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20.0 REGION OF WATERLOO TIER 3 WATER BUDGET AND RISK ASSSSMENT

This section describes the Region of Waterloo Tier 3 Water Budget and Local Area Risk Assessment, herein referred to as the Tier 3 Assessment, completed for the municipal drinking water systems of the Cities of Kitchener, Waterloo and Cambridge and rural communities of New Dundee, Conestogo, and Elmira, respectively. This project was undertaken to evaluate the current and future sustainability of the water supply wells, and to identify potential threats to the drinking water supplies from a quantity perspective.

20.1 Introduction

Tier 3 Assessments aim to determine if a municipality is able to meet their current and future water demands. Specifically, Tier 3 Assessments estimate the likelihood that a municipal drinking water aquifer or surface water feature (i.e., river or lake) can sustain pumping at their future pumping rates, while accounting for the needs of other water uses such as cold water streams, or other permitted water takers in the area. Tier 3 Assessments consider current and future municipal water demand, future land development plans, drought conditions, and other water uses as part of the evaluation.

Specific tasks completed for the Region of Waterloo's (Region) Tier 3 Assessment included the:

1. Development of detailed numerical models to predict whether or not municipal drinking water aquifers could meet current and future municipal water demands;

2. Evaluation of whether municipal drinking water sources can reliably pump their future (Allocated) pumping rates, while maintaining the requirements of other water uses (e.g. ecological requirements and other water takings);

3. Mapping of water quantity vulnerable areas (areas that contribute water to municipal drinking water systems) and assigning risk levels to those areas; and

4. Identification of water quantity threats that may influence the Region's ability to meet its future (Allocated) rates.

The Tier 2 Assessment for the Grand River Watershed completed by the GRCA (AquaResource, 2009a, 2009b) identified that a Tier 3 Assessment was required for the Central Grand River Subwatershed (groundwater systems for most of the cities of Kitchener, Waterloo and Cambridge as well as the community of New Dundee) as well as the rural communities of Elmira, West Montrose, and Conestogo. These areas are shown in Map 20-1.

The Region of Waterloo operates a total of twenty six (26) municipal drinking water systems that serve a total population of approximately 513,445 people (2009). The Integrated Urban System (IUS) is comprised of six municipal drinking water systems. It is an interconnected network of wells and a surface water intake on the Grand River in Kitchener (the Hidden Valley Surface Water Intake) which supplies the Mannheim Water Treatment Plant, reservoirs, and pumping stations. The IUS supplies water to approximately 488,342 (2009) people living in the communities of Cambridge, Kitchener, Waterloo, Elmira, Baden, New Hamburg and St. Jacobs. Fourteen (14) smaller water supply systems provide water to settlement areas not connected to the IUS, and which are located in the rural townships. There are three additional drinking water systems that are currently not active. In all, groundwater is currently extracted from 122 wells throughout the Region and one surface water intake. Together these sources are capable of supplying approximately 269,000 cubic metres of water a day. However, it is recognized that this number of wells may change in coming years as wells are decommissioned.

The following sections outline the steps taken in the Tier 3 Assessment to characterize the groundwater systems, develop and calibrate numerical modelling tools, and complete a water quantity risk assessment for the municipal groundwater supplies for the Region of Waterloo.

20.2 Groundwater and Surface Water Characterization

20.2.1 Topography and Physiography

The Waterloo Moraine is a topographic feature present within the western portions of the Region. The Grand River valley lies in the central and eastern portions of the Region and also forms a prominent topographic feature in the area.

The physiography of the Tier 3 Assessment study area was shaped by glacial advances and re-advances that ceased approximately 10,000 years ago. Fluvial erosion has also been active in shaping the landscape, especially along the Grand and Speed Rivers. Five dominant physiographic regions exist within the Tier 3 Assessment area as described by Chapman and Putnam (1984):

Waterloo Sand Hills (Waterloo Moraine) - the Waterloo Sand Hills lie in the central and western part of the Tier 3 Assessment area. The surface is composed of well drained hills of sandy till or sand and gravel filled kames or kame moraines, with thick sequences of outwash sands occupying the intervening hollows.

Guelph Drumlin Field - the Guelph Drumlin Field is located in the eastern portion of the Tier 3 Assessment area, on the east side of the Grand River, and is characterized by till drumlins fringed by gravel terraces and separated by swampy valleys.

Horseshoes Moraines - this region covers the southeastern portion of the Tier 3 Assessment area and is characterized in this area by the Galt and Paris moraines, and old spillways with broad gravel and sand terraces and swampy floors.

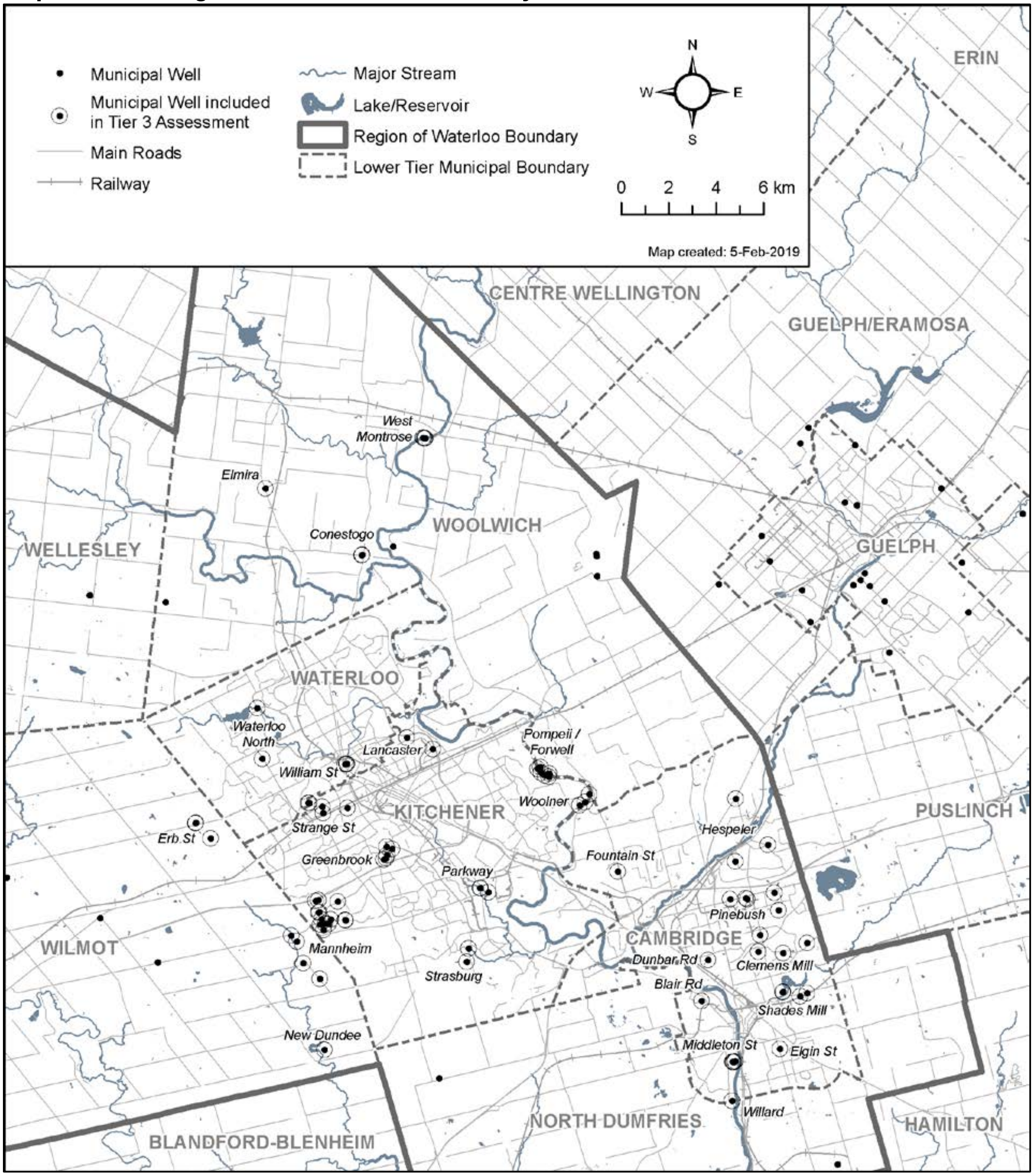
Oxford Till Plain - this region is located in the northern portions of the Region, west of the Grand River, and on the northern reaches of the City of Waterloo and is characterized as a slightly undulating, loam till plain.

Stratford Till Plain - this region is located in the northwestern and southwestern portions of the Region and is described as a level to slightly undulating silty-clay till or silt till plain that slopes gradually to the southwest.

20.2.2 Surface Water Features

Several large tributaries of the Grand River flow through the Region, including the Conestogo, Speed and Nith Rivers, as well as numerous smaller tributaries such as Alder Creek, Laurel Creek, Schneider Creek, Canagagigue Creek, Hunsberger Creek, Hopewell Creek and Mill Creek.

Map 20-1: Region of Waterloo Tier 3 Study Area



20.2.3 Geology and Hydrogeology

Geologic Overview

Bedrock beneath the Region consists of limestone, dolostone and shale Paleozoic bedrock formations that overlie deeply buried Precambrian basement rocks (Armstrong and Dodge, 2007). The Paleozoic bedrock formations dip regionally to the southwest (Johnson et al., 1992) and in most of the western portions of the Region outside Cambridge, the bedrock is deeply buried beneath thick Quaternary-aged overburden sediments. Paleozoic bedrock outcrops in the Cambridge area along the banks of the Grand River valleys, and in the southeast corner of the Region in the Rockton area.

Paleozoic bedrock formations that underlie the Region are listed in **Table 20-1**, with the youngest Formations listed at the top of the table and the oldest deposits at the bottom. Researchers at the Ontario Geological Survey (OGS) studied the bedrock formations within the Region (Brunton, 2008, 2009), and re-interpreted the depositional environment under which the formations were laid down. **Table 20-1** outlines the current understanding of the Paleozoic bedrock beneath the Region.

Table 20-1: Paleozoic Geology Beneath the Region of Waterloo

Previous Conceptualization		Revised Conceptualization		Lithology Description
Formation	**Member**	**Formation**	**Member**	
Bois Blanc Fm.		Bois Blanc Fm.		Grey-brown, cherty, thin- to medium-bedded and fine- to medium-grained fossiliferous limestone
Bass Island Fm.		Bass Island Fm.		Grey-buff, dense dolostone
Salina Fm.		Salina Fm.		Interbedded dolostone, mudstone and shale with lenses of evaporates
Guelph Fm.		Guelph	Hanlon	Cream coloured, medium- to thick-bedded, fossiliferous grainstones, wackestones, and reefal complexes
			Wellington	
Amabel	Eramosa	Eramosa	Stone Road	Cream coloured, coarsely crystalline dolostone
			Reformatory Quarry	Light brown-cream, thickly bedded, coarsely crystalline dolostone
			Vinemount	Grey-black, thinly-bedded, fine crystalline dolostone with shaley beds
	Wiarton / Colpoy / Lions Head	Goat Island	Ancaster	Grey, cherty, fine crystalline dolostone
			Niagara Falls	Fine crystalline, cross-laminated crinoidal grainstone with small reef mounds
		Gasport	Gothic Hill	Cross-bedded crinoidal grainstone-packstone with reef mounds and shell beds

Table 20-1: Paleozoic Geology Beneath the Region of Waterloo

Previous Conceptualization		Revised Conceptualization		Lithology Description
Formation	**Member**	**Formation**	**Member**	
		Rochester		Calcareous shale with carbonate interbeds
		Irondequoit		Thick-medium bedded crinoidal limestone
		Rockway		Green-grey fine crystalline argillaceous dolostone with shaley partings
		Merritton Fm.		Pinkish-brown, fine crystalline dolostone with shaley partings
Cabot Head / Reynales Fm.		Cabot Head Fm.		Grey-green non-calcareous shale interbedded with sandstone and limestone

(after Brunton, 2008, 2009)

Overburden units deposited during the Quaternary period (2 million to 10,000 years ago) detail a record of repeated ice advance and retreat of ice lobes that originated from the Huron-Georgian Bay and the Erie-Ontario lake basins (Bajc and Shirota, 2007). The overburden sediments within the Region range from Mid-Wisconsinan age fine and coarse textured tills to recently deposited coarse-grained sands and gravels along the banks of the Grand, Speed and Nith Rivers. The overburden units, as interpreted and outlined in Bajc and Shirota (2007), are listed in **Table 20-2** (from youngest to oldest). In the naming convention used by Bajc and Shirota (2007), the first two letters identify if the unit is interpreted as an aquitard (AT) or an aquifer (AF), while the latter two characters correspond to the sequence of the units, with A (and 1) as the youngest grouped sequence and F (and 3) as the oldest.

Descriptions of the geologic units within the Tier 3 Assessment area on a regional scale are described in Bajc and Shirota (2007), summarized in the Physical Characterization Summary Report (AquaResource 2009c), and discussed on the well field scale in the well field characterization reports (Blackport, 2012a, 2012b; Golder, 2011a, 2011b, 2011c; Stantec, 2009, 2012a, 2012b, 2012c).

Table 20-2: Overburden Geology within the Waterloo Moraine

OGS Layer Name	Interpreted Units	Predominant Materials
ATA1	Whittlesey clay	Silt and Clay
AFA1	Whittlesey sand	Very fine to coarse sand
ATA2	Wentworth Till (may contain abundant stratified drift)	Stony, sandy till
AFA2	Outwash deposits (mainly Grand River valley outwash)	Coarse sand and gravel
ATA3	Fine-grained deposits in the Grand River valley (beneath AFA2)	Sandy silt and silt
ATB1	Upper Maryhill Till, Port Stanley, Tavistock, Mornington and Stratford Tills	Silty to clayey till
AFB1	Upper Waterloo Moraine Stratified Sediments and equivalents	Fine sand, some gravel
ATB2	Middle Maryhill Till and equivalents	Silty to clayey till, silt, clay
AFB2	Middle Waterloo Moraine Stratified Sediments and equivalents	Fine sand, some gravel
ATB3	Lower Maryhill Till and stratified equivalents	Silty to clayey till, silt, clay
AFB3	Lower Waterloo Moraine Stratified Sediments or Catfish Creek Till Outwash	Sand, some gravel
ATC1	Upper / Main Catfish Creek Till	Stoney, silty to sandy till
AFC1	Middle Catfish Creek Stratified Deposits	Sand and gravel
ATC2	Lower Catfish Creek Till	Stoney, silty to sandy till
AFD1	Pre-Catfish Creek coarse-grained glaciofluvial/lacustrine deposits	Sand and gravel
ATE1	Canning Drift (till and fine-textured glaciolacustrine deposits)	Silty to clayey till, silt, clay
AFF1	Pre-Canning coarse-textured glaciofluvial/glaciolacustrine deposits	Sand and gravel
ATG1	Pre-Canning coarse-textured till	Stony, silty to sandy till

(after Bajc and Shirota 2007)

Hydrogeologic Overview

The Region contains overburden water supply aquifers that are primarily associated with coarse-grained sand and gravel deposits, and bedrock water supply aquifers that include the upper fractured bedrock horizon as well as the Guelph and upper to middle Gasport Formations. Aquitard units in the Region include fine-grained glacial tills and poorly transmissive bedrock units such as the Vinemount Member of the Eramosa Formation and the Cabot Head Formation.

Table 20-3 lists and describes the hydrostratigraphic units identified within the Region. Aquifer units listed are defined solely on the basis of the estimated ability of the unit to yield water and do not consider water quality or vulnerability to surficial contamination.

Table 20-3: Hydrostratigraphic Units in the Tier 3 Assessment Area

Layer Type	Unit Type	Interpreted Units	Predominant Materials
Overburden	Aquitard	Whittlesey clay (surficial geology) [ATA1]	Silt and clay
	Aquifer	Whittlesey sand [AFA1]	Very fine to coarse sand
	Aquitard	Wentworth Till (may contain abundant stratified drift) [ATA2]	Stony, sandy till
	Aquifer	Outwash deposits (mainly Grand River valley outwash) [AFA2]	Coarse sand and gravel
	Aquitard	Fine grained deposits in Grand River valley [ATA3]	Sandy silt and silt
	Aquitard	Upper Maryhill Till, Port Stanley Till, Tavistock Till, Mornington Till, etc [ATB1]	Silty to clayey till
	Aquifer	Upper Waterloo Moraine Stratified Sediments and equivalents [AFB1]	Mainly fine sand, some gravel
	Aquitard	Middle Maryhill Till and equivalents [ATB2]	Silty to clayey till, silt, clay
	Aquifer	Middle Waterloo Moraine Stratified Sediments and equivalents [AFB2]	Mainly fine sand, some gravel
	Aquitard	Lower Maryhill Till and stratified equivalents [ATB3]	Silty to clayey till, silt, clay
	Aquifer	Lower Waterloo Moraine Sediments or Catfish Creek Till Outwash [AFB3]	Sand, some gravel
	Aquitard	Upper/ Main Catfish Creek Till [ATC1]	Stoney, silty to sandy till

Table 20-3: Hydrostratigraphic Units in the Tier 3 Assessment Area

Layer Type	Unit Type	Interpreted Units	Predominant Materials
	Aquifer	Middle Catfish Creek Stratified Deposits [AFC1]	Sand and gravel
	Aquitard	Lower Catfish Creek Till [ATC2]	Stoney, silty to sandy till
	Aquifer	Pre-Catfish Creek coarse-textured glaciofluvial/ lacustrine deposits [AFD1]	Sand and gravel
	Aquitard	Canning Drift (till, associated fine-textured glaciolacustrine deposits) [ATE1]	Silty to clayey till, silt, clay
	Aquifer	Pre-Canning coarse-textured glaciofluvial/ glaciolacustrine deposits [AFF1]	Sand and gravel
	Aquitard	Pre-Canning coarse-textured till [ATG1]	Stony, silty to sandy till
Bedrock	Contact Zone Aquifer	Fractured bedrock and overlying basal unconsolidated deposits	Coarse-grained deposits on weathered bedrock
	Aquifer	Bois Blanc Fm.	Grey-brown, cherty, thin- to medium-bedded and fine- to medium-grained fossiliferous limestone
	Aquifer	Bass Island Fm.	Grey-buff, dense dolostone
	Aquifer/ Aquitard	Salina Fm.	Interbedded dolostone, mudstone and shale with lenses of evaporites
	Aquifer	Guelph Fm. and Stone Road Mbr, Eramosa Fm	Medium to thick bedded fossiliferous dolostone
	Aquifer/ Aquitard	Eramosa Fm; Reformatory Quarry Mbr	Thickly bedded, coarsely crystalline dolostone
	Aquitard	Eramosa Fm; Vinemount Member	Thinly, shaley bedded, fine crystalline dolostone
	Aquifer/ Aquitard	Goat Island Fm.	Chert-rich, fine crystalline dolostone and crinoidal grainstone
	Aquifer	Upper Gasport Fm.	Cross-bedded grainstone-packstone with sequences of reef mound and coquina lithofacies

Layer Type	Unit Type	Interpreted Units	Predominant Materials
	Aquifer	Middle Gasport Fm.	Cross-bedded grainstone-packstone with reef mounds and coquina lithofacies; High transmissivity
	Aquifer/ Aquitard	Lower Gasport Fm.	Cross-bedded grainstone-packstone with sequences of reef mound and coquina lithofacies

Table 20-3: Hydrostratigraphic Units in the Tier 3 Assessment Area

Stratigraphic units immediately below the Gasport include the Rochester, Irondequoit, Rockway and Merritton units which comprise a regional aquitard (< 5 m thick); this is further underlain by the Cabot Head Formation, which is considered to be a very low hydraulic conductivity shale unit. These units were excluded from the model; little exchange of water between the Gasport Formation and the underlying low hydraulic conductivity formations were interpreted.

The conceptual hydrostratigraphic framework presented in **Table 20-3** was used as the basis for the development of the groundwater models used in the Tier 3 Assessment. Further details are provided in Matrix and SSPA (2014a).

Local Characterization

Considerable work has been conducted in the Region over the last 40 plus years to refine the understanding of the geology and water resources. Historically, geological information from borehole logs was used to build or refine a conceptual geological model. In previous studies, the details regarding the depositional environments and/or structure of the Quaternary sediments throughout the Region were not examined in full detail. Key geologic units such as the Maryhill Till or the Catfish Creek Till were often used as “marker” units to attempt to interpret the vertical hydrostratigraphic location of sand and gravel (aquifer) units. These aquifer units were then laterally “connected” based on whether they were found above or below the more regional till units.

The geologic model evolved into a multi-aquifer system of aquifers separated by aquitards. The complexity of the multi-aquifer system was refined at individual well fields, usually by drilling several boreholes and installing numerous observation wells in different geologic units. Pumping tests or well field shut down tests were conducted, depending on operational constraints, and transmissivity and storage coefficients were estimated using the results of the pumping tests. Additional data on hydraulic conductivity values of various geologic units were obtained through response testing of monitoring wells, and in some cases local groundwater flow models were developed. In the last 10 to 15 years from when most of the work for this assessment was completed, broader-area models were developed to refine the conceptual geologic interpretation on a more regional scale.

As a part of the Tier 3 Assessment, 2 numerical groundwater flow models were developed: the Regional model and the Cambridge model. The Regional model was developed to simulate groundwater flow within the overburden and upper bedrock for the entire region, whereas the

Cambridge model was developed to analyze groundwater flow in the bedrock system in the vicinity of the City of Cambridge.

The three-dimensional Quaternary geologic model developed by the OGS (Bajc and Shirota, 2007) was used as the basis for the Regional conceptual model. This model contains 18 hydrostratigraphic units. The OGS hydrostratigraphic interpretation was incorporated into the Regional groundwater flow model; however, the number of overburden layers was reduced from 18 to twelve. **Table 20-4** describes the overburden layer designations used in the Regional groundwater flow model.

Similarly, the bedrock stratigraphic conceptualization developed by the OGS (Brunton, 2008, 2009) was used as the basis to characterize the hydrogeologic conditions throughout the Cambridge model domain. **Table 20-4** describes the bedrock layer designations used in the Cambridge groundwater flow model.

Table 20-4: Hydrostratigraphic Units in the Tier 3 FEFLOW Models

<table>
<tr><th rowspan="2">OGS Name</th><th rowspan="2">Interpreted Units</th><th colspan="2">Regional Model</th><th rowspan="2">Cambridge Model</th></tr>
<tr><th>Waterloo Moraine</th><th>Cambridge Area</th></tr>
<tr><td></td><td>Surficial Geology</td><td>Layer 1</td><td>Layer 1</td><td>Layer 1</td></tr>
<tr><td>ATA1</td><td>Whittlesey clay</td><td rowspan="5">Units not present in the Waterloo Moraine area.</td><td rowspan="3">Layers 2 and 3</td><td rowspan="3">Layer 2</td></tr>
<tr><td>AFA1</td><td>Whittlesey sand</td></tr>
<tr><td>ATA2</td><td>Wentworth Till (may contain abundant stratified drift)</td></tr>
<tr><td>AFA2</td><td>Outwash deposits (mainly Grand River valley outwash)</td><td>Layer 4</td><td rowspan="2">Layer 3</td></tr>
<tr><td>ATA3</td><td>Fine-grained deposits in the Grand River valley (beneath AFA2)</td><td>Layer 5</td></tr>
<tr><td>ATB1</td><td>Upper Maryhill Till, Port Stanley, Tavistock, Mornington and/or Stratford Tills</td><td>Layer 3</td><td>Layers 6 and 7</td><td>Layer 4</td></tr>
<tr><td>AFB1</td><td>Upper Waterloo Moraine Stratified Sediments and equiv.</td><td>Layer 4</td><td rowspan="3">Layers 8 and 9</td><td rowspan="3">Layer 5</td></tr>
<tr><td>ATB2</td><td>Middle Maryhill Till and equivalents</td><td>Layer 5</td></tr>
<tr><td>AFB2</td><td>Middle Waterloo Moraine Stratified Sediments and equivalents</td><td>Layers 6 and 7</td></tr>
<tr><td>ATB3</td><td>Lower Maryhill Till and stratified equivalents</td><td>Layer 8</td><td rowspan="3">Layers 10 and 11</td><td rowspan="3">Layer 6</td></tr>
<tr><td>AFB3</td><td>Lower Waterloo Moraine Stratified Sediments or Catfish Creek Till Outwash</td><td>Layer 9</td></tr>
<tr><td>ATC1</td><td>Upper/ Main Catfish Creek Till</td><td>Layer 10</td></tr>
</table>

Table 20-4: Hydrostratigraphic Units in the Tier 3 FEFLOW Models

OGS Name	Interpreted Units	Regional Model		Cambridge Model
		Waterloo Moraine	Cambridge Area	
AFC1	Middle Catfish Creek Stratified Deposits			
ATC2	Lower Catfish Creek Till			
AFD1	Pre-Catfish Creek coarse-grained glaciofluvial/lacustrine deposits	Layer 11	Layers 12 and 13	Layer 7
ATE1	Canning Drift- till and fine-textured glaciolacustrine deposits	Layer 12		
AFF1	Pre-Canning coarse-textured glaciofluvial/glaciolacustrine deposits	Layer 13		
ATG1	Pre-Canning coarse-textured till			
Bedrock	Contact Zone	Layer 14	Layer 14	Layer 8
	Bass Islands, Bois Blanc, Salina Formations	Layer 15 to 21	Formations not present	
	Guelph Formation		Layer 15	Layer 9
	Eramosa Fm., Reformatory Quarry Mbr.	Deeply buried beneath Waterloo Moraine (not part of active groundwater flow system; not simulated)	16	Layer 10
	Eramosa Fm., Vinemount Mbr.		17	Layer 11
	Goat Island Fm.		18	Layer 12
	Upper Gasport		19	Layer 13
	Middle Gasport		20	Layer 14
	Lower Gasport		21	Layer 15
	Cabot Head			

* Bedrock layers transition west of the Grand River (in the Cambridge area) to represent different bedrock units west and east of the moraine. In the Cambridge area, the Bois Blanc, Bass Island Formations and Salina Formations are present west of the Grand River (note: Salina is present east of the Grand River in areas north of Cambridge including Breslau). The remaining units in the table are present throughout the model domain but are deeply buried by overburden and bedrock west of the Waterloo Moraine, where active groundwater flow is interpreted to be negligible. Therefore, Layers 14 to 21 represent groundwater flow in the contact zone, Bois Blanc, Bass Island Formations and Salina Formations west of the Moraine, and layers 14 to 21 represent the Guelph, Eramosa, Goat Island and Gasport Formations in areas east of the Moraine.

Hydraulic conductivity values were assigned to the various hydrostratigraphic units based on data collected from pumping tests, response tests and values found in the literature for similar types of geologic materials. Average values were initially assigned to each hydrostratigraphic unit. The hydraulic conductivity estimation processes for the Regional Model and the Cambridge Model are described in Matrix and SSPA (2014a).

The model layer structures were further refined using additional detailed geologic and hydrogeologic characterization within and surrounding municipal wells (Golder, 2011a, 2011b, 2011c; Stantec, 2009, 2012a, 2012b, 2012c; Blackport, 2012a, 2012b). Cross-sections were generated and interpreted across the well field areas to refine the OGS model layer interpretations. Geologic, hydrogeologic, geochemical and hydraulic information was used to guide the interpretation of the continuity of the aquifers and aquitards and to refine the model layer structure within the well field areas. Boreholes were categorized into high, medium and low quality data, with geologic picks assigned for the various geologic units in each borehole. Data from high quality boreholes were preferentially used to refine the layer structure for each of the hydrostratigraphic units, with lesser quality data used to fill in areas where high quality data were limited.

The model was calibrated to long-term average annual conditions (steady-state) by reducing the discrepancies between the observed and model simulated groundwater elevations within a reasonable margin of error. Hydraulic conductivity values and/or model boundary conditions were adjusted based on available information to improve the fit between the observed and model-simulated groundwater elevations and streamflow values.

As part of the calibration, individual borehole logs were examined to identify potential areas where till units, for example, may have interbeds of gravel, sand or silt and may be less dense or competent than expected. In these areas, elevated hydraulic conductivity zones within the till layer were created to help achieve a better match between the observed and simulated groundwater elevations. Both the Regional and Cambridge models were calibrated to regional-scale and well-specific steady state calibration targets, as well as to transient well-specific pumping test responses.

In addition to the review of the borehole logs, local aquifer response tests were used to provide information on where the hydraulic conductivity values of a portion of an aquifer or aquitard unit may differ from the average value considered in the conceptual model. Pumping or shut down test data were examined to assess the hydraulic connections between aquifers, and between groundwater aquifers and nearby surface water features. Variability in the hydraulic conductivity zones within the test areas were evaluated using the water level responses in monitoring wells screened in different aquifer units or in surface water features.

Whenever available, water quality data were used to verify or refine the conceptual geologic and hydrogeologic models. Long-term general trends in water quality and local surficial sources of contamination were reviewed as part of this assessment. Knowledge of industrial contamination at some municipal wells was used to validate or help refine the local geologic and hydrogeologic conceptual models. The simulated groundwater flow field and gradients were reviewed to ensure the flow from the source area(s) were consistent with the understanding of elevated contaminant concentrations.

The calibration process and updates to the conceptual geologic and hydrogeologic models are discussed in more detail in Matrix and SSPA (2014a), and in the individual technical memoranda that summarize the steady-state and transient model calibration for each well field.

Groundwater Flow

Map 20-2 illustrates the model-simulated groundwater level elevation contours produced in the Regional steady-state groundwater flow model for the upper AFB2 (Middle Waterloo Moraine Sands) aquifer. As illustrated, groundwater level elevation contours generally mimic the ground surface topography, and flow converges toward the higher order streams and wetlands. The simulated groundwater elevation contours compare well with the observed elevation contours presented in AquaResource (2009d).

The largest groundwater flow gradients, represented as tightly spaced contours on **Map 20-2,** occur at regional discharge locations, which include the Grand and Speed Rivers. The lowest gradients occur on the till plains and areas further from the Waterloo Moraine.

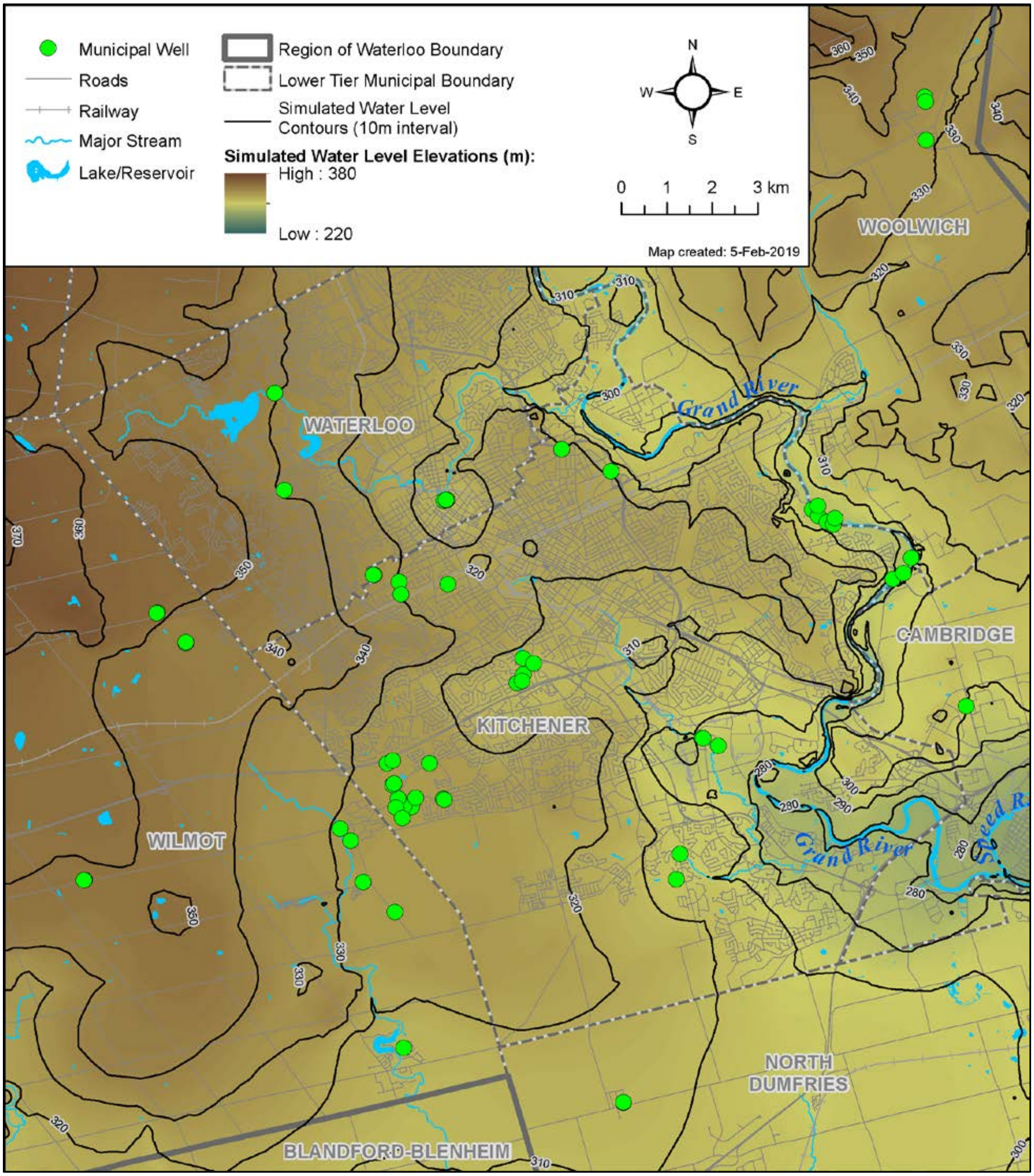
Map 20-3 illustrates the model-simulated deep aquifer groundwater level elevation contours from the Regional steady-state groundwater flow model for the lower AFD1 (Pre-Catfish Creek coarse-grained sediments) aquifer. The deep groundwater level elevation contours are similar but more subdued than the shallow elevations. The groundwater level elevation contours converge along the larger river valleys such as the Grand and Speed Rivers. The simulated groundwater elevation contours compare well with the observed elevation contours presented in AquaResource (2009d).

In the Cambridge area, the municipal wells are most commonly completed in the bedrock or the contact zone between the overburden and bedrock. The groundwater flow assessment discussed herein is therefore focused on the upper bedrock units.

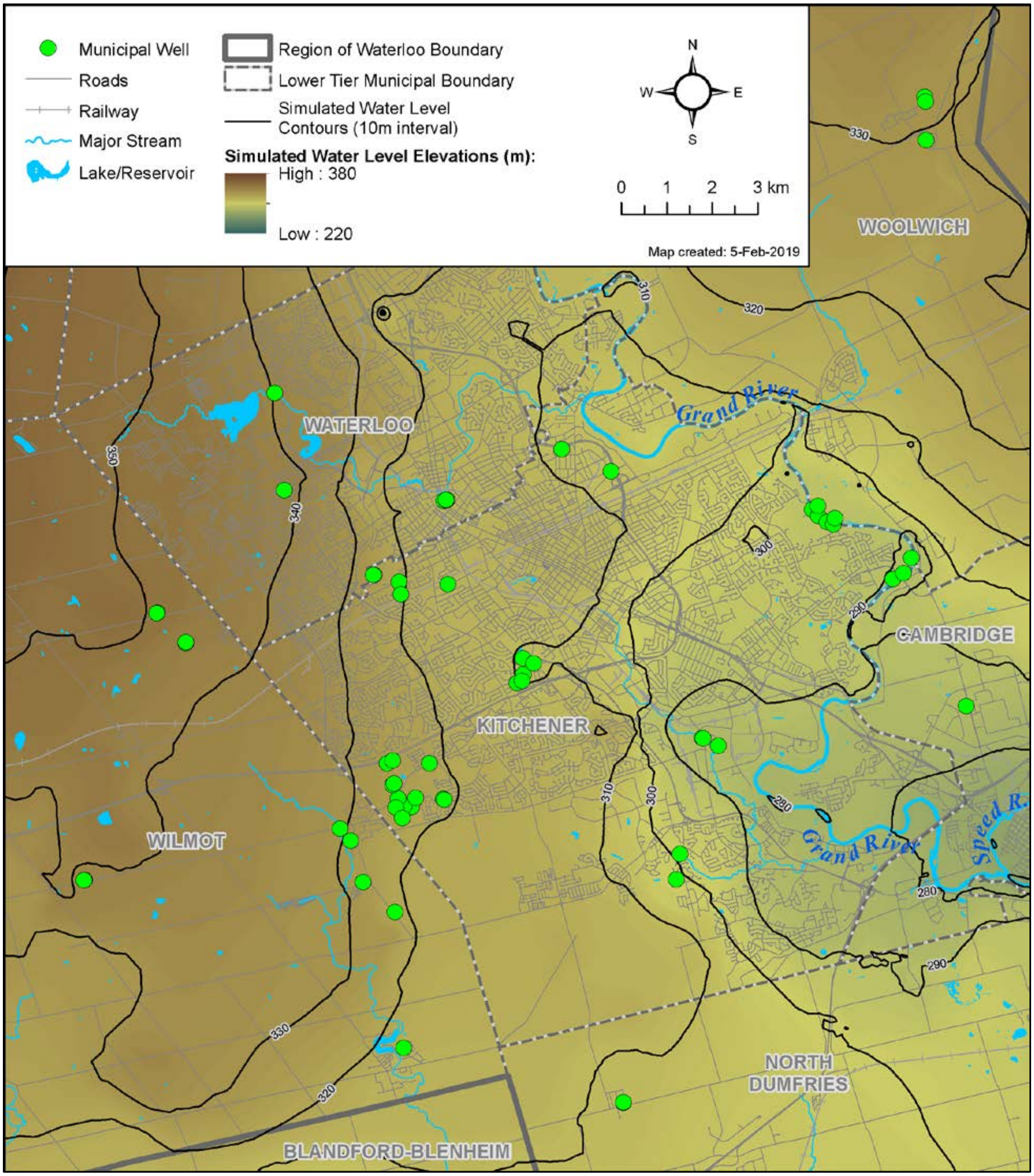
Map 20-4 illustrates the simulated shallow bedrock groundwater level elevation contours from the Regional steady-state groundwater flow model. The groundwater level elevation contours illustrate a north-south regional pattern with convergence from both the east and west on the Grand River valley. Modelling to date also simulated a broad area of low groundwater elevations south of the Strasburg Well Field, which may be associated with a buried bedrock valley in that area.

The simulated groundwater level elevations in the Upper Bedrock aquifer (Guelph Formation and Reformatory Quarry) in the Cambridge Model are presented on **Map 20-5**. The general trend of simulated groundwater flow in the Upper Bedrock Aquifer was toward the southwest, and groundwater elevation contours converge along the larger river valleys such as the Grand and Speed Rivers. This general trend is consistent with the interpreted groundwater flow direction for the area developed for the Guelph Formation (Golder, 2011b).

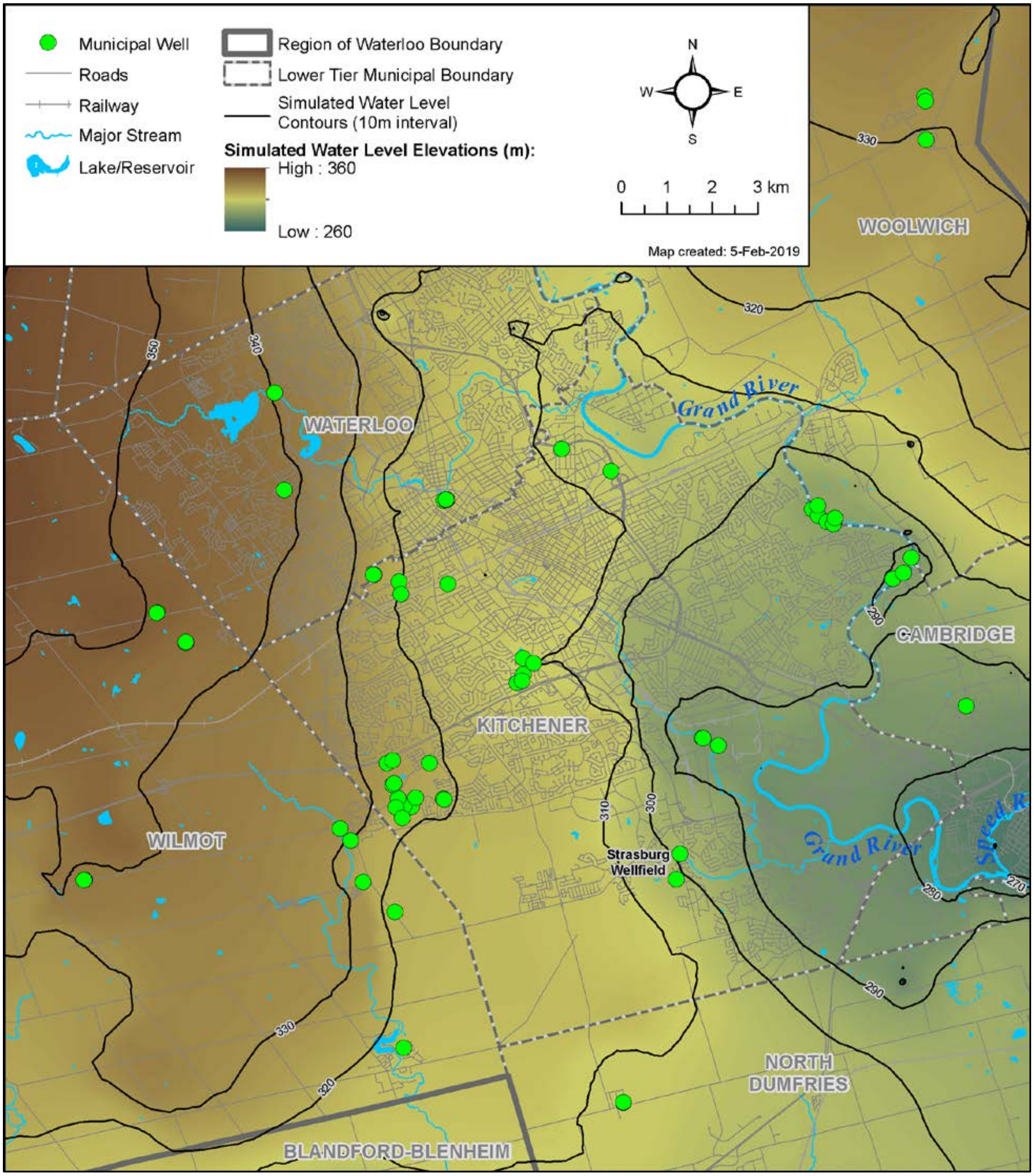
Map 20-2: Simulated groundwater level elevations for upper AFB2 aquifer



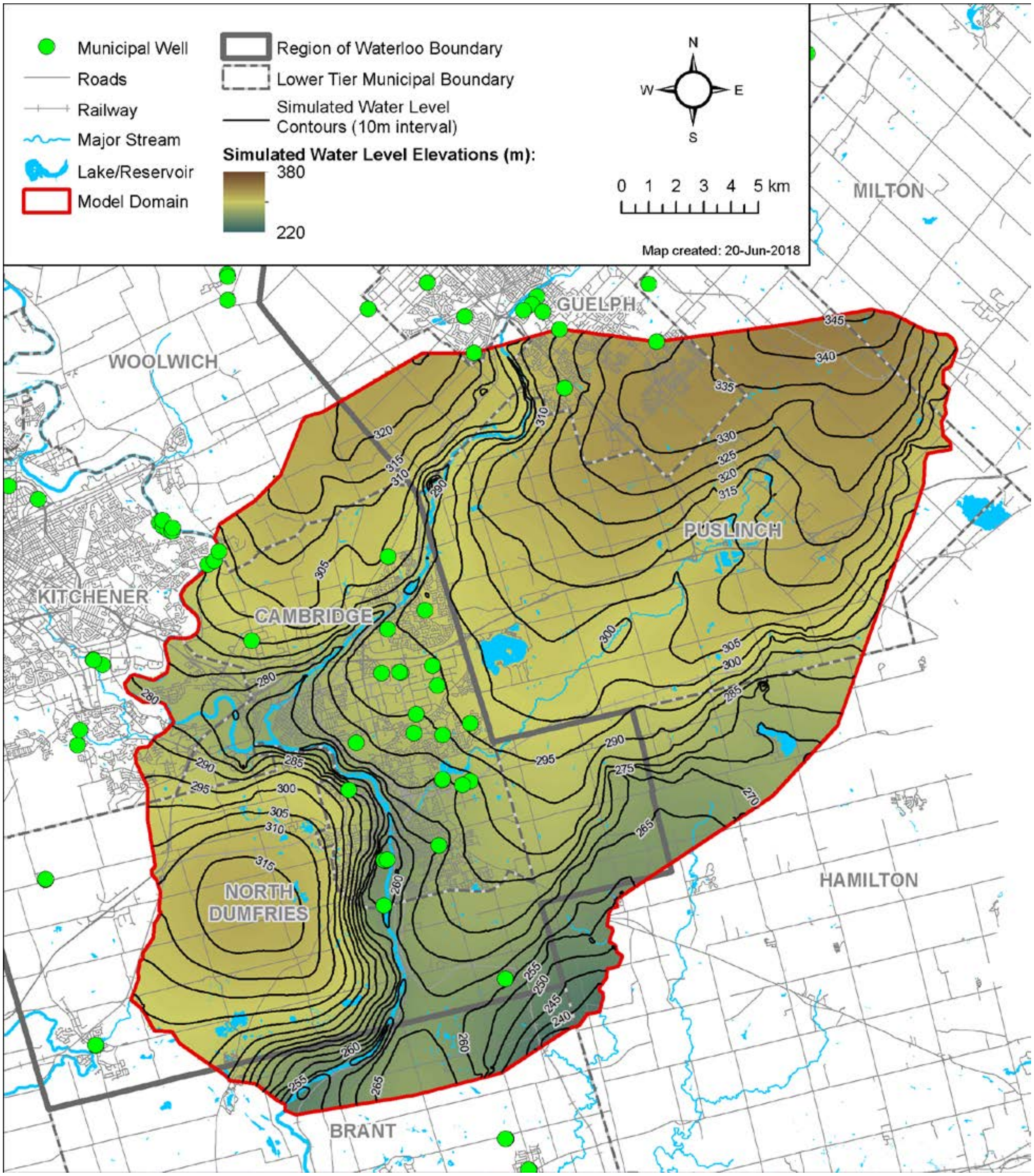
Map 20-3: Simulated groundwater elevations for aquifer AFD1



Map 20-4: Simulated shallow bedrock groundwater level elevation contours (Regional steady state groundwater flow model)



Map 20-5: Simulated groundwater level elevations in the Upper Bedrock aquifer (Guelph Formation and Reformatory Quarry) in the Cambridge Model



20.2.4 Water Demand and Other Water Uses

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. This section summarizes the known consumptive water takers identified in the Tier 3 study area, and separates them into permitted municipal and non-municipal water takings.

All municipal water supply wells within the Region are considered 100% consumptive as water is pumped from groundwater aquifers and discharged to the Grand River via waste water treatment plants. This is with the exception of the Aquifer Storage and Recovery (ASR) wells located in the Mannheim area. These wells were not simulated in the Tier 3 assessment, 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 from which it was derived.

As a part of the evaluation of water demands within the Tier 3 assessment area, ‘other’ non-consumptive water uses, such as groundwater discharge for the support of ecological needs, waste water assimilation, and/or to support recreational water uses, was considered. These other non-consumptive water uses are described further in this section.

Municipal Water Supply Systems

For the Region of Waterloo Tier 3 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 3 Assessment were undertaken. The exceptions to this are the wells at Shades Mill which weren’t operating in 2008. For those wells, 2009 average pumping rates were used for the assessment.

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.

Building on the LTWS update, as part of the Tier 3 Assessment, the allocated quantity of water (Allocated Rate) was evaluated for each existing groundwater well to meet projected 2031 water demands. The Allocated Rates for the WHPA-Q1 were established in accordance with the Provincial Technical Rules (MOE, 2009) and other Provincial guidance (MOE, 2013). The 2031 Allocated Rates were estimated based on an evaluation of the existing and future committed water demand up to the current lawful PTTW taking (MOE, 2013). All municipal pumping rates utilized in the Tier 3 assessment were within current permitted rates. As such, Planned Demands (i.e. demands exceeding permitted rates) were not included in this assessment.

The hydrologic and hydrogeologic responses to increases in municipal pumping associated with the 2031 Allocated Rates were assessed using the Tier 3 Regional and Cambridge numerical groundwater flow models.

The 2008 average annual pumping rates and the 2031 Allocated Rates listed in **Table 20-5** are the rates applied in the Risk Assessment Scenarios.

Table 20-5: 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
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

Table 20-5: 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)
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
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

Table 20-5: 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)**
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
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.

In addition to the groundwater pumping rates specified in **Table 20-5**, 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 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 3 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.

Non-Municipal Water Demand

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. 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.

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.

Non-Permitted Water Uses

The potential impacts of non-permitted groundwater takings (domestic, agricultural and commercial water wells) 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). Some wells that are located in serviced areas pre-date the supply of serviced water to these areas. Although these wells 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 models, 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).

Other Water Uses: Coldwater Streams and Provincially Significant Wetlands

The Tier 3 Assessment identified all other water uses and estimated the water quantity requirements for those uses where possible. Other water uses that were relevant to the Study Area included non-municipal groundwater takings (discussed previously), aquatic habitat, Provincially Significant Wetlands (PSWs), waste water assimilation, and recreational uses. The Province introduced the use of thresholds to evaluate identified other water uses. Thresholds applied in the Region's Tier 3 Assessment are discussed in the following sections.

Aquatic Habitat

A WHPA-Q1 can be designated as having a higher 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.

The Province prescribed specific baseflow reduction thresholds to 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 to 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 and MNR, 2010).

Map 20-6 shows streams mapped as cold water communities (GRCA) that 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 to the east of the Grand River and the cities of Kitchener and Waterloo. Within the Cambridge area, cold water streams examined in the Tier 3 Assessment included Mill Creek located to the northeast of the Grand River, Moffatt Creek, which is located to the south of the Shades Mill wells, and Blair and Cedar Creeks on the west side of the Grand River.

Provincially Significant Wetlands

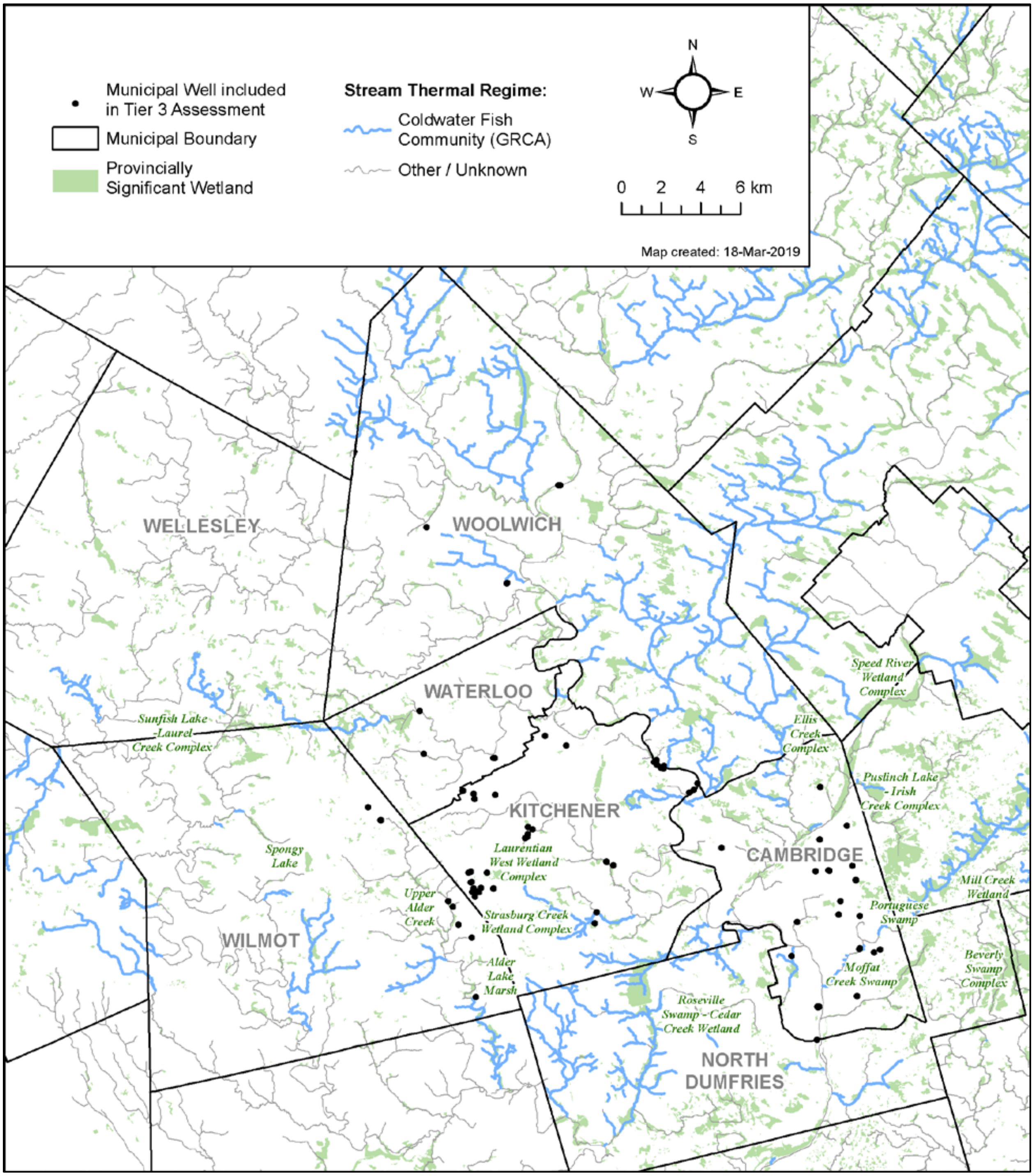
The Technical Rules (MOE, 2009) also identify PSWs as other water uses that, if significantly impacted by municipal pumping, would result in an elevated Risk Level for the WHPA-Q1.

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 which groundwater flow model (Regional or Cambridge) was applied to evaluate potential impact, are summarized in **Table 20-6.**

Table 20-6: Summary of Sensitive Wetland Features and Applied Modelling Tool

Complex	Sub-complexes	Wetland Type	Modelling Tool
Laurel Creek Complex	Sunfish Lake	Open Water,	Regional
Laurel Creek Complex	Sunfish Lake, Optimist	Bog	Regional
Mannheim Area	Laurentian West	Marsh, Swamp	Regional
Mannheim Area	Middle Alder Creek	Swamp	Regional
Mannheim Area	Upper Alder Creek	Swamp, Marsh	Regional
Roseville Swamp	Cedar Creek Wetland	Swamp, Marsh	Regional
Roseville Swamp	Roseville Swamp	Swamp (Marsh)	Regional
Spongy Lake		Fen, Bog, Marsh,	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	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

Map 20-6: Other Water Uses within the Region of Waterloo



20.2.5 Land Use and Land Use Development

Existing Conditions

The existing land use cover used in the Tier 3 Assessment was very similar to the land uses applied in the Tier 3 GAWSER surface water 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.

Future (Official Plan) Land Use

The Risk Assessment scenarios also included an assessment of the impact of future land use development, as specified in Official Plans, on municipal water sources (as of 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.

Land use development has the potential to reduce groundwater recharge. Region staff reviewed the future land use mapping and updated the land use classifications in some areas where development had occurred since 2008 (existing conditions).

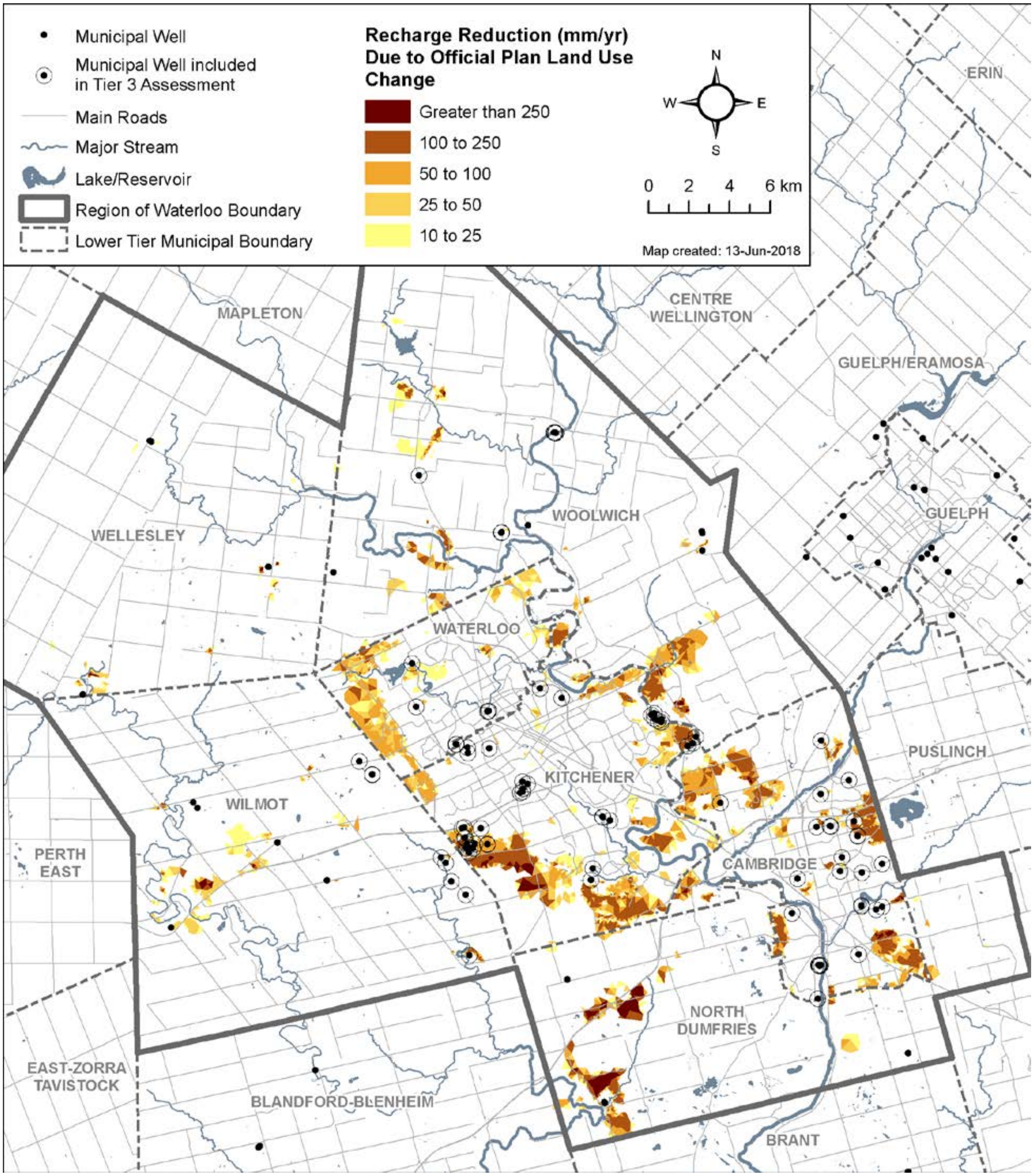
Changes in land uses from existing to revised Official Plan land uses were assessed to identify where changes in land use from existing to future conditions were expected. Changes in land use that lead to interpreted decreases in groundwater recharge (due to increases in imperviousness) were applied in the Tier 3 Assessment scenarios.

The groundwater flow model represented the changes in land use development by increasing or decreasing groundwater recharge proportionally to the percentage of impervious area. Each of the land use areas were assigned a perviousness value as described in the GAWSER Model Update Report (AquaResource, 2009b). **Table 20-7** 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 reductions arising when a parcel of land is developed. Recharge reductions were assumed to be equal to estimated percent impervious values.

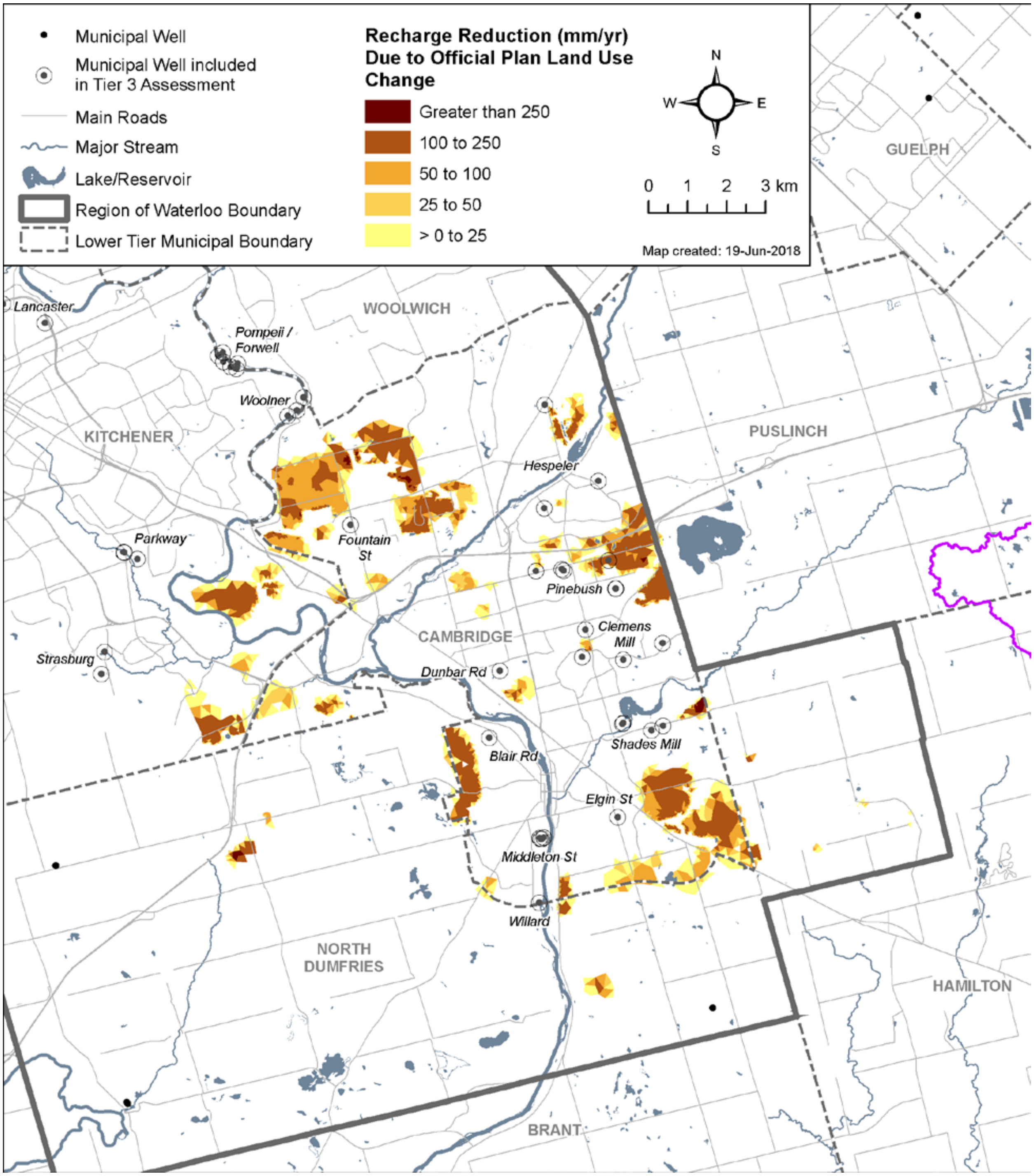
Map 20-7 and **Map 20-8** illustrate the spatial distribution of reductions in groundwater recharge between existing and future conditions for the Regional and Cambridge models, respectively. These distributions illustrate the extent that reductions in recharge are predicted to occur due to future land use development in the Region.

Table 20-7: 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%

Map 20-7: Recharge Reductions due to Land Use Changes in the Regional Model



Map 20-8: Recharge Reductions due to Land Use Changes in the Cambridge Model



20.3 Risk Assessment

20.3.1 Model Development and Application

Three numerical modelling tools were applied in the Region's Tier 3 Assessment. Specifically, one GAWSER hydrologic streamflow generation model was used to simulate surface water partitioning and streamflow generation and two FEFLOW groundwater flow models were used to simulate subsurface (groundwater) flow: the Regional and Cambridge models. Using these models, a combined modelling approach was adopted whereby the recharge (i.e. precipitation that infiltrates down into the groundwater flow system) estimated by GAWSER (as a simulated output) was used as a boundary condition input (i.e., the driving force) for the two FEFLOW models.

Calibration and verification of the GAWSER model was achieved using observed streamflow data from nine Water Survey of Canada (WSC) and GRCA gauges, as well as the observed groundwater levels. The model predicted reasonable water budgets (e.g., runoff, evapotranspiration, groundwater recharge) demonstrating that precipitation was realistically partitioned into the various hydrologic components.

Most natural components of the hydrologic cycle were explicitly included in the GAWSER model (i.e., precipitation, evapotranspiration, snow melt, overland flow, channel flow, unsaturated flow, interflow, and saturated flow), as well as some of the effects of human activity (i.e., land use, irrigation, and water usage). Further details on the GAWSER model development and calibration are provided in AquaResource (2009b).

Two consistent FEFLOW models were calibrated and implemented for the Region's Tier 3 Assessment. The first was the Regional Model which focused on the Waterloo Moraine overburden groundwater flow systems that supply the Kitchener-Waterloo municipal wells, but included the entire Region of Waterloo area. The second was the Cambridge Model which focused on the bedrock groundwater flow systems that supply the Cambridge municipal wells, and extended northeastward to include portions of the City of Guelph. These models have consistent layer structure, boundary conditions, and parameter values applied. Applying separate models for these two areas facilitated a greater focus on different water resources in each area, and facilitated progressing in parallel. The development and calibration of these two models are discussed in detail in Matrix and SSPA (2014a).

The Regional and Cambridge groundwater flow models were calibrated together so the models had consistent input values, and each model was able to reasonably replicate observed groundwater level elevations and streamflows. The Cambridge model was also compared to the City of Guelph/Guelph Eramosa Tier 3 groundwater flow model to ensure they produced similar results in areas where they overlapped. The groundwater flow models were calibrated at the well field scale to long-term average conditions, as well as time-varying conditions.

The wells used to calibrate the models included high quality water level data collected in the Region's Groundwater Monitoring Program (GMP). The models were also calibrated to groundwater discharge estimates collected from streamflow gauges, groundwater level elevations collected over time in municipal wells and monitoring wells, and to historic transient pumping tests for each supply system. In general, following the model calibration, the hydraulic properties and layer structure from the Cambridge Model were applied in the Regional Model to ensure consistency between the two models.

The groundwater flow models were used to simulate groundwater flow conditions across the Region and to conduct the required Tier 3 Risk Assessment scenarios for the municipal wells in the Local Areas. The following sections describe the risk assessment results.

20.3.2 Risk Assessment Results

Vulnerable Areas

The first step in the Risk Assessment was the delineation of vulnerable areas. Water quantity vulnerable areas were delineated to protect the quantity of water required by the Region's existing and Allocated Rates. The results of the WHPA-Q1 delineations are described in the following sections.

WHPA-Q1

The differences in the model-simulated groundwater level elevations in each aquifer model layer under the non-pumping and pumping conditions were defined 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 encompassed the full extent of the zone of influence associated with the Allocated Rates.

The average observed seasonal groundwater level elevation fluctuations in monitoring wells completed in the overburden production aquifers of the Waterloo Moraine is approximately 2 m. Therefore, a 2 m drawdown contour interval was selected for use in delineating the WHPA-Q1 as a variation of at least 2 m in observed groundwater water level elevations 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 3 Assessment.

The Cambridge Model was designed to also include the simulated responses to municipal pumping within the nearby City of Guelph by applying boundary conditions in the Cambridge Model that were representative of pumping groundwater level elevations in the City of Guelph Tier 3 Assessment 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 3 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 level elevations within each of the modelled aquifers was estimated and contoured.

The average observed seasonal groundwater level elevation fluctuations for monitoring wells completed in bedrock and deep overburden production aquifers within the Cambridge area is approximately 2 m. Therefore, the 2 m drawdown contour interval was selected for use in delineating the WHPA-Q1 for the Cambridge municipal wells, because a variation of at least 2 m in observed groundwater level elevations would be required before considering whether the change was due to increased pumping or seasonal variability.

Four WHPA-Q1 areas lie within the Region as illustrated on **Map 20-9**. The westernmost is WHPA-Q1A, which underlies the western portions 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 Cambridge, and extends in a northwestward direction toward Guelph. The WHPA-Q1B extends into Guelph, as the northern model boundary condition for the Cambridge Model coincides with the pumped groundwater level elevations for the aquifers in Guelph. As a result, the drawdown associated with groundwater pumping in Guelph was simulated in the Cambridge Model. The Guelph Tier 3 Assessment model 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 (**Map 20-9**).

The WHPA-Q1 for Guelph is considered more representative of the drawdown in the vicinity 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 than the drawdown simulated in the Guelph Model. The Grand River marked the southwestern limit of the Guelph 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.

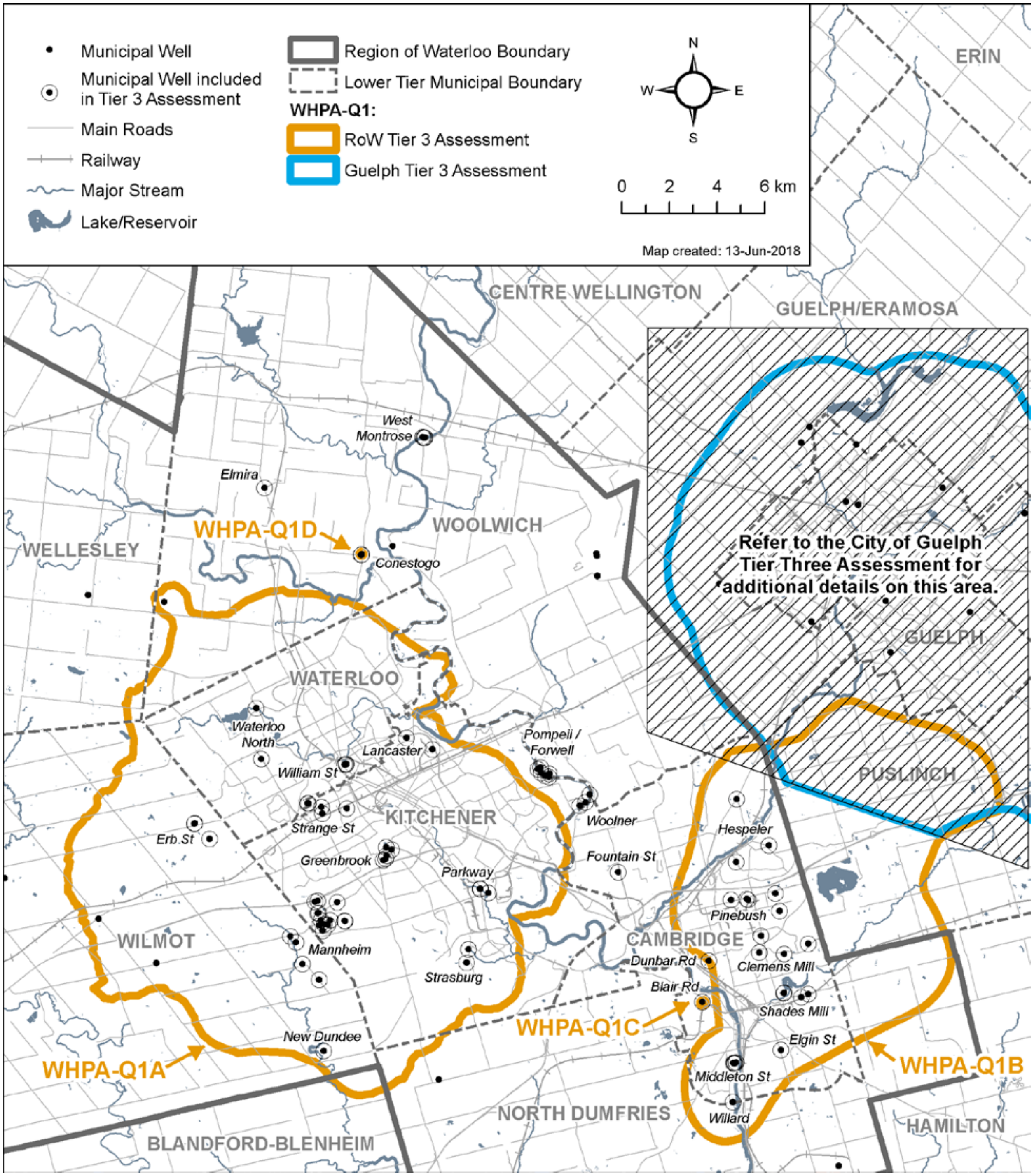
Review of the simulated groundwater level elevation contours in both the Cambridge and Guelph Models identified a groundwater divide within the Gasport Formation between the two cities. The gradient in this area is shallow and changes in groundwater demand in this area, or within the two cities, has the potential to shift the location of this inferred groundwater flow divide. Additional studies may need to 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 Guelph's water supply sources, as well as other water uses, including coldwater streams and wetlands.

The WHPA-Q1C 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.

The WHPA-Q1D 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-Q1D (Conestogo) area.

Following the delineation of the vulnerable areas, a series of Risk Assessment scenarios were completed to assess: changes in groundwater level elevations at the municipal wells, and changes in groundwater discharge to specified surface water features. The predicted changes in groundwater level and groundwater discharge values were compared to an established set of drawdown and ecological thresholds to determine whether the predicted changes were acceptable or not. The following sections summarize the results of the Region's Tier 3 Risk Assessment.

Map 20-9: Vulnerable Area: WHPA-Q1



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. Where the safe additional drawdown is low, 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 additional drawdown predicted in each of the Risk Assessment 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 level elevations in the wells in the existing conditions scenario (Scenario C) and the groundwater level elevations at the end of each model scenario were recorded as the additional predicted drawdown. For the transient scenarios, the lowest simulated groundwater level elevation in the aquifer at each municipal pumping well was compared to the water level in Scenario C. 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.

In all Risk Assessment scenarios, the predicted drawdowns were 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.

Ecological Thresholds – Stream Baseflow

The Province has developed prescribed specific baseflow reduction thresholds. These thresholds were applied when assigning Risk Levels associated with predicted impacts to cold water fish community streams due to increased municipal pumping. For cold water streams, a Moderate Risk Level was assigned when groundwater discharge was predicted to be reduced by at least 10% of existing monthly stream baseflow. Potential baseflow reductions on cold water streams due to changes in land use conditions were not taken into account when assigning the Risk Level through the Tier 3 Risk Assessment; such impacts are reviewed for information purposes only.

Map 20-6 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.

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 discharges under Scenario G2 to the groundwater discharges predicted under Scenario C (Existing Conditions). The differences in these groundwater discharge values were then normalized by the observed baseflow value to estimate the percent groundwater reduction (or increase).

Table 20-8 summarizes the steady-state model scenario results with respect to predicted reductions in groundwater discharges 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. Scenario G1 refers to reduced recharge and municipal wells pumping at their allocated rates; Scenario G2 refers to existing recharge and municipal wells pumping at their allocated rates, and Scenario G3 refers to reduced recharge, municipal wells pumping at existing demand, and other permitted water users pumping at their anticipated demand.

Under Scenario G2, the predicted reduction to groundwater discharge, relative to current conditions, to reaches hosting cold water fish communities, were 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 in this document as water is simulated in the groundwater flow model to flow out of these surface water features into the underlying groundwater flow system, 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, 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 realized if land use development were to take place without any mitigating factors.

Table 20-8: 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%*

Table 20-8: Impacts to Groundwater Discharge - Regional Model				
Reach	**Thermal Regime**	**Simulated Discharge (% Reduction)**		
		Scenario G1	**Scenario G2**	**Scenario G3**
Freeport Creek	*Warm water*	*10%*	*0%*	*10%*
Laurel Creek	*Warm water*	*8%*	*8%*	*1%*
Schneider Creek	*Warm water*	*3%*	*1%*	*2%*
Shoemaker Creek	*Warm water*	*19%*	*17%*	*4%*

Table 20-9 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 discharges, relative to current conditions, to reaches hosting cold water fish communities, were 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, Moffatt Creek was predicted to have a 13% reduction in groundwater discharge due to recharge reduction.

Table 20-9: 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%*

Ecological Thresholds – Provincially Significant Wetlands

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

In this assessment, the predicted changes in groundwater level elevations beneath wetland complexes (see **Table 20-10**), in each of the Risk Assessment scenarios, were noted and tabulated. The companion Model Calibration and Water Budget Report (Matrix and SSPA, 2014a) provides additional information on the wetland features of interest listed in **Table 20-10**.

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 level elevations provides a quantitative measure of how the function of wetlands may potentially change.

The changes in groundwater level elevations between the model simulated groundwater level elevations under Scenario C (existing land use and municipal pumping) and Scenario G2 (existing land use and Allocated Rates) were evaluated and are summarized in **Table 20-10**. 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 directions of vertical hydraulic gradients (recharge or discharge) are also summarized in **Table 20-10**. In all steady-state scenarios, no changes in gradients were predicted at any of the wetland complexes.

In general under Scenario G2, municipal pumping was simulated to reduce the water level elevation on average less than 10 cm at 14 of the 18 wetlands assessed. 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, Spongy Lake, and Portuguese Swamp. 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 level elevation beneath the wetland of approximately 0.9 m.

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 groundwater 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 groundwater 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;) include the Laurentian West Wetland near Mannheim, and the Mill Creek Wetland in Cambridge. 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. The same impacts due to land use development were noted in several other areas of the Region, stressing the importance of mitigative measures.

Table 20-10: Summary of Wetland Impacts for Steady-State Risk Assessment

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

WHPA-Q Risk Level

The WHPA-Qs for the Region of Waterloo with area of land use change are illustrated on **Map 20-10**. The Risk Level classification applied to the WHPA-Qs 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.

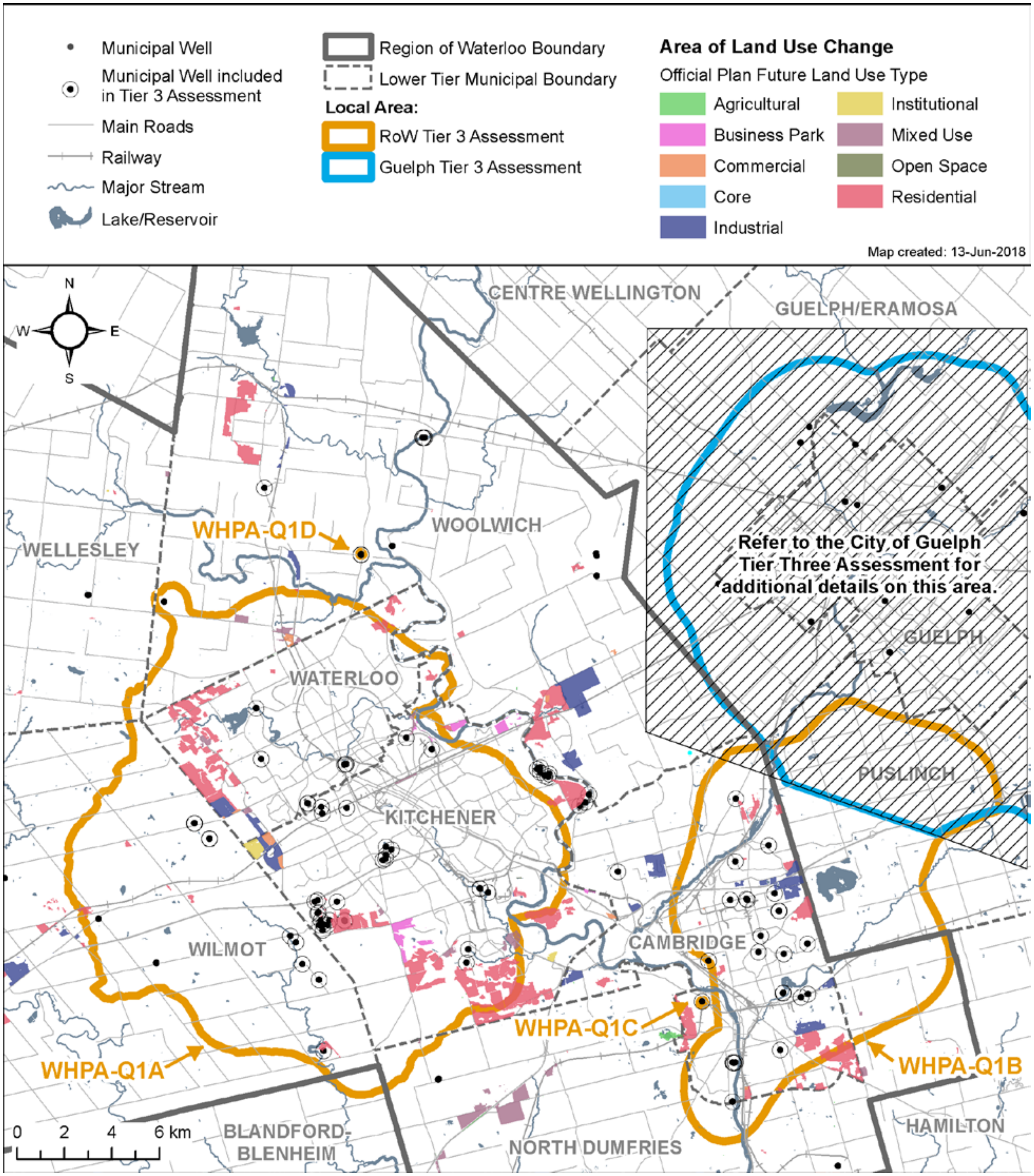
Risk Level Circumstances

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 stream baseflow value, and the reductions in groundwater level elevations beneath the PSWs was considered low enough that a Moderate Risk Level was not warranted.

Consequently, the four WHPA-Q1s 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.

Map 20-10: Vulnerable Area: WHPA-Q1 with Area of Land Use Change



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. Three alternative calibrated model realizations were developed for the Regional Model and for the Cambridge Model. 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, 2014a) 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.

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. 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 WHPA-Q1s. Further details on these assessments are available in the Tier Three Water Budget and Local Area Risk Assessment Report (Matrix and SSPA, 2014b)

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 WHPA-Q1s within the Region was considered appropriate, and consequently, the uncertainty associated with the Risk Level was Low.

20.3.3 Significant Groundwater Recharge Areas

A Significant Groundwater Recharge Area (SGRA) is defined as a specific type of vulnerable area on the landscape which has a hydrologic connection to an aquifer that is a source for a municipal drinking water system. A threshold of 115% of the average groundwater recharge rate was used to define SGRAs. The groundwater recharge rate was estimated using the regional GAWSER streamflow generation model. This methodology was used to delineate SGRAs in the Tier 2 Water Budget and Water Quantity Stress Assessment (AquaResource, 2009b), and so the same threshold was used in the Tier 3 Assessment, to maintain consistency between the two studies.

Delineation of SGRAs is limited by the processes used by the GAWSER model to estimate recharge, the mapping used to create hydrologic response units, and the climate data available. The hydrologic model is a simplification of natural processes. Advancements in the Tier 3 models allowed for better representation of evapotranspiration rates both in sandy soils and clay/silt soils. The updated model also incorporated a better representation of overland runoff estimates to include factors such as land slope, surface roughness, soil water content, and infiltration potential.

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 below ground surface. In the remaining distribution small, spurious polygons were removed; an area of less than 0.4 ha (4,000 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 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.

Central Grand Assessment Area

SGRAs are delineated on a subwatershed-scale to protect the broader landscape. **Map 20-11** shows the SGRAs mapped as a part of the Tier 3 Assessment 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 2 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 3 SGRA threshold value reflects updated characterization and increased refinement. Second, the Tier 3 threshold was estimated specific to the simulated recharge of the Central Grand Subwatershed, whereas the Tier 2 value was calculated considering the Grand River Watershed as a whole.

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.

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 2 Study (AquaResource, 2009a) was 202 mm/year, which considered the entire Grand River Watershed.

The spatial distribution of SGRAs in the Canagagigue Creek Subwatershed is presented on **Map 20-12**. 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.

20.3.4 Risk Management Measures Evaluation

The Risk Management Measures (RMM) Evaluation Process is completed following the Tier 3 Assessment to inform the policy development process. The goal of the evaluation is to identify and assess alternative Risk Management Measures that would effectively manage the Significant water quantity threats within vulnerable areas that have Significant Risk Levels. The key deliverable from the RMM evaluation is a Threats Management Strategy that provides guidance to the Source Protection Committee to establish policies that will help ensure the long-term sustainability of the municipal drinking water supplies.

In the Region of Waterloo, the risk level was determined to be low and as a result, a RMM evaluation was not required.

20.4 Section Summary

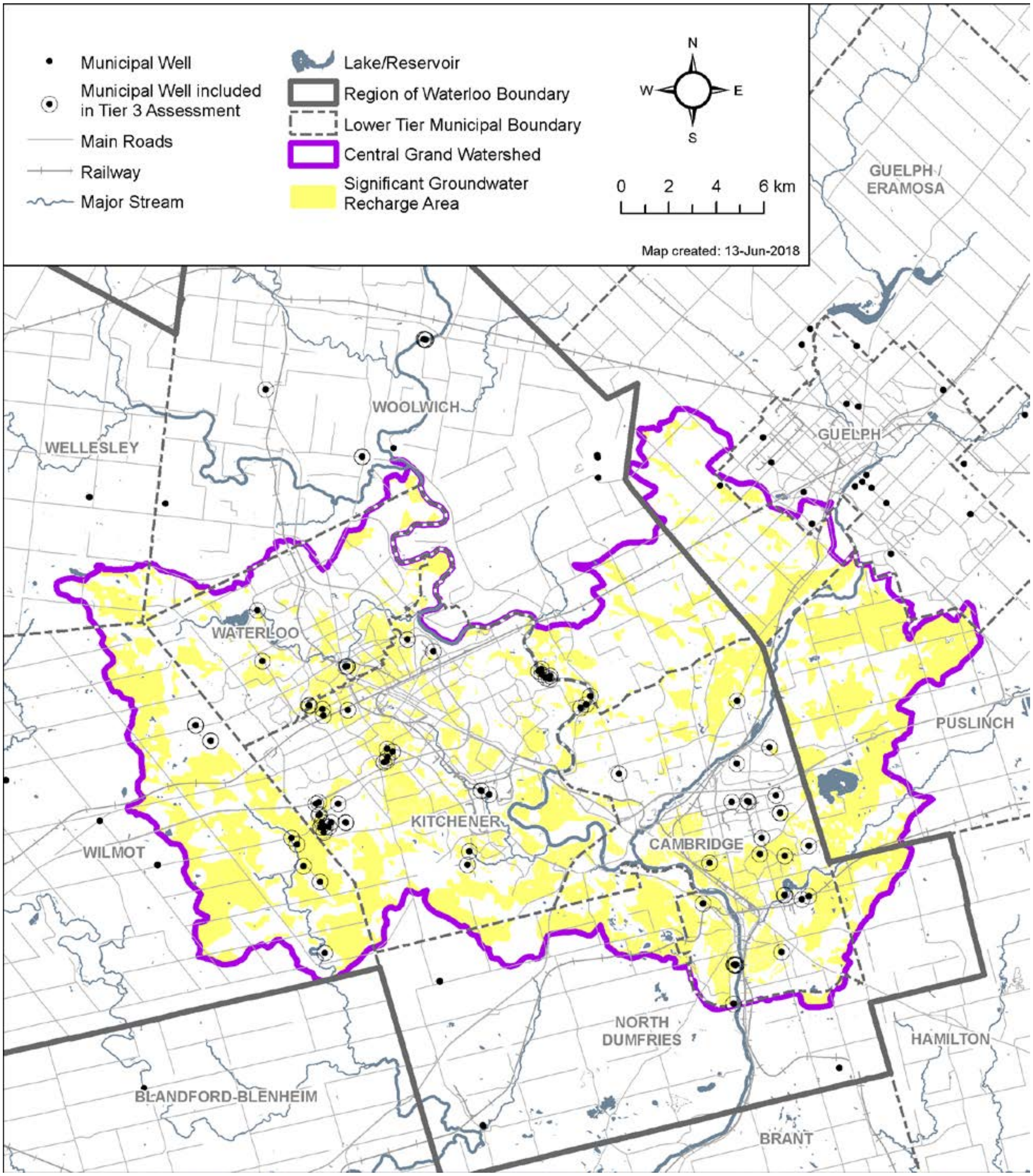
Four WHPA-Q1's were delineated for the various municipal supply wells within the Tier 3 study area as shown on **Map 20-10**. The areas were delineated following the Province's Technical Rules (MOE, 2009), based on a combination of the cone of influence of each municipal well, as well as land areas where reductions in recharge have 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 WHPA-Q1s within the Region of Waterloo as having a Low Risk Level. The Low Risk Level is considered appropriate for the WHPA-Q1A (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.

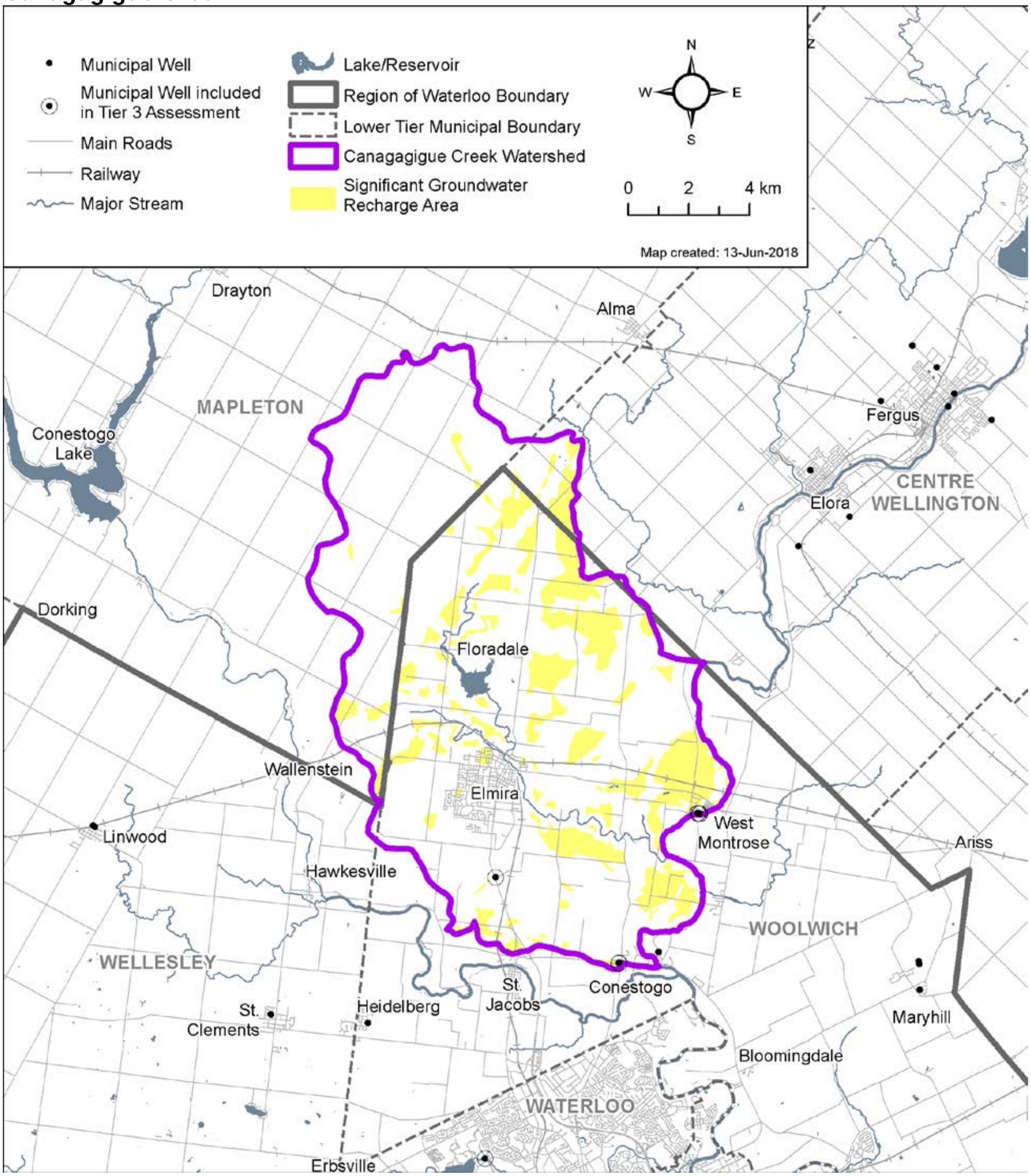
Similarly, the municipal wells located within WHPA-Q1B (i.e., Cambridge wells) are completed within productive overburden and bedrock units that are able to transmit volumes of water on a long-term basis that more than meet the 2031 demands, without causing negative impacts on other water uses. WHPA-Q1C and WHPA-Q1D (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 WHPA-Q1s were not classified as Significant or Moderate water quantity threats. The potential reductions to groundwater discharges 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 identify areas where groundwater recharge and discharge are predicted to be most sensitive to land use changes, and where the Region or the GRCA may wish to more closely monitor baseflow or stream flow in the future.

Map 20-11: Spatial Mapping of Significant Groundwater Recharge Areas of Central Grand



Map 20-12: Spatial Mapping of Significant Groundwater Recharge Areas of Canagagigue Creek



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