.3	3.4	1.1	2.3	3.4	1.1	0.0	0.0	0.0
Willard	G15	9.8	0.2	0.9	0.7	0.2	0.8	0.7	0.2	0.0	0.0	0.0

Note: R1 is the Transient; R2 is the Leaky Aquitards and R3 is the Bedrock realization

TABLE 5-10 Assessment Drawdown Results for Uncertainty Realizations (Drought Climate)– Cambridge Model

Well Field	Well Name	SAAD (2008)	In-Well Losses (m)	D Existing Rates, Land Use			H1 Allocated Rates, Future Land Use			H2 Allocated Rates			H3 Future Land Use		
				R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
Blair Road	G4A	9.5	0.0	0.4	0.4	0.4	2.1	1.6	1.8	2.1	1.6	1.7	0.4	0.4	0.7
Dunbar Road	P6	9.6	-0.6	0.2	1.2	1.2	-0.4	-4.1	-4.1	-0.4	-4.2	-4.2	0.2	1.1	1.2
Hespeler	H3	17.8	3.5	2.3	2.9	2.9	4.7	6.8	6.8	4.5	6.5	6.5	2.5	3.2	3.0
	H4	9.0	4.7	0.8	1.0	1.0	3.9	**6.4**	**6.4**	3.7	**6.1**	**6.1**	0.9	1.3	1.2
	H5	12.2	0.4	5.1	5.9	5.9	7.5	8.7	8.7	7.4	8.7	8.7	5.3	5.9	6.2
Pinebush	G5A	30.9	0.0	2.2	17.4	17.4	0.7	1.9	1.9	0.4	-0.1	-0.1	2.4	18.6	17.5
	P10	6.6	0.2	1.2	1.2	1.2	2.4	2.8	2.8	2.1	2.0	2.0	1.5	1.8	1.7
	P11	33.9	1.1	1.8	2.5	2.5	2.8	3.8	3.8	2.5	3.1	3.1	2.1	3.0	2.9
	P15	13.8	0.3	1.4	1.9	1.9	2.9	4.0	4.0	2.6	3.4	3.4	1.7	2.4	2.1
	P17	20.3	-0.2	3.3	3.3	3.3	-2.6	-2.5	-2.5	-2.9	-3.1	-3.1	3.6	3.7	3.6
	P9	15.7	-0.3	1.1	1.3	1.3	1.8	1.8	1.8	1.5	1.3	1.3	1.4	3.7	1.5
Clemens Mill	G16	19.8	2.4	1.4	1.3	1.3	9.6	8.6	8.6	9.5	8.0	8.0	1.5	1.4	1.4
	G17	6.7	0.1	2.2	2.9	2.9	3.9	5.0	5.0	3.7	4.1	4.1	2.5	3.2	3.0
	G18	19.9	0.2	3.1	4.4	4.4	6.7	9.4	9.4	6.5	8.6	8.6	3.3	4.6	4.5
	G6	13.6	-0.3	1.4	1.8	1.8	-1.1	-2.3	-2.3	-1.3	-3.0	-3.0	1.6	2.1	1.9
Shades Mill	G38	20.4	0.9	1.1	1.1	1.1	9.9	13.0	13.0	9.7	12.9	12.9	1.3	1.3	1.3
	G39	21.8	0.8	1.1	1.1	1.1	14.7	17.3	17.3	14.6	17.2	17.2	1.3	1.3	1.3
	G7	3.7	-0.1	1.4	1.6	1.6	2.4	2.8	2.8	2.2	2.5	2.5	1.6	1.8	1.8
	G8	4.0	-0.2	1.7	1.7	1.7	1.8	2.6	2.6	1.6	2.3	2.3	1.9	1.98	1.9
Elgin Street	G9	5.9	-0.8	2.4	2.6	2.6	-3.8	-5.4	-5.4	-3.9	-5.5	-5.5	2.6	2.7	2.8
Middleton Street	G1	9.5	0.6	1.2	1.5	1.5	2.1	2.4	2.4	2.1	2.4	2.4	1.2	1.4	1.4
	G14	22.7	-0.6	0.7	0.8	0.8	0.7	0.6	0.6	0.7	0.6	0.6	0.7	0.6	0.6
	G1A	15.1	-1.8	0.7	0.7	0.7	0.7	0.4	0.4	0.7	0.4	0.4	0.7	0.7	0.6
	G2	15.1	0.3	2.4	4.1	4.1	3.4	5.4	5.4	3.4	5.4	5.4	2.4	4.1	4.1
	G3	18.9	0.6	1.4	2.3	2.3	3.0	4.6	4.6	3.0	4.6	4.6	1.4	2.3	2.3
Willard	G15	9.8	0.2	0.9	0.9	0.9	1.1	1.5	1.5	1.1	1.5	1.5	0.9	0.9	0.8

Note: R1 is the Long-Term Transient; R2 is the Leaky Aquitards and R3 is the Bedrock realization

Hespeler

The predicted additional drawdown at Well H4 in the Hespeler Well Field exceeded the safe additional available drawdown under several drought scenarios for the Leaky Aquitards and Bedrock realizations. Well H4 is completed approximately 15 to 30 m below ground surface (bgs) in a shallow bedrock aquifer. In 2008, the Region drilled Well H4A adjacent to Well H4, into a much deeper bedrock production aquifer (Gasport Formation) and completed this well from approximately 50 to 125 m bgs.

Well H4A was not included in the base case groundwater flow model and was not simulated in the Risk Assessment scenarios. The Region is currently pumping Well H4A in place of Well H4. The Risk Assessment scenarios conservatively assumed the future Allocated Rates would be withdrawn from the shallow aquifer at Well H4, rather than from Well H4A, which is completed in the higher transmissivity underlying Gasport Formation. Therefore, while the predicted drawdown at Well H4 exceeded the safe additional available drawdown at the well, it was not necessary to elevate the Risk Level for Local Area B as Well H4A has significantly more safe additional available drawdown than Well H4.

5.4.2.2 Uncertainty Realizations - Baseflow Impact Results

The changes in groundwater discharge, in each of the steady-state Risk Assessment scenarios, in each of the three uncertainty realizations, were calculated and are summarized in Table 5-11. The results were comparable in magnitude to the predicted reductions in groundwater discharge under the base case (Table 5-4). In some instances, the percentage of baseflow reductions in the uncertainty realizations was greater than that of the base case, and in other instances, the base case model-predicted larger baseflow impacts.

As noted previously, predicted reductions in groundwater discharge in Scenario G2 is of particular interest, as discharge reductions that exceeded 10% of the existing measured baseflow could result in the classification of a Moderate Risk Level for the Local Area. Predicted reductions in groundwater discharge to cold water streams were less than 10% at all reaches under Scenario G2.

Moffatt and Irish Creek exhibited the greatest impacts due to municipal pumping at the Allocated Rates; however, the reductions remained below the 10% threshold in all uncertainty realizations. In general, the changes in groundwater discharge/ baseflow for the Risk Assessment scenarios, in the three uncertainty realizations (Table 5-8), were comparable to the results predicted in the base case (Table 5-4).

TABLE 5-11 Risk Assessment Baseflow Results for Uncertainty Realizations– Cambridge Model

Stream / Reach	Thermal Regime	Scenario G1 Allocated Rates, Future Land Use		Scenario G2 Allocated Rates		Scenario G3 Future Land Use	
		Min Percent Reduction	Max Percent Reduction	Min Percent Reduction	Max Percent Reduction	Min Percent Reduction	Max Percent Reduction
Blair Creek	Cold water	0.2%	0.8%	-0.5%	0.1%	0.7%	0.9%
Mill Creek Headwaters (Aberfoyle Creek)	Cold water	-0.2%	0.2%	-0.2%	0.1%	0.0%	0.2%
Mill Creek (downstream of Aberfoyle gauge)	Cold water	0.3%	0.8%	0.2%	0.5%	0.2%	0.3%
Mill Creek (upstream of Shades Mill Reservoir)	Cold water	6.4%	11.9%	4.7%	8.6%	1.9%	3.4%
Mill Creek Reservoir to the Grand River	Cold water	3.8%	4.6%	3.4%	4.2%	0.4%	0.4%
Ellis Creek	*Warm water*	*3.2%*	*4.8%*	*-0.9%*	*2.9%*	*1.8%*	*4.6%*
Irish Creek	*Warm water*	*12.3%*	*14.0%*	*7.1%*	*8.6%*	*5.2%*	*5.5%*
Moffat Creek	*Warm water/ Cold water*	*18.5%*	*19.9%*	*5.0%*	*8.6%*	*11.4%*	*13.5%*

5.5 Risk Assessment Summary

The Risk Assessment scenarios prescribed in the Technical Rules (MOE 2009) were evaluated using the Regional and Cambridge Models to assess potential impacts in the western and eastern portions of the Study Area, respectively. The Risk Assessment scenarios were evaluated using the calibrated base case versions of the models (see Matrix and SSPA 2012), and the predicted drawdown under each of the eight Risk Assessment scenarios was assessed at each of the 77 municipal wells included in the Tier Three Assessment.

The Regional and Cambridge calibrated base case models predicted additional drawdown values to be less than the safe additional available drawdown values at each of the municipal wells. These results suggested that the existing groundwater wells and Grand River intake will be able to supply the water needed to supply the Region to the year 2031. The predicted reductions in groundwater discharge, due to pumping at the Allocated Rates, were less than 10% at all cold water creeks. Minimal impacts on the PSWs of interest in this study were also predicted by the models.

In addition to the base case, three alternative calibrated model realizations were developed for the Regional Model and for the Cambridge Model, using the software code PEST. The eight Risk Assessment scenarios were evaluated, for each of the three alternative realizations for the Regional and Cambridge Models, to assess the sensitivity of the models to changes in the model input parameters. Although the safe additional available drawdown thresholds for a few wells within the Region were exceeded under these alternative realizations, the tolerance afforded by the integrated system, and the availability of other nearby groundwater wells with additional available drawdown, suggested that the Region will operationally be able to overcome any potential difficulties that may occur during short or long-term droughts, or under average climatic conditions.

The Low Risk Level applied to the four Local Areas within the Region was considered appropriate, and consequently, the uncertainty associated with the Risk Level applied to each of the Local Areas was Low.

6 SIGNIFICANT GROUNDWATER RECHARGE AREAS

6.1 Introduction

The Technical Rules require that SGRAs be delineated for each source protection area. SGRAs are one of four types of vulnerable areas that are used in vulnerability assessments. The other vulnerable areas are wellhead protection areas, intake protection zones, and highly vulnerable aquifers.

6.2 Methodology Used to Delineate Significant Groundwater Recharge Areas

The Technical Rules (MOE 2009) provide the following instructions for the delineation of SGRAs:

> *Part V.2 - Delineation of significant groundwater recharge areas*
>
> *44. Subject to rule 45, an area is a significant groundwater recharge area if:*
>
> *(1) the area annually recharges water to the underlying aquifer at a rate that is greater than the rate of recharge across the whole of the related groundwater recharge area by a factor of 1.15 or more; or*
>
> *(2) the area annually recharges a volume of water to the underlying aquifer that is 55% or more of the volume determined by subtracting the annual evapotranspiration for the whole of the related groundwater recharge area from the annual precipitation for the whole of the related groundwater recharge area.*
>
> *45. Despite rule 44, an area shall not be delineated as a significant groundwater recharge area unless the area has a hydrological connection to a surface water body or aquifer that is a source of drinking water for a drinking water system.*

46. The areas described in rule 44 shall be delineated using the models developed for the purposes of Part III of these rules and with consideration of the topography, surficial geology, and how land cover affects groundwater and surface water.

This Assessment follows rule 44(1) to define the thresholds for SGRAs; a review of estimated recharge distribution across the watersheds provides further justification of the threshold value used. The "related groundwater recharge area" identified in Rule 44(1) was taken as the entire area covered by the GAWSER flow generation model for the entire Grand River Watershed. This methodology was used to delineate SGRAs in the Tier Two Water Budget and Water Quantity Stress Assessment (AquaResource 2009a), and so the same threshold was used in the Tier Three Assessment, to maintain consistency between the two studies.

6.3 Significant Groundwater Recharge Area Delineation Results

The SGRAs cover a large portion of the Region, but are largely absent in the urban areas and along groundwater discharge areas including lakes, ponds and wetlands. Their delineation for the Central Grand and Canagagigue Creek Subwatersheds is described in the following sections.

6.3.1 Central Grand Assessment Area

SGRAs are delineated on a subwatershed-scale to protect the broader landscape. For the Central Grand Subwatershed, the average annual recharge rate (as determined by the GAWSER model), and SGRA threshold were 188 and 216 mm/year, respectively. For comparison, the threshold value for the Tier Two Study (AquaResource 2009a) was 202 mm/year.

There are two main contributing factors that account for the difference in threshold SGRA values. First, the Tier Three SGRA threshold value reflects updated characterization and increased refinement. Second, the Tier Three threshold was estimated specific to the simulated recharge of the Central Grand Subwatershed, whereas the Tier Two value was calculated considering the Grand River Watershed as a whole.

Professional judgment was used to remove potential groundwater discharge areas from the SGRA mapping. Discharge areas were defined as areas where the model simulated groundwater elevations were less than 2 m bgs. The 2 m criterion was chosen to account for seasonal water level fluctuations not captured by the steady-state groundwater flow model. In the remaining distribution small, spurious polygons were removed; an area of less than 0.4 ha (40,000 m^2) was applied as a guide. The SGRA mapping was not clipped to the Local Areas, as the delineated SGRA area accounts for municipal as well as domestic water users. The spatial distribution of the resulting SGRAs in the Central Grand Subwatershed is presented on Figure 6-1.

In general, the SGRAs are located outside the urban centres, as the impervious cover increases runoff to storm sewers and reduces the rate of infiltration (recharge). In the western portion of the subwatershed, the SGRA is large, continuous, and coincides with the core of the Waterloo Moraine. It covers an area from St. Agatha in the north to the New Dundee Well Field in the south.

East of the Waterloo Moraine, several small SGRA areas were mapped in the urban area of Kitchener-Waterloo, including portions in Waterloo North near the Laurel Creek Conservation Area, an area from the Strange Street Well Field in the west, to the Lancaster Well Field in the east, and south to the Greenbrook Well Field.

In the southern limits of the subwatershed, a SGRA is mapped from the Mannheim West Well Field in the west to the Strasburg Well Field, and eastward to the Grand River near the Blair Road Well Field.

All the urban well fields in the City of Cambridge, with the exception of Hespeler and Pinebush, were within the SGRA mapped area. Northeast of Cambridge, toward the City of Guelph, large areas of SGRA were mapped, coinciding with the sands and gravels associated with the Paris Moraine. Thick sands and gravels were mapped along the Grand River and these translate into pockets of mapped SGRAs as well. Notable areas include the Pompeii, Forwell and Woolner Well Fields, as well as the Lancaster Well Field.

Along with the spatial mapping of SGRAs, the recharge distribution was also reviewed with respect to the distribution of rates (see Figure 6-2). The chart illustrates percent recharge area distribution, percent cumulative recharge area, and percent cumulative recharge volume.

The percent area distribution series, shown in blue columns, uses the left y-axis (percent area distribution) and shows the percent of subwatershed area for each recharge rate. For example, 9% of the subwatershed area (see left y-axis) coincides with land areas with recharge rates that vary between 100 and 150 mm/year.

The percent cumulative area series, shown as a purple line, uses the right y-axis (percent cumulative area) and was calculated as the sum of all recharge values less than, or equal to, the horizon rate (normalized by the total area). As an example, this line shows that 47% (see right y-axis) of the subwatershed area corresponds to recharge rates less than, or equal to, 150 mm/year.

The percent cumulative volume series, shown as a green line, uses the right y-axis (percent cumulative volume) and was calculated as the sum of recharge volume for all recharge values less than, or equal to, the horizon rate (normalized by the total volume of recharge). As an example, this series shows that 8% of the subwatershed recharge volume corresponds to areas where the recharge rates are less than, or equal to, 150 mm/year. Therefore, areas with recharge rates less than, or equal to, 150 mm/year contribute to 8% of the recharge volume in the watershed but cover 47% of the area (Figure 6-2).

The SGRA threshold (216 mm/year) is represented by the 200 to 250 mm/year bar on the bar graph illustrated on Figure 6-2. The recharge rates greater than the SGRA threshold account for 65% of the subwatershed area while contributing 37% of the recharge volume.

6.3.2 Canagagigue Creek Assessment Area

For the Canagagigue Creek Subwatershed, the average annual recharge rate and SGRA threshold were 127 and 146 mm/year, respectively. For comparison, the threshold value for the Tier Two Study (AquaResource 2009a) was 202 mm/year, which considered the entire Grand River Watershed. Potential groundwater discharge areas were removed from the SGRA mapping using the same approach applied to the Central Grand Subwatershed (Section 6.3.1)

The spatial distribution of SGRAs in the Canagagigue Creek Subwatershed is presented on Figure 6-3. The SGRAs were typically situated on the eastern half of the subwatershed, which corresponds to permeable ice-contact drift materials at ground surface. On the western half of the subwatershed, patches of SGRA were limited to areas surrounding Conestogo Lake.

Along with the spatial mapping of SGRAs, the recharge distribution was also evaluated (Figure 6-4). The percent area distribution, percent cumulative area, and percent cumulative volume are presented and are quite different from the same information presented for the Central Grand Subwatershed (Figure 6-2).

The recharge rate range of 0 to 50 mm/year covers 58% (left y-axis) of the subwatershed area but only contributes 11% (right y-axis) of the recharge volume. In contrast, the recharge rate range of 300 to 350 mm/year covers 21% of the subwatershed area and 60% of the recharge volume. These plots are most helpful when used in conjunction with the spatial distribution of recharge (Figure 6-3) at targeted areas that contribute the most recharge to the area being investigated.

The SGRA threshold was represented by the 100 to 150 mm/year bar on the bar graph illustrated on Figure 6-4. The cumulative area and volume plots indicate that rates greater than this range account for 28% of the subwatershed area, while contributing 77% of the recharge volume.

7 KNOWLEDGE AND DATA GAPS

A number of data and knowledge gaps were encountered during the Tier Three Assessment. Data and knowledge gaps which pertained specifically to the design and construction of the groundwater and watershed-based flow generation models were discussed in the companion report (Matrix and SSPA 2012) and some were reiterated for completeness with the data and knowledge gaps that specifically pertain to the Risk Assessment.

7.1 Knowledge Gaps

Knowledge gaps refer to areas where understanding of the groundwater flow system is limited due to a general lack of characterization that is hindered by the difficulty in collecting sufficient volumes of data to fill the knowledge gap. Below are a few knowledge gaps noted in the Region as part of the Tier Three Assessment.

7.1.1 Groundwater Recharge Distribution

Recharge is the driving force of the groundwater flow system, yet it is difficult to reliably measure at a regional, or well field scale. Instead, we are reliant on water partitioning approximations to estimate recharge rates. For example, recharge can be estimated using a watershed-based flow generation model such as GASWER, or a coupled groundwater-surface water model such as MIKE-SHE. The key knowledge gaps with respect to groundwater recharge include;

- Recharge on above the water table aggregate pits/quarries. Several sand and gravel pits exist on the western side of the Moraine, and little is known about how much water is moving through these features into the underlying groundwater flow system. In this study, recharge of up to 1,000 mm/year was applied on these closed depression features, where runoff and evaporation are considered negligible, although previous studies suggest recharge could be as high as 2,500 mm/year.

- Recharge on existing urban areas where Low-Impact-Development and Best Management Practices have been employed is poorly understood. Development on the Waterloo Moraine has taken place over the past decade with the understanding that pre-development recharge rates will occur post-development. This assumption was carried forward into the groundwater flow model; however, a knowledge gap remains with respect to the actual effectiveness of the enhancements to groundwater recharge over time. The model estimated recharge is based on assumed performance of these features over the long-term and deviations from this assumption may impact the model predictions.

- The increased percentage imperviousness, and the corresponding reduction in recharge, that may arise due to development of land as outlined on the Official Plans. It was estimated that the imperviousness due to future development would be similar to the imperviousness from prior development. However, the actual imperviousness, without best management practices, may be higher or lower than those used in the Risk Assessment scenarios.

Studies undertaken by stormwater utilities that included continuous measurements of stream flow from subwatersheds, could be used alongside available meteorological data (e.g. precipitation, air temperature and representative wind speed) would provide the data needed to establish better groundwater recharge estimates from the permeable portions of the measured subwatershed.

7.1.2 Water Loss due to Municipal Infrastructure

There is a knowledge gap related to the loss of water from municipal infrastructure beneath the urban portions of the Study Area due to leaky pipes (i.e., storm sewers, sanitary pipes, etc.). Leaky underground pipes can recharge the groundwater flow system and may locally increase groundwater elevations above those applied in the groundwater flow model.

7.1.3 Impacts on Wetlands

The predicted decrease in groundwater elevation was 1.0 m beneath the Mill Creek and Laurentian West Wetlands in the Region under Scenario G2. The significance of this reduction in water table or the reduction in groundwater discharge to portions of the wetland are knowledge gaps. Data gaps also exist with respect to the gradients within/surrounding the wetlands and installation of staff gauges and nested piezometers would shed light on the recharging or discharging nature of the wetland seasonally and over time. Improved detailed characterization of the wetland type could also assess whether the wetland is perennially surface water or groundwater fed, and this information could also be used to enhance the calibration in the area, and reduce the uncertainty associated with the model predictions.

7.1.4 Salina Formation

The hydraulic characteristics of the Salina Formation that underlies the Waterloo Moraine are not well characterized. Little is known about the distribution of the various members of the Salina Formation beneath the Waterloo Moraine, as the bedrock is so deeply buried beneath overburden sediments. The formation members were mapped by the OGS on a Provincial scale, and broad generalizations were made regarding its hydraulic properties. Local-scale aquifer test information or groundwater elevations within the formation were not available to help constrain the hydraulic parameters of the formation.

7.1.5 Waterloo Moraine Aquitards

There is a knowledge gap related to the size and extent of “windows” within overburden aquitards (e.g., Upper and Middle Maryhill Till, Catfish Creek Till, etc.) within the Region exist. Borehole logs identify where these windows may exist, but the size and extent of the windows and the continuity of windows between boreholes is a data or knowledge gap. Lithologic data reported on drilling logs enhances the uncertainty with respect to potential windows, especially in the Catfish Creek Till, as some drillers may describe the Catfish Creek Till as till or hardpan, whereas others may describe the same units as sand and gravel. Observed groundwater level and water quality data where used whenever possible, to help identify where there are connections between the surface and deeper aquifer units. However, the spatial distribution, size and continuity of these windows on a large-scale remains a knowledge gap.

In addition, the hydraulic conductivity values of the overburden aquitards represent another knowledge gap. The Region does not typically install wells within the aquitard units or conduct hydraulic testing on the aquitard units, and as such, the hydraulic conductivity values are poorly defined. While it is generally understood that the clay-rich Maryhill Till has a low hydraulic conductivity (i.e., $< 1 \times 10^{-8}$ m/s), the hydraulic conductivity values of the deeper overburden aquitards including the over-consolidated, stony Catfish Creek Till are not well constrained. Additional testing of these aquitard units would improve the overall understanding of the potential connections between the municipal production aquifers.

7.1.6 Cambridge Bedrock Formations

The stratification and the hydraulic properties representing the complex bedrock groundwater flow system in the Cambridge area, beyond the areas where high quality cored, lithologic or geophysical data exist, is a knowledge gap. The OGS (Brunton 2009) greatly improved the conceptual understanding of the bedrock units within the Cambridge and Guelph areas using all of the available data. However, where high quality data were not present, broad assumptions were made regarding the bulk properties of each of the bedrock units. Specifically, the following represent knowledge gaps with respect to the bedrock formations in the Cambridge area:

- Presence and absence of the reef mounds and high hydraulic conductivity "coquina beds" associated with the Gasport Formation, especially south of the urban portion of the City of Cambridge.

- The thickness and elevation of the Middle Gasport Formation. This unit is currently simulated as a uniform thickness and a constant elevation in the model. Variability in the elevation and thickness likely exists within this unit but the paucity of data has prevented more detailed delineation.

- The vertical stratification of the Guelph Formation. This unit is simulated as one model layer in the model; however, the uncertainty assessment suggested the unit could be further subdivided to better replicate stratification within the unit.

7.2 Data Gaps

Data gaps generally refer to areas where there is a paucity of data, missing data, or where the available data are incomplete. The presence of a data gap may limit the understanding of the system, such as areas where there are no water level measurements to constrain calibration of material properties, or the data gap may hinder the representation of certain conditions. For example, the lack of knowledge regarding a permitted water taker could lead to errors in the modelled connection between groundwater wells. Large-scale data gaps are outlined below, followed by well field specific data gaps.

7.2.1 Permits to Take Water

The numeric modelling component of this study identified several data gaps regarding the characterization of private PTTWs. Although these features can be represented in a numeric model, without proper geologic characterization, the predictions regarding their influence on the groundwater flow system, and their potential impacts to other users, is limited.

The majority of private PTTWs lacked well completion details (e.g., screened interval), a lithology record, and aquifer testing. Each of these attributes provides information that can enhance the quality of the model. The completion details allow the groundwater production to be assigned to the correct aquifer unit and the lithology and aquifer testing allows for characterization of the aquifer local to the permitted taking. The absence of this information hindered local refinement, particularly in areas outside of the Study Area.

Reported estimates of groundwater taking (volume), and the consumptive demand, were also typically not available. These factors limited the characterization of the groundwater flow system local to these PTTWs. Modelling is a data-driven process; limited or inadequate characterization hampers the model's ability to predict the potential influence of these PTTWs to other water users.

Additional characterization and data collection for the PTTWs at Kraus Carpets (Permit 72-P-0432) in Waterloo, and Air Boss Rubber compounding facilities (Permit 6708-6FLNRH) in the Strange Street Well Field in particular, would benefit the local characterization.

7.2.2 Surface Water Monitoring Data

Surface water features such as streams and lakes are typically an expression of the groundwater table above ground surface. Stream flow measurements are sparse, particularly in urban areas where impacts from production have the potential to be greater. The numbers of locations and the frequency of surface water monitoring represent data gaps in the Region. Stream flow measurements can be used to improve the baseflow calibration and representation of the groundwater and surface water interaction in groundwater flow models. Baseflow separation techniques or spot flow measurements under low flow conditions can be used to estimate a range of baseflow values. The range of values can then help constrain the local-level estimates of recharge and hydraulic conductivity values.

Increasing the number of stream flow monitoring locations along a reach can provide insight into the portions of the reaches that are receiving significant groundwater contribution, and increasing the frequency of measurements provides an improved understanding of how groundwater discharge to surface water features varies seasonally and over time. This would improve the overall understanding of the current groundwater and surface interactions, which can then be used as a baseline for establishing an adaptive management plan. Stream flow monitoring could be supplemented with hydraulic gradient measurements between the stream and underlying aquifer (via streambed piezometers) and temperature profiling to provide direct measurements of groundwater-surface water interactions. Results of the Risk Assessment scenarios indicated that a 20% reduction in average annual baseflows in some cool and warm water streams in the Region may be possible under future pumping and unmitigated land use development conditions. Larger reductions in baseflow may occur during annual minimum flow periods and monitoring would be helpful to assess the impact of the baseflow reduction during these low-flow periods.

Some specific areas of interest include examining the groundwater-surface water interaction along the following stream reaches:

- Beaver Creek headwaters. The collection of field data would help confirm the presence/absence of a connection between these headwaters and the Waterloo well fields.

- Silver Lake area in Waterloo. The collection of field data would help confirm whether there is a hydraulic connection to the William Street Well Field.

- Surface water features near and upgradient of the Greenbrook, Parkway and Strasburg Well Fields, such as Shoemaker Creek and Lake, Schneider Creek, Strasburg Creek and the Laurentian West Wetlands. Additional field data would help confirm if there are hydraulic connections between these urban streams and the underlying aquifers.

- Alder Creek near the Mannheim West Well Field. Losing conditions in a portion of Alder Creek near the Manheim West Well Field were reported in the Alder Creek Groundwater Study (CH2M 2003) and these conditions were replicated in the groundwater flow model. Additional field data could refine the characterization of the gaining or losing conditions along this portion of the creek.

- Mill Creek between the Shades Mill Reservoir and the Grand River. Additional field data would help refine the understanding of hydraulic connections between Mill Creek and the Shades Mill Shades Mill Reservoir and the underlying groundwater flow system.

- Moffatt Creek. Additional field data collected in the urban area, especially near the Grand River, would help refine the understanding of hydraulic connections to the underlying groundwater flow system.

- Portuguese Bog and Puslinch Lake. Little is known about the groundwater and surface water interactions in the wetlands that lie within the urban areas of Cambridge. Perched conditions are present in a number of well fields within the Cambridge East area, and a more detailed study regarding the hydraulic interactions between stormwater ponds, nearby wetland features and the underlying groundwater flow system would improve the overall understanding of the available groundwater resources in this area.

7.2.3 Well Field Specifc Data Gaps

The following sections outline the well field specific data gaps identified during the Tier Three Assessment.

7.2.3.1 Waterloo Well Fields

Upgradient groundwater elevation measurements were limited at the Erb Street Well Field to the St. Agatha area. Little is understood about conditions toward Wilby Road between Notre Dame Drive and Wilmot Line, which increased the uncertainty in the groundwater flow gradients and directions upgradient of the well field. Similarly, few groundwater elevation measurements exist within 2 km of Well W10.

Pumping tests conducted at Well W5A showed responses in the upper hydrogeologic units, suggesting windows exist in the Maryhill Till (ATB2 and ATB3) between Well W5A and Erbsville. The exact location of these windows was uncertain and additional drilling may help confirm the presence or absence of Maryhill Till in this area.

7.2.3.2 Kitchener Well Fields

There was a data gap with respect to the continuity and hydraulic properties of the surficial till (ATB2) that overlies the Strange Street production aquifer. The hydraulic properties of this upper till were poorly characterized, and additional information regarding this unit would help constrain the volume of water that recharges the production aquifer.

In addition, there was little high quality borehole data available to evaluate any potential hydraulic connections between the Strange Street and Greenbrook Well Fields. Specifically, there was little lithologic or hydrogeologic data available beneath the Strange Street Well Field or in the area between the two well fields to characterize the continuity or hydraulic properties of the deep overburden aquifer units (i.e., AFD1 and AFF1).

Within the Greenbrook area, a potential higher hydraulic conductivity channel may exist in the deep overburden aquifer (AFD1) trending north and west of the well field; however, there was insufficient data available to confirm the location of the channel. This hypothesis was hindered by the lack of deep overburden lithologic data between the Greenbrook and Parkway Well Fields. The BMW series of wells near the former Ottawa Street Landfill provided information on the shallow overburden, but they did not reach the deeper overburden aquifer unit (i.e., AFD1). Additional deep borehole data between Greenbrook and Parkway could help map and characterize potential high conductivity channelized features that may be supplying the Greenbrook and Parkway Well Fields.

Limited high quality water level data and pumping test data existed in the Mannheim Well Fields area. Additional pumping tests are recommended in the well fields to properly constrain the estimates in the groundwater flow model. In addition, few boreholes in the Mannheim area extend to depth below the Lower Maryhill Till (ATB3). Additional high quality boreholes drilled to the top of bedrock would greatly aid in confirming the stratigraphy of the lower aquifer units, and shed light on the potential hydraulic connections between the Mannheim Well Fields in the west and the Strasburg Well Field in the east.

Within the Parkway Well Field area, the continuity of the interpreted high hydraulic conductivity channel in the production aquifer (AFD1) was poorly understood and additional deep borehole data in this area may help to refine the hypothesis that the Greenbrook, Parkway and Strasburg Well Fields are completed in glaciofluvial channel aquifers that are separated by low hydraulic conductivity till units. Drilling may also help determine the extent of the high hydraulic conductivity zone or window in the Lower Maryhill Till (ATB3), near observation well PK8.

The pumping rates of the Kuntz well(s) were simulated to have an impact on the groundwater elevations in the Parkway production aquifer; however, lack of deep overburden and bedrock groundwater elevations between the two wells hampered the understanding of the hydraulic connection between the Kuntz Well and the Parkway Well Field. Additional drilling and characterization in this area would determine the impact of the Kuntz Wells pumping on the well field.

Within the Lancaster and River Wells area there was limited high quality data in and around the Grand River to verify the hydraulic connections between the wells and the River (including the deep Lancaster production aquifer (AFD1). A hydraulic connection was simulated in the model to exist between the production aquifers and the River, yet this connection has not been confirmed with high quality water level data.

The lateral extent of the production aquifer at the Fountain Street Well Field beyond the 1 km buffer area around the wells was not well-defined (see Golder 2011c). West of the well, it is not currently known if the AFD1 production aquifer extends to the Grand River, has a hydraulic connection to the Grand River, or if the aquifer extends beneath the Grand River toward the Parkway Well Field. Additional field data outside the Fountain Street area would improve the overall understanding of the continuity and thickness of this unit.

7.2.3.3 Cambridge Well Fields

In the Middleton and Willard Well Field areas, one key data gap was the degree of hydraulic connection between the bedrock production aquifers and the Grand River. Some of the groundwater pumped by the Middleton Street and Willard wells is interpreted to be sourced by the Grand River; however, the quantity or percentage of the pumped water sourced from the river was a data gap. Improving the understanding of the flux between the two has implications for the local water budget at the well field and in ensuring reasonable delineation of well field capture zones or Well Head Protection Areas. Additional studies or insights into the very high hydraulic conductivity zones present in the bedrock at the Middleton Well Field area would also be beneficial to improve the overall understanding of groundwater flow in this area.

In the Cambridge East area, one key data gap was the interaction between Puslinch Lake and the underlying groundwater flow system. Leakage from Puslinch Lake to the underlying groundwater flow system, that was used to constrain the groundwater flow model calibration, was a rough estimate based on a desktop water budget study of the entire catchment, as site-specific data were unavailable. A refined study of Puslinch Lake and its immediate surroundings may provide an independent check on the results of the modelling and the Risk Assessment.

There was a data gap with respect to the understanding of the vertical stratification within the Guelph Formation. An uncertainty realization was completed that highlighted that additional layering within this unit in the groundwater flow model may improve the local representation of groundwater flow. Additional studies could be completed in the vicinity of municipal wells completed in Guelph Formation aquifer (i.e., Wells G5, P15 and H4) to ensure the modelled representation of these wells is not currently over- or under-predicting the connection between the Guelph Formation and the overburden system (and nearby surface water features).

Within the Shades Mill area, little geologic or hydrogeologic information existed to characterize the overburden channel that hosts the production aquifer for Wells G7 and G8. Additional lithologic data, pumping test data and review of the potential connections between these wells and Wells G38 and G39 and the nearby Shades Mill Reservoir would improve the overall conceptual understanding of the Shades Mill Well Field.

7.3 Conclusions

Despite the knowledge and data gaps presented above, the approach undertaken in this study enabled the assignment of an appropriate Risk Level to the four Local Areas. During the course of this study all available data sources were consulted to develop a conceptual understanding of the flow system. This conceptual framework was built into the hydrologic and groundwater flow models and the understanding was refined during the model calibration process.

8 SUMMARY AND CONCLUSIONS

The Province of Ontario introduced the *Clean Water Act* (Bill 43; MOE 2006) to ensure that all residents have access to safe drinking water. Under the *Clean Water Act* (MOE 2006), Source Protection Authorities are required to conduct technical studies to identify existing and potential water quality and quantity threats to municipal drinking water. Through the development of community-based Source Water Protection Plans, actions will be implemented to reduce or eliminate any Significant drinking water threats.

Under the requirements of the *Clean Water Act* (MOE 2006), municipalities may be required to complete a Tier Three Water Budget and Local Area Risk Assessment to assess the ability of the municipal water sources to meet their allocated water demands. Municipalities that are predicted to be unable to meet their water demands will be required to identify Significant threats to their water supplies.

This report details the Local Area Risk Assessment carried out for the Region of Waterloo. The report documents the existing and committed municipal water demands, and the results of the groundwater flow modelling scenarios used to complete the Local Area Risk Assessment. Several companion reports summarize the well field characterization efforts (AquaResource 2009c, 2011; Blackport 2012a, 2012b; Golder 2011a, 2011b and 2011c; Stantec 2009, 2011a, 2011b, 2012a, 2012b and 2012c), and the development and calibration of the hydrologic and hydrogeologic models (AquaResource 2009b; Matrix and SSPA 2012) used to complete the Tier Three Assessment.

8.1 Summary of the Water Budget Tools and Results

The Tier Two Assessment completed for the Grand River Watershed (AquaResource 2009a) identified two subwatersheds as having a Moderate or Significant potential for groundwater stress. As a result, a Tier Three Assessment was required for the municipal wells located within these two subwatersheds. To date, the Region of Waterloo has not had any issues meeting its water quantity requirements. However, the Tier Three Assessment was completed to ensure that future water supply demands can be met by the water sources without causing a negative impact on other water uses.

A GAWSER watershed-based flow generation model was refined and used in this assessment to evaluate surface water conditions and to partition precipitation into overland flow, evapotranspiration and groundwater recharge. Two FEFLOW groundwater flow models were used in the Tier Three Assessment. One was used to evaluate the well fields within the Kitchener-Waterloo area (the Regional Model), and a second was used to evaluate the well fields within the Cambridge area (the Cambridge Model). The groundwater flow models were calibrated using recharge estimates and cross-boundary flows provided by the GAWSER hydrologic model.

The Tier Three Assessment included the interpretation of local-scale cross sections across the urban well fields of the Study Area, to refine the subsurface hydrostratigraphy, and to assign hydrogeologic parameters in the groundwater flow models that were consistent with local hydraulic testing results within the subwatershed and surrounding areas. The groundwater flow models were calibrated to a finer level of detail, paying close attention to observations at high quality monitoring wells. The Tier Three Assessment groundwater flow models were calibrated at the municipal well field-scale to steady-state (long-term average) and transient (time-varying) conditions.

The Tier Three Assessment included an in-depth compilation of current and historical groundwater pumping and monitoring data. This assessment of monitoring data indicated that the Region can meet water demands with existing municipal groundwater wells and the Grand River surface water intake.

Following the development and calibration of the 3D groundwater flow models, the water budget components in the two subwatersheds were quantified (Matrix and SSPA 2012), and the models were used to conduct a series of Risk Assessment scenarios. The scenarios examined the change in groundwater elevations and discharge to sensitive surface water features with varying pumping and land use conditions under average annual and drought climate simulations.

8.2 Local Area Risk Assessment Summary

Four Local Areas were delineated for the various municipal supply wells within the Study Area (Figure 5-2). The areas were delineated following the Province’s Technical Rules (MOE 2009), based on a combination of the cone of influence of each municipal well, as well as land areas where reductions in recharge has the potential to have a measurable impact on the municipal wells.

A series of Risk Assessment scenarios were undertaken, consistent with the Technical Rules (MOE 2009). The Risk Assessment scenario results, and the results of the uncertainty analysis, classified the Local Areas within the Region of Waterloo as having a Low Risk Level. The Low Risk Level is considered appropriate for Local Area A (containing the Kitchener - Waterloo municipal wells) because the integrated system of groundwater wells and well fields are completed in productive overburden aquifers within and beneath the Waterloo Moraine. The municipal production aquifers can supply water at sufficient rates to meet the Region's 2031 water demands without causing a negative impact on other water uses. In addition, the surface water intake on the Grand River and the ASR system at Mannheim are also available to supplement the groundwater wells within the Region.

Similarly, the municipal wells located within Local Area B (i.e., Cambridge wells) are completed within productive overburden and bedrock units that are able to transmit volumes of water on a long-term basis that more than meet the 2031 demands, without causing negative impacts on other water uses. Local Areas C and D (Blair Road and Conestogo, respectively), were also assigned a Low Risk Level as the future water demands for these wells are only marginally higher than what they are currently pumping, and pumping from these wells will not cause detrimental impacts to other water uses in these areas.

In accordance with the Technical Rules (MOE 2009), the consumptive water users and potential reductions to groundwater recharge within the Local Areas were not classified as Significant or Moderate water quantity threats. The potential reductions to groundwater discharge to sensitive surface water features such as cold water streams due to land use development varied from minor to significant. The model scenarios did not consider the influence of best management practices, or Low Impact Development measures; rather groundwater recharge was reduced proportionally to the imperviousness for areas where land use development was expected to occur. While these scenarios are conservative, as the Region has bylaws in place to mandate stormwater management practices for new developments in sensitive recharge areas, the results indicate where groundwater recharge and discharge is predicted to be most sensitive to land use change, and where the Region or the GRCA may wish to more closely monitor baseflow or stream flow in the future.

8.3 Recommendations

The following recommendations are provided based on results of this Tier Three Water Budget and Local Area Risk Assessment:

- Maintain and Enhance Monitoring Programs.
    - Monitoring and reporting programs associated with Permits to Take Water and the Region's municipal groundwater quality and quantity programs are in place and should be continued. Monitoring data should be reviewed and maintained on an ongoing basis, recognizing the relationship between municipal groundwater withdrawals and surface water discharge.

- Stream flow gauges and other assessments of key surface water features such as Alder, Strasburg, Mill and Moffatt Creeks should be enhanced to monitor the long-term trends in surface water flow data. These data could be used to better characterize the streams and their interactions with groundwater flow systems. These data could also be used to refine future calibration updates of the groundwater or surface water flow models.

- Maintain and Update Regional Water Budget Models and associated geodatabase. The Region of Waterloo maintains water budget modelling tools to help manage and protect the water resources across the Region. These modelling tools and associated GIS and geodatabase tools should be updated on an ongoing basis as new information is gathered and insights evolve.

- Maintain and Enhance Water Conservation Programs. Although the Region of Waterloo is able to meet municipal water demands under average and drought climatic conditions, current water conservation programs could be enhanced to decrease the per-capita water demand, which has the potential to enhance local ecosystem health.

- Educate the land developers and homeowners within the Region about the value of stormwater management controls, best management practices and/or low impact development techniques implemented within new or existing developments across the Region. This will help keep rear-yard swales, infiltration facilities, stormwater management ponds and roof leaders directing water to permeable areas to enhance recharge, functioning properly, thereby reducing runoff to storm sewers.

9 ACKNOWLEDGEMENTS

A large number of individuals representing a broad spectrum of agencies, organizations and technical disciplines contributed to the development of this report. The project team was comprised of the following members:

Team Member	Affiliation
Michael Garraway	Ministry of Natural Resources – Project Sponsor
Scott Bates	Ministry of Natural Resources - Representative
Rick Vanfoort	Ontario Ministry of the Environment – Representative
Richard Wootton	Region of Waterloo - Representative
Eric Hodgins	Region of Waterloo - Representative

Team Member	Affiliation
James Etienne	Grand River Conservation Authority - Representative
David Rudolph	University of Waterloo - Peer Review
Hugh Whiteley	University of Guelph – Peer Review
Tony Lotimer	ARL Groundwater Resources Ltd. – Peer Review
Chris Neville	S.S. Papadopoulos and Associates – Consultant
Jinhui Zhang	S.S. Papadopoulos and Associates – Consultant
Paul Martin	Matrix Solutions Inc. - Consultant
Patricia Meyer	Matrix Solutions Inc. - Consultant
Martinus Brouwers	Matrix Solutions Inc. – Consultant
Gaelen Merritt	Matrix Solutions Inc. - Consultant

This study was made possible with financial contributions from the Province of Ontario.

10 REFERENCES

AquaResource Inc. (AquaResource). 2012. *Permits to Take Water Review, Region of Waterloo FEFLOW Numeric Model*. Technical memorandum submitted to Region of Waterloo. Waterloo, Ontario. November 2012.

AquaResource Inc. (AquaResource). 2012. *Region of Waterloo Tier Three Water Budget and Local Area Risk Assessment Rural Well Fields Characterization Report*. Final Report prepared for Region of Waterloo. Waterloo, Ontario. January 2012.

AquaResource Inc. (AquaResource). 2009a. *Integrated Water Budget Report, Grand River Conservation Authority*. Report prepared for Grand River Conservation Authority. Waterloo, Ontario. June 2009.

AquaResource Inc. (AquaResource). 2009b. *Tier Three Water Budget and Local Area Stress Assessment: Hydrological Model Update, Regional Municipality of Waterloo and City of Guelph*. Draft report prepared for the Regional Municipality of Waterloo and City of Guelph. Waterloo, Ontario. August 2009.

AquaResource Inc. (AquaResource). 2009c*. Tier Three Water Budget and Local Area Risk Assessment: Draft Physical Characterization Summary Report*. Summary report submitted to Region of Waterloo. Waterloo, Ontario. August 2009.

Beak, Raven Beck, Waterloo Hydrogeologic Inc. 1995*. Delineation of the Capture Zone for the Middleton Street Wellfield, Cambridge, Ontario*. Draft report prepared for the Regional Municipality of Waterloo. Waterloo, Ontario.

Blackport Hydrogeology Inc. (Blackport). 2012a. *Tier Three Water Budget and Local Area Risk Assessment: Waterloo North, William Street and Lancaster Well Fields Characterization Study*. Report submitted to the Regional Municipality of Waterloo. Waterloo, Ontario. January 2012.

Blackport Hydrogeology Inc. (Blackport). 2012b. *Tier Three Water Budget and Local Area Risk Assessment: River Wells; Pompeii, Woolner and Forwell and Woolner Well Fields Characterization Study*. Report submitted to the Regional Municipality of Waterloo. Waterloo, Ontario. January 2012.

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

DHI-WASY. 2011. *FEFLOW 6.0 – Finite Element Subsurface Flow and Transport Simulation System*. WASYGmbH. Berlin, Germany.

Golder and Associates Ltd. (Golder). 2011a. *Tier Three Water Budget and Local Area Risk Assessment: Mannheim Well Fields Characterization*. Report prepared for the Regional Municipality of Waterloo. November 2011.

Golder and Associates Ltd. (Golder). 2011b*. Tier Three Water Budget and Local Area Risk Assessment: Cambridge East Well Field Characterization.* Report prepared for the Regional Municipality of Waterloo. November 2011.

Golder and Associates Ltd. (Golder). 2011c. *Tier Three Water Budget and Local Area Risk Assessment: Fountain Street Well Field Characterization*. Report prepared for the Regional Municipality of Waterloo. November 2011.

Government of Canada (Canada). 2013. Indian Act of Canada. R.S.C., 1985, c. I-5.

Matrix Solutions Inc. (Matrix) and S.S. Papadopulos and Associates (SSPA). 2012. Draft *Tier Three Water Budget and Local Area Risk Assessment, Model Calibration and Water Budget Report.* Report prepared for the Regional Municipality of Waterloo. November 2012.

Ontario Ministry of Municipal Affairs and Housing (OMMAH). 2005. *Provincial Policy Statement*. Queens Printer for Ontario, 2005.

Ontario Ministry of the Environment (MOE). 2013. *Assignment of Water Quantity Risk based on Evaluation of Impacts to Other Water Uses*. Memo from H. Malcolmson, Source Protection Programs Branch, Dec. 2, 2013.

Ontario Ministry of the Environment (MOE). 2009. *Technical Rules: Assessment Report*. Clean Water Act. November 16, 2009.

Ontario Ministry of the Environment (MOE). 2007. *Water Quantity Risk Assessment Guidance Module 7*. Unpublished document.

Ontario Ministry of the Environment (MOE). 2006. *Clean Water Act.* S.O. 2006, CHAPTER 22, Ontario Regulation 287/07. Royal Assent: October 19, 2006.

Ontario Ministry of the Environment and Ministry of Natural Resources (MOE and MNR). 2010. *Technical Bulletin: Part IX Local Area Risk Level*. Released April 2010. Accessible (July 19, 2010) at: www.ene.gov.on.ca/en/water/cleanwater/cwdocs/7611e.pdf

Ontario Ministry of Natural Resources and Ministry of Environment (MNR and MOE). 2011. *Water Budget & Water Quantity Risk Assessment Guide*. Prepared for the Ontario Ministries of Natural Resources and Environment by AquaResource Inc. Drinking Water Source Protection Program. 206 p. Accessible (April 4, 2014) at: http://www.waterbudget.ca/system/files/publications/2011_MNR_MOE_WaterBudgetGuide.pdf

Stantec Consulting Ltd. (Stantec). 2012a. *Tier Three Water Budget and Water Quantity Risk Assessment: Erb Street Well Field Characterization Study.* Report submitted to the Regional Municipality of Waterloo. January 2012.

Stantec Consulting Ltd. (Stantec). 2012b. *Tier Three Water Budget and Local Area Risk Assessment: Greenbrook Well Field Characterization Study*. Report submitted to the Regional Municipality of Waterloo. January 2012.

Stantec Consulting Ltd. (Stantec). 2012c. *Tier Three Water Budget and Local Area Risk Assessment: Parkway and Strasburg Well Fields Characterization Study.* Report submitted to the Regional Municipality of Waterloo. January 2012.

Stantec Consulting Ltd. (Stantec). 2011a*. Tier Three Water Budget and Local Area Risk Assessment: Cambridge Southwest Characterization Study.* Report submitted to the Regional Municipality of Waterloo. December 2011.

Stantec Consulting Ltd. (Stantec) 2011b. *Tier Three Water Budget and Local Area Risk Assessment: Cambridge Northwest Characterization Study*. Report submitted to the Regional Municipality of Waterloo. December 2011.

Stantec Consulting Ltd. (Stantec). 2009. *Tier Three Water Budget and Water Quantity Risk Assessment: Strange Street Well Field Characterization Study*. Report submitted to the Regional Municipality of Waterloo.

Watermark Numerical Computing. 2012*. Addendum to the PEST Manual*. May 2012.