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19.0 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.

19.1 Introduction

The purpose of a Tier 3 Assessment is 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 well or intake can sustain pumping at their predicted future pumping rates, while ensuring the needs of other existing water uses such as cold water streams, or other permitted water takers in the area can be met. 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 include:

1. Development of detailed numerical models;
2. Evaluation of whether municipal drinking water sources can reliably pump their future pumping rates, while maintaining the requirements of other water uses (e.g. ecological requirements and other water takings); and
3. Delineation of water quantity vulnerable areas (areas that contribute water to municipal drinking water systems) and assigning risk levels to those areas.

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) and the Canagagigue Subwatershed (groundwater systems for Elmira and Conestogo). These areas are shown in **Map 19-1**.

A full description of the Region of Waterloo's drinking water system is presented in Section 8.0 of the Assessment Report. In 2009, the assessment year for the Tier 3 Assessment, the Region of Waterloo operated a total of twenty six (26) municipal drinking water systems that serve a total population of approximately 513,445 people. 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). 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 portions of settlement areas not connected to the IUS, and which are located in the rural townships. There are two 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.

19.2 Groundwater and Surface Water Characterization

19.2.1 Topography and Physiography

The physiography of the Tier 3 Assessment study area was shaped by glacial advances and re-advances that ceased approximately 10,000 years ago. 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.

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.

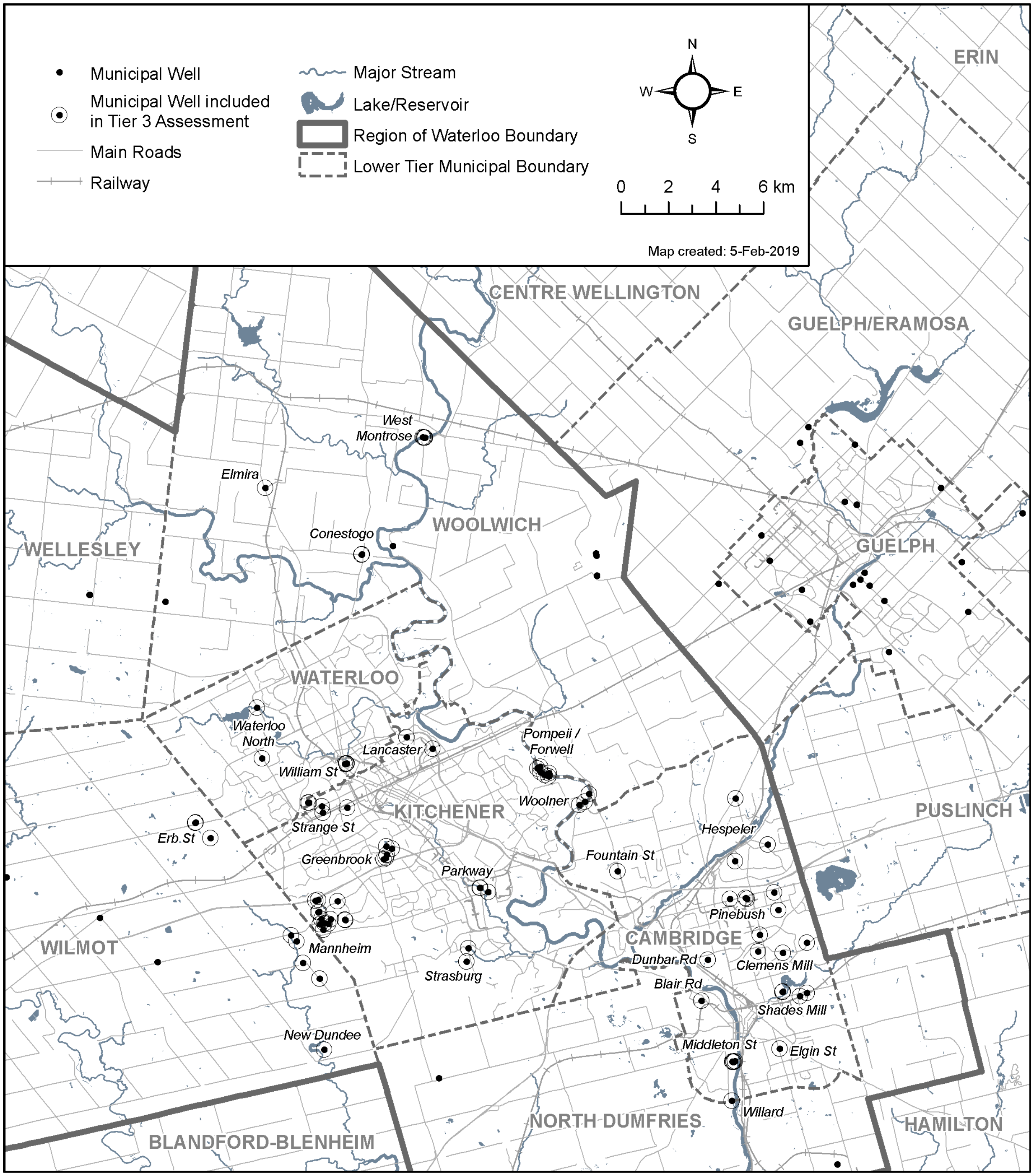
Oxford Till Plain - this region is located in the northern portions of the Region, west of the Grand River, and on the northern reaches of the City of Waterloo and is characterized as a slightly undulating, loam till plain.

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.

19.2.2 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 19-1: Region of Waterloo Tier 3 Study Area



19.2.3 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.

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 fine and coarse textured tills to coarse-grained sands and gravels along the banks of the Grand, Speed and Nith Rivers.

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).

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 19-1 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. The overburden units, as interpreted and outlined in Bajc and Shirota (2007), are also listed in **Table 19-1** (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.

Table 19-1: 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

Table 19-1: Hydrostratigraphic Units in the Tier 3 Assessment Area

Layer Type	Unit Type	Interpreted Units	Predominant Materials
	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
	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

Table 19-1: Hydrostratigraphic Units in the Tier 3 Assessment Area

Layer Type	Unit Type	Interpreted Units	Predominant Materials
	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
	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

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 as there was little exchange of water between these units and the aquifers used for municipal water supply

Further details on the hydrostratigraphic framework for Waterloo Region is 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.

Over time 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 and hydraulic properties estimated. 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. As a part of the Tier 3 Assessment, two 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 19-1** 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 19-2** describes the hydrostratigraphic units used in the both the Regional and Cambridge models. It is important to note that the identification of layers in each model while covering the same geologic units were somewhat different to account for the different focus of each model.

Table 19-2: 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>
</table>

Table 19-2: Hydrostratigraphic Units in the Tier 3 FEFLOW Models

OGS Name	Interpreted Units	Regional Model: Waterloo Moraine	Regional Model: Cambridge Area	Cambridge Model
ATB1	Upper Maryhill Till, Port Stanley, Tavistock, Mornington and/or Stratford Tills	Layer 3	Layers 6 and 7	Layer 4
AFB1	Upper Waterloo Moraine Stratified Sediments and equiv.	Layer 4	Layers 8 and 9	Layer 5
ATB2	Middle Maryhill Till and equivalents	Layer 5		
AFB2	Middle Waterloo Moraine Stratified Sediments and equivalents	Layers 6 and 7		
ATB3	Lower Maryhill Till and stratified equivalents	Layer 8	Layers 10 and 11	Layer 6
AFB3	Lower Waterloo Moraine Stratified Sediments or Catfish Creek Till Outwash	Layer 9		
ATC1	Upper/ Main Catfish Creek Till	Layer 10		
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			

Table 19-2: Hydrostratigraphic Units in the Tier 3 FEFLOW Models

OGS Name	Interpreted Units	Regional Model		Cambridge Model
		Waterloo Moraine	Cambridge Area	
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.

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.

All of the above information was used as part of the calibration process. 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. 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.

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 19-2 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 which is the largest overburden aquifer used for municipal supply for Kitchener and Waterloo. 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 19-2,** 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.

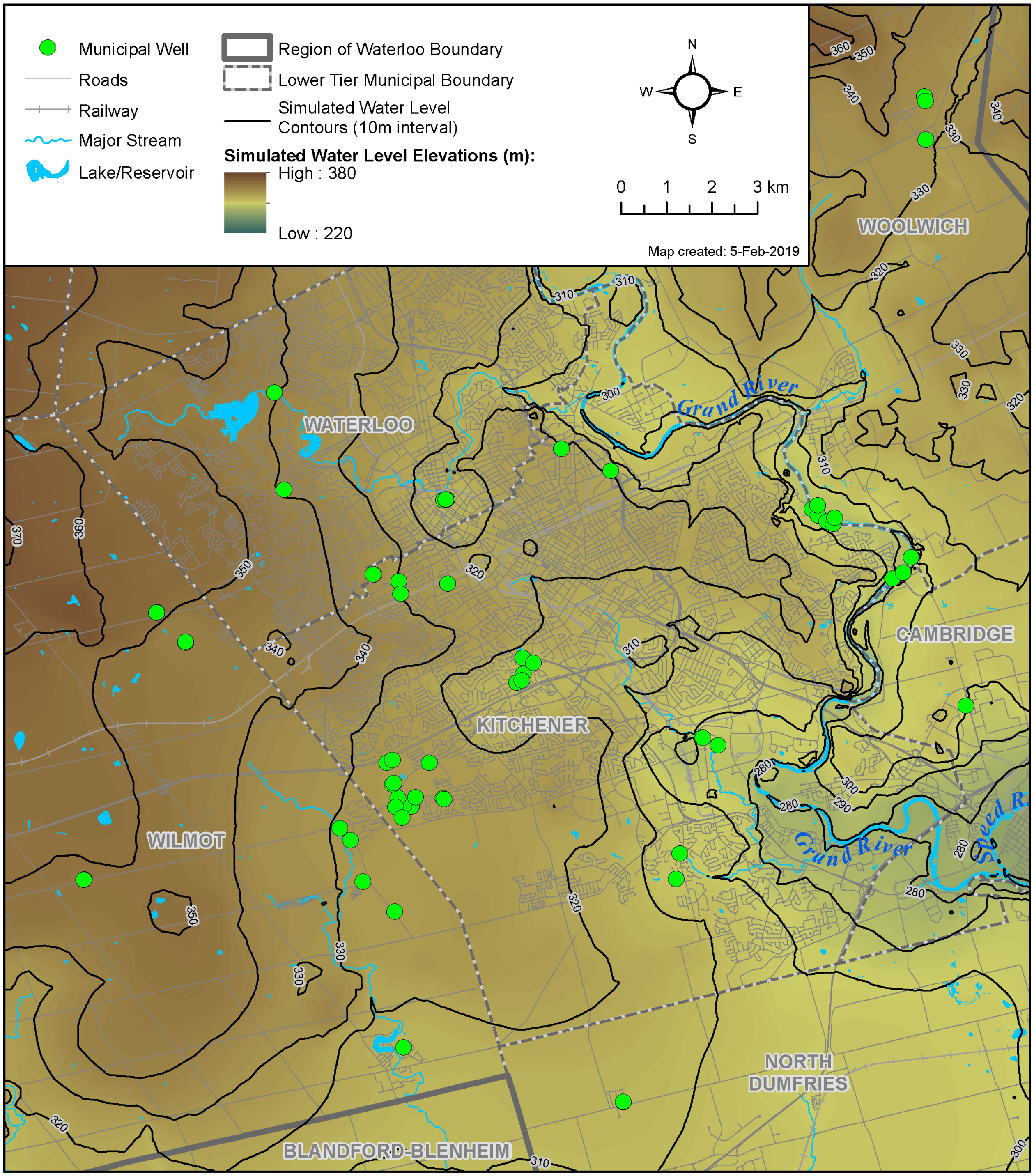
Map 19-3 illustrates the model-simulated deep aquifer groundwater level elevation contours from the Regional steady-state groundwater flow model for the lower AFD1 (Pre-Catfish Creek coarse-grained sediments) aquifer. The deep groundwater level elevation contours are similar but more subdued than the 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.

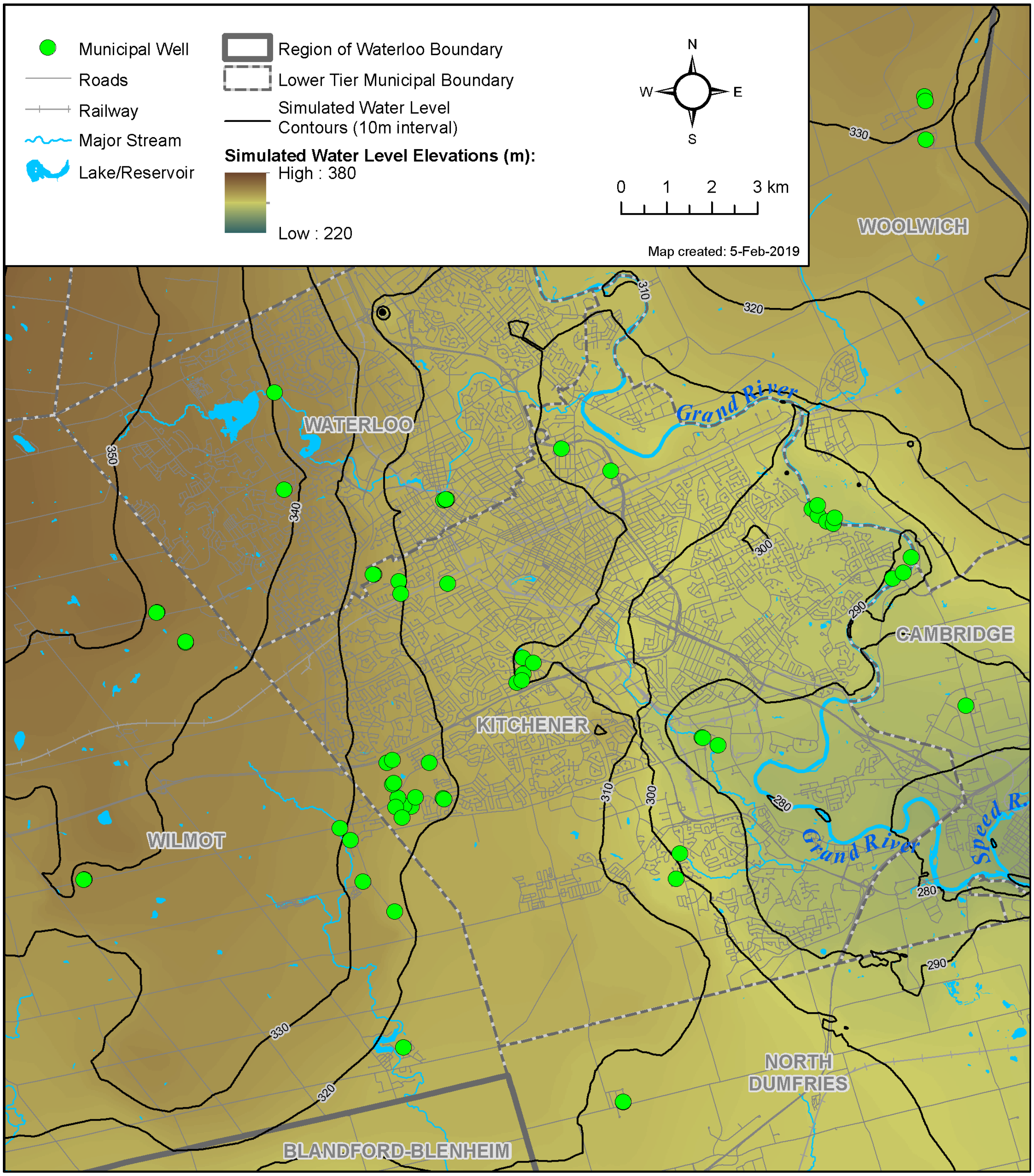
Map 19-4 illustrates the simulated shallow bedrock groundwater level elevation contours from the Regional steady-state groundwater flow model. The groundwater level elevation contours illustrate a north-south regional pattern with convergence from both the east and west on the Grand River valley. Modelling ~~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 19-5**. 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).

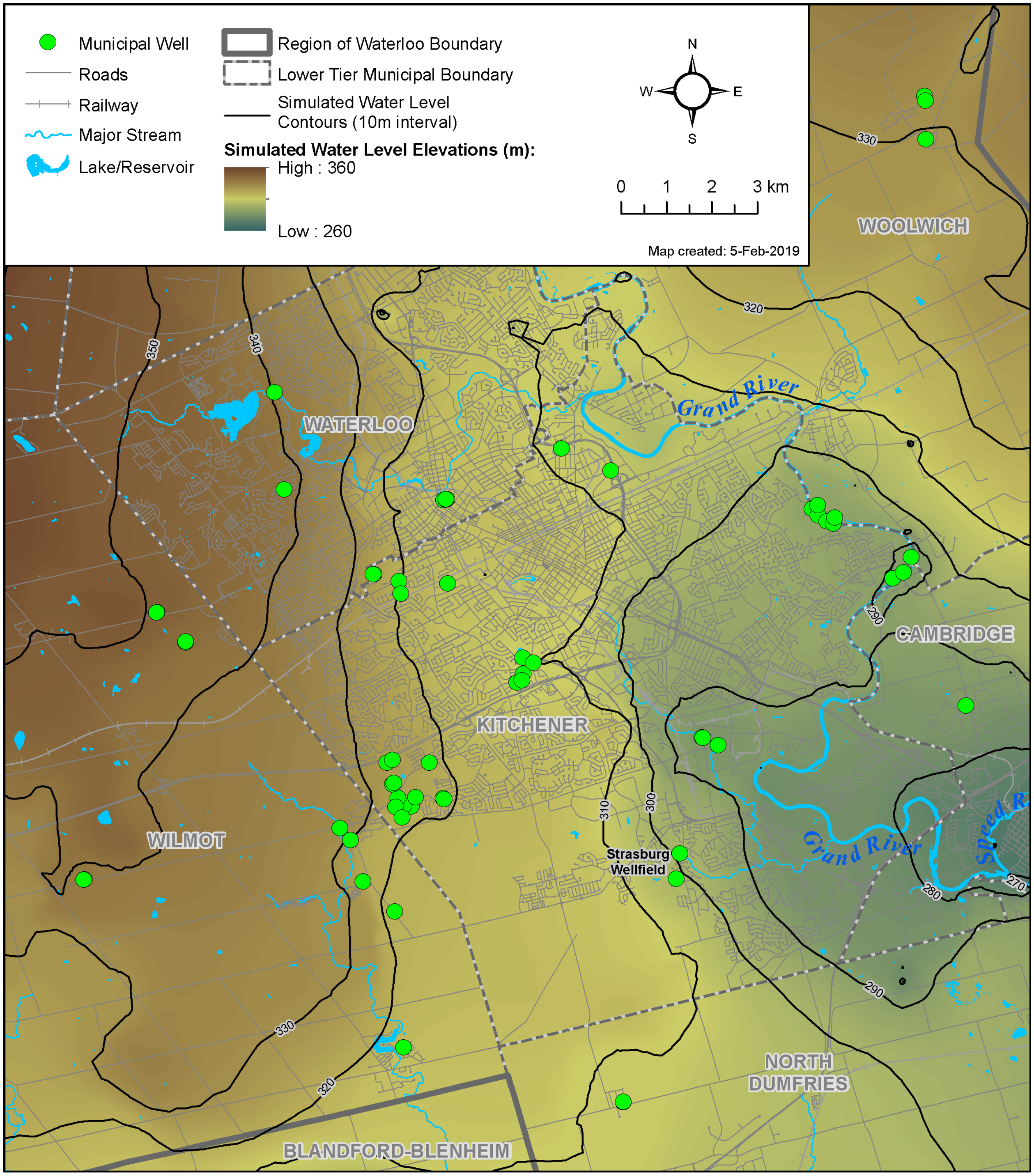
Map 19-2: Simulated groundwater level elevations for upper AFB2 aquifer



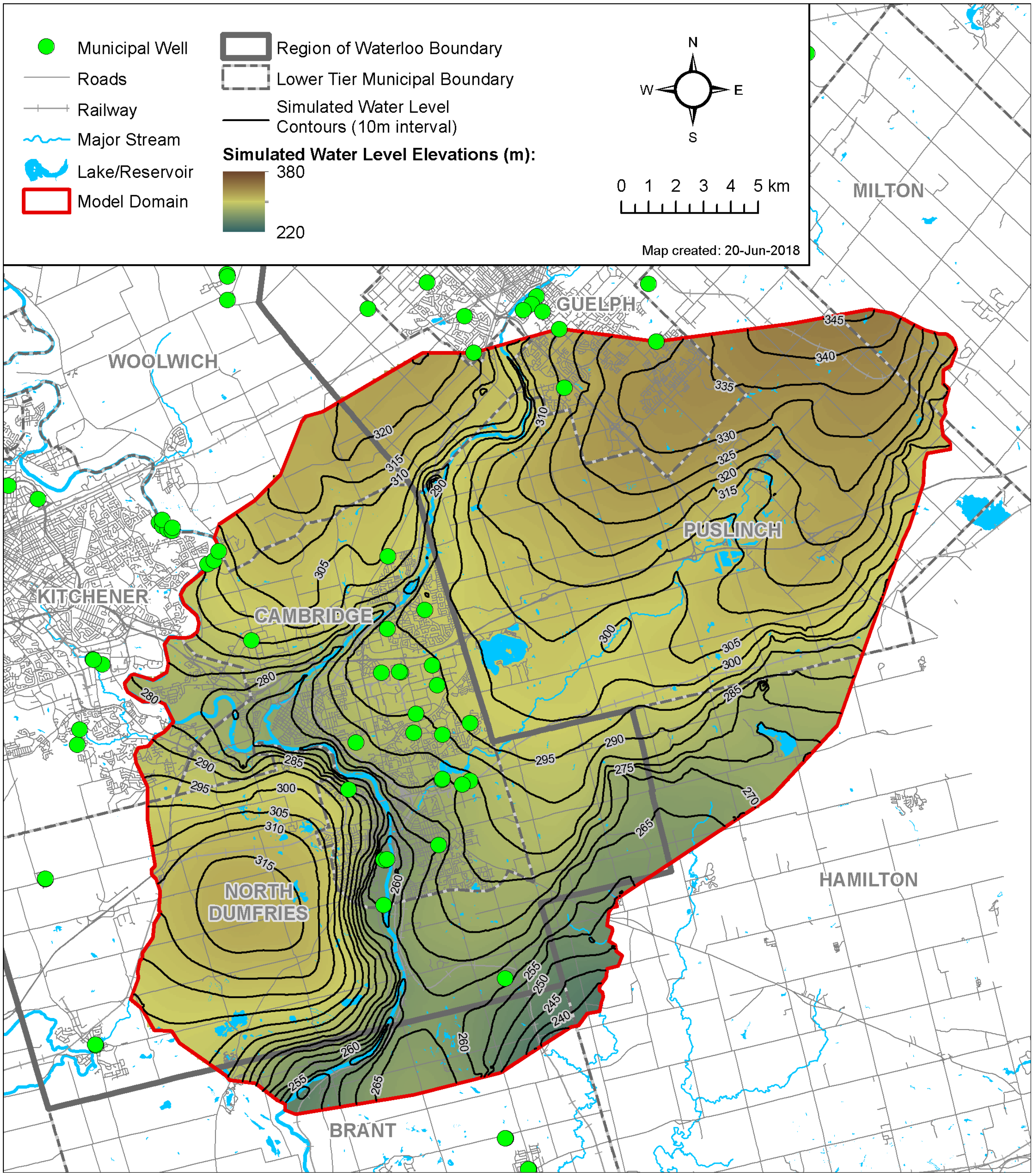
Map 19-3: Simulated groundwater elevations for aquifer AFD1



Map 19-4: Simulated shallow bedrock groundwater level elevation contours (Regional steady state groundwater flow model)



Map 19-5: Simulated groundwater level elevations in the Upper Bedrock aquifer (Guelph Formation and Reformatory Quarry) in the Cambridge Model



19.2.4 Water Demand and Other Water Uses

Tier 3 Assessments require an inventory of both municipal and other water users to assess the sustainability of municipal supply sources. In both cases, the degree of consumptive water demand, which refers to the amount of water removed from a source that is not returned directly to that source, is estimated. This section summarizes the known consumptive water takers identified in the Tier 3 study area, both permitted municipal and non-municipal water takings as well as ‘other’ non consumptive water uses, such as groundwater discharge to support of ecological needs, waste water assimilation, and/or recreational water uses.

Municipal Water Supply Systems

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.

Table 19-3 presents the municipal pumping rates applied in the water budget models for Waterloo Region. Two rates were used: 2008 rates which represent existing demand and 2031 rates which represent future demand. The Permit to Take Water limit is also presented for comparison.

Municipal pumping rates for the 2008 calendar year were selected as the most representative of existing conditions and demand, as all well fields were in operation in 2008 and pumping at fairly consistent rates. 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. Future demand was determined from the Region’s 2015 Water Supply Master Plan (Stantec, 2015). As noted in **Table 19-3**, some of the pumping rates for individual wells decreased for the future demand. This occurs for wells in the IUS because of the interconnection of the supply wells throughout the service area. Accordingly, the 2031 rates were derived iteratively with the Tier 3 Assessment and development of the Master Water Supply Plan to ensure water was available throughout the urban areas to meet future demand.

Table 19-3: 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

Table 19-3: 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)
P6	Dunbar Rd	Grandfathered[2]	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 ~~m³/day~~[3]	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
K26	Mannheim West	9,092	6,841	6,048
G1	Middleton	Max annual daily average of 24,000[4]	3,491	5,184
G14	Middleton		3,206	2,160
G1A	Middleton		3,994	1,728
G2	Middleton		5,366	6,912
G3	Middleton		3,396	4,752

Table 19-3: 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)
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	Max annual daily average of 10,000	327	432
K11[1]	Strange Street		199	-
K11A[1]	Strange Street		-	1,728
K13	Strange Street		526	1,296
K18	Strange Street		2,160	1,296
K19	Strange Street		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

Table 19-3: 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)**
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
[2] These wells have no PTTWs as they were constructed before the implementation of the Ontario Water Resources Act.
[3] 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 m3/day.
[4] Individual pumping rates for the Middleton Wells 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 m^3/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.
[5] 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.

In addition to the groundwater pumping rates specified in **Table 19-3,** the Region also extracts water from the Grand River using a surface water intake located in Kitchener. Extracted surface water is pumped to the Mannheim Water Treatment Plant where it is treated to drinking water standards, mixed with groundwater 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. These features are described below.

Aquatic Habitat

Several cold water streams that support cold water fish communities occur within the study area, primarily outside of or on the edge of the major urban areas.

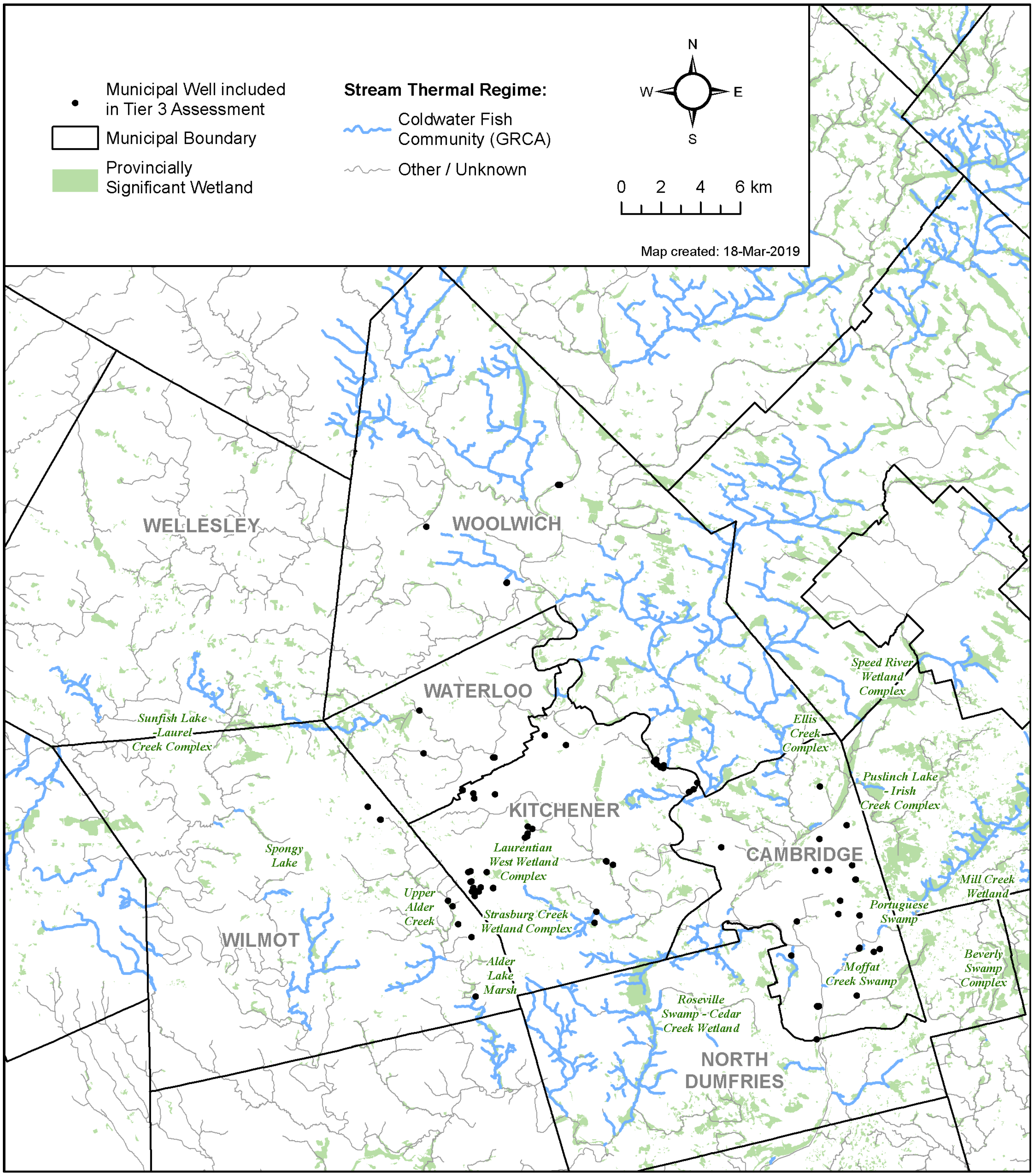
Map 19-6 shows streams mapped as cold water communities (GRCA) in the study area. Cold water communities within the Kitchener and Waterloo area include the headwaters of Laurel Creek in northwest Waterloo, Strasburg Creek at the Strasburg Well Field, and the main branch of Alder Creek from the Erb Street 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

Wetland features such as swamps and fens as they are partially or entirely reliant on groundwater discharge for their ecological health were also evaluated in the Tier 3 Assessment. 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 19-4.**

Table 19-4: 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 19-6: Other Water Uses within the Region of Waterloo



19.2.5 Land Use and Land Use Development

Existing Conditions

Land use development has the potential to reduce groundwater recharge and affect the sustainability of water supply sources. The existing land use cover used in the Tier 3 Assessment was based on 1992 imagery and updated within the urban areas with the most recent land use mapping for Kitchener, Waterloo, and Cambridge. 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 also made to the existing 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 uses in that area.

Future (Official Plan) Land Use

Changes in land uses from existing to revised Official Plan land uses (as of July 4, 2012) were assessed to identify where changes in land use from existing to future conditions were expected. 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 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 19-5** 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.

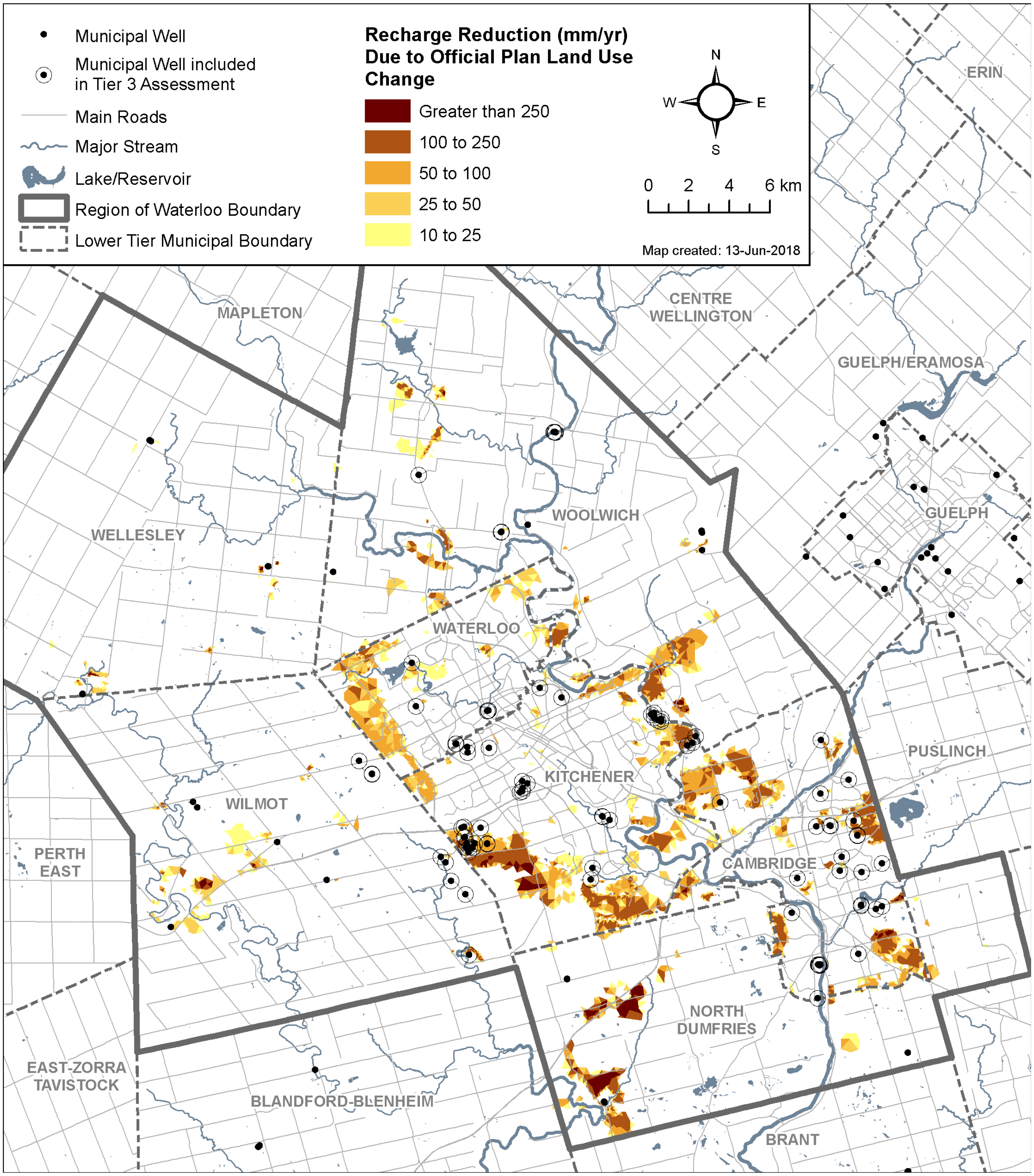
Map 19-7 and **Map 19-8** illustrate the spatial distribution of reductions in groundwater recharge between existing and future conditions for the Regional and Cambridge models, respectively. These distributions illustrate the extent that reductions in recharge are predicted to occur due to future land use development in the Region.

Table 19-5: Land Use Impervious Estimates

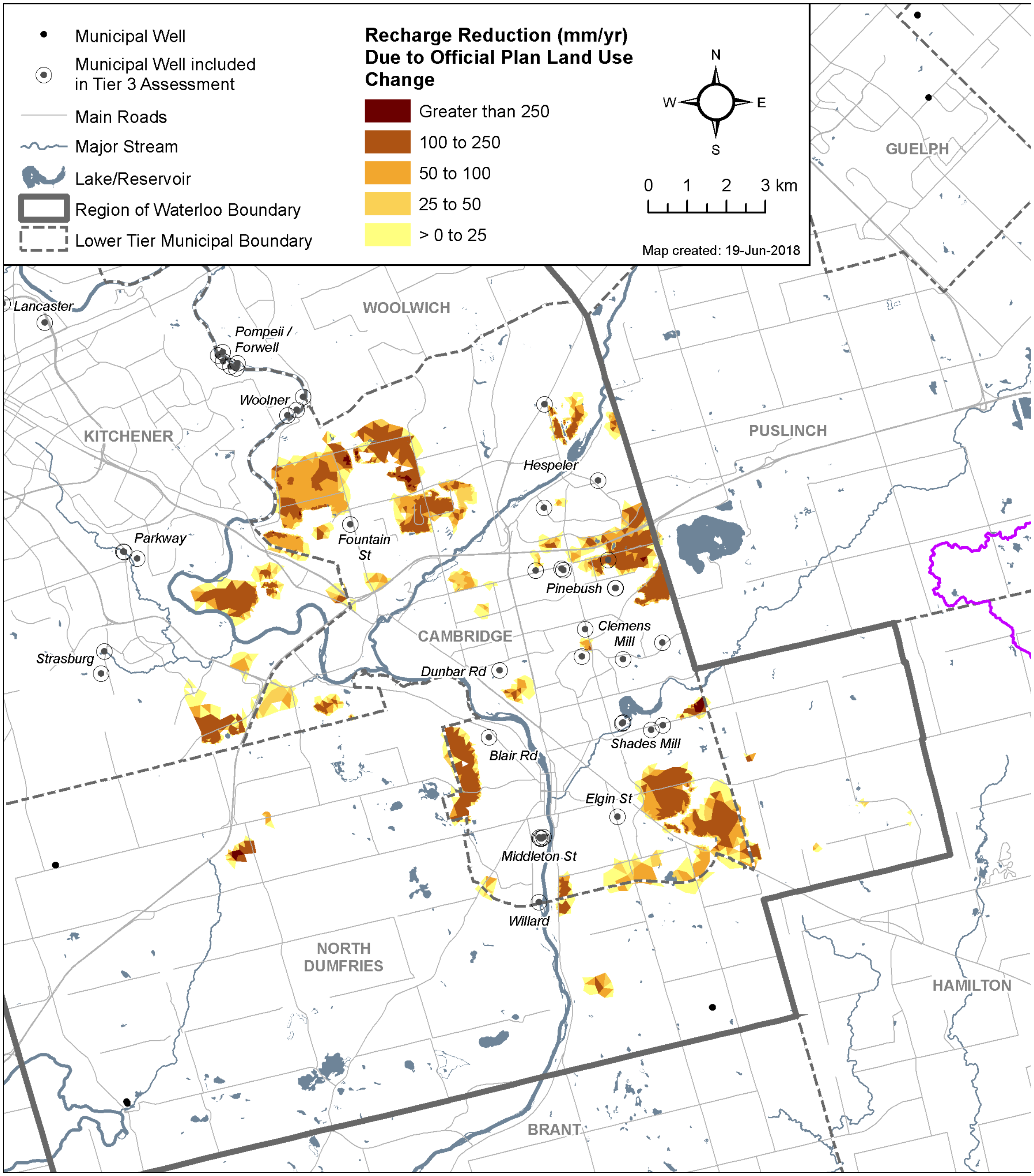
Land Use Type	Imperviousness (%)
Agriculture	0%
Open Space	0%
Institutional	32%
Low Density Residential	40%
Medium Density Residential	50%
High Density Residential	80%
Low Density Commercial	60%

Table 19-5: Land Use Impervious Estimates	
Land Use Type	**Imperviousness (%)**
Medium Density Commercial	80%
Industrial	80%
Urban Commercial Core	90%

Map 19-7: Recharge Reductions due to Land Use Changes in the Regional Model



Map 19-8: Recharge Reductions due to Land Use Changes in the Cambridge Model



19.3 Risk Assessment

19.3.1 Model Development and Application

To represent the complex hydrological and hydrogeological conditions present in the study area, three numerical modelling tools were applied in the Region's Tier 3 Assessment. Specifically, The Guelph All-Weather Sequential-Events Runoff (GAWSER) streamflow generation model was used to simulate surface water partitioning and streamflow generation and two FEFLOW groundwater flow models, one covering the entire Region and another for covering Cambridge were used to simulate subsurface (groundwater) flow. 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.

GAWSER was initially developed in the early 1990s to assist the Grand River Conservation Authority with water management decisions. It has been continuously updates and refined to improve the representation of surface water flow within the Grand River. 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). 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.

Further details on the GAWSER model development and calibration are provided in AquaResource (2009b).

The two consistent FEFLOW models were developed to represent the two different hydrogeologic environments that supply water to the Region. The Regional Model 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 Cambridge Model 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.

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. The development and calibration of these two models are discussed in detail in Matrix and SSPA (2014a).

19.3.2 Risk Assessment Results

The groundwater flow models were used to simulate groundwater flow conditions across the Region and to conduct the required risk scenarios to assess the sustainability of the supply wells. The approach involved applying a series of land use, recharge and pumping rate changes and calculating the additional drawdown in each supply well predicted for each scenario. The scenarios were evaluated within an area delineated as being vulnerable to changes in groundwater levels. The delineation and results are presented below.

Delineation of Vulnerable Areas

The first step in the Risk Assessment was the delineation of vulnerable areas. This area is identified as the Well Head Protection Area for quantity (WHPA-Q) and consists of the sum of two individual water quantity thresholds. First, the differences in the model-simulated groundwater level elevations under 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 future pumping rates. Second, the WHPA-Q2 is delineated to include the WHPA-Q1 area, plus any area where a future reduction in recharge may have a measurable impact on wells located in that area.

A threshold value representing the seasonal fluctuation in water levels was calculated to form the basis for the WHPA-Q delineation. The average observed seasonal fluctuations in groundwater levels 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 average observed seasonal fluctuations in groundwater levels for monitoring wells completed in bedrock and deep overburden production aquifers within the Cambridge area is also approximately 2 m. Therefore, the 2 m drawdown contour interval was also used to delineate the WHPA-Q1 for the Cambridge municipal wells.

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). Future pumping 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.

As noted above, the second step in the delineation of the WHPA-Q is to assess where a reduction in future recharge may have a measurable impact on wells located in the WHPA Q1 area. It was determined that the majority of the land use development that is expected to occur will be located within the WHPA-Q1 areas. Also the seasonal variations in groundwater level elevations would mask any changes in proposed land use changes for the developments lying outside the WHPA Q1 areas. Finally, the simulated incremental additional drawdown at the municipal wells was much smaller than the available drawdown. Therefore, the reductions in recharge due to land use 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 coincident with their respective WHPA Q1 areas.

Four WHPA-Q areas lie within the Region as illustrated on **Map 19-9**. The westernmost is WHPA-QA, which underlies the western portions of Kitchener and Waterloo. The WHPA-QA area extends north to the town of Heidelberg, south to New Dundee, west to St. Agatha and east toward the Grand River.

The WHPA-QB underlies the majority of the urban portion of Cambridge, and as noted above extends in a northwestward direction toward Guelph. The WHPA-QB 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-Q for Guelph and it overlaps with the Region’s WHPA-QB; consequently, a combined WHPA-Q area for the two cities was delineated.

The WHPA-Q 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-QB delineated in the Cambridge Model extends further to the south and west as compared to the WHPA-Q 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 potentially affecting the ability of the municipal wells in both areas to sustain water demand. Because each respective model is more representative of pumping within that municipality, separate WHPAS-Qs were delineated with each area including an area that overlaps with the adjacent municipal WHPA-Q to reflect the potential that wells in both municipal systems could be affected by additional water taking (**Map 19-9**).

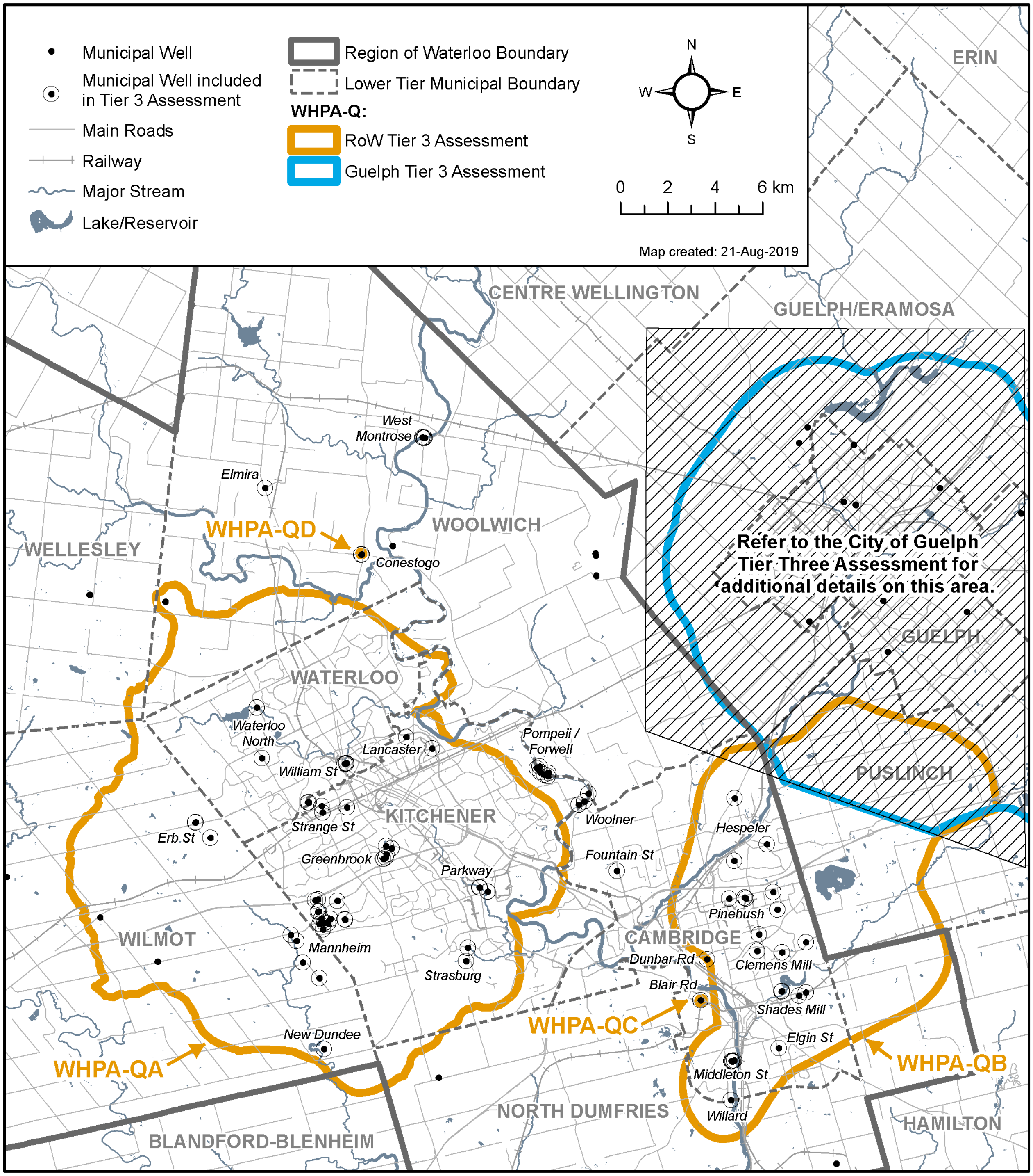
The WHPA-QC area is a small drawdown cone located around the Blair Road Wells (Wells G4 and G4A). The drawdown extends approximately 140 m from the Blair Road Well Field Wells on the west side of the Grand River.

The WHPA-QD 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-QD (Conestogo) area.

Application of Risk Scenarios

Following the delineation of the vulnerable areas, the risk of not being able to meet future water demand due to changes in pumping rates, precipitation and/or land use was assessed by calculating changes in groundwater level elevations at the municipal wells, and changes in groundwater discharge to specified surface water features. These scenarios included existing pumping, land use and precipitation (Scenario C), future pumping rates and maximum extend of development in accordance with municipal plans (Scenario G), reduction in precipitation due to a ten-year drought at existing land use and pumping conditions (Scenario D), and future pumping rates and maximum development (Scenario H). The scenarios were run using the model in steady-state mode for existing conditions and future pumping rates/maximum development (Scenarios C and G) and in transient mode for scenarios that involved assessing a drought (Scenarios D and H). 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 19-9: Vulnerable Area: WHPA-Q



Drawdown Thresholds

To assess the impact of increased pumping, changes in land use cover and precipitation were considered. The safe additional drawdown level is calculated as the additional depth that the water level within a pumping well could fall and still maintain the well's future 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 additional drawdown predicted in each of the scenarios was estimated and compared to the estimated safe additional drawdown at each municipal well.

In the steady-state scenarios 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 existing water level. The model-simulated drawdowns in each scenario were then compared to the safe additional drawdown values.

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 future rates over the long-term (including drought conditions) under existing and future land use development conditions.

Ecological Thresholds – Stream Baseflow

The risk assessment process requires an assessment of the impact for each of the scenarios to stream base flow of cold water fish community streams. Specifically, reductions of greater than 10 percent of an existing monthly stream base flow would increase the risk ranking. 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 19-6 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.

Table 19-6 summarizes the results of predicted reductions in groundwater discharges for the Regional Model for the three future scenarios of increased development only (G1), increased pumping only (G2), and both increased pumping and maximum development (G3). Both cold water streams and warm water streams are listed; however, only the impacts to cold water streams are required to be assessed.

Changes in base flow due to pumping only (Scenario G2) in-reaches hosting cold water fish communities were predicted to be less than 10%. It is noted that 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 (Scenario G3) were also assessed. Specifically, 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 19-6: 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%*
Schneider Creek	*Warm water*	*3%*	*1%*	*2%*
Shoemaker Creek	*Warm water*	*19%*	*17%*	*4%*

Table 19-7 summarizes the reductions in groundwater discharge to all stream reaches in the Cambridge area. Under future pumping rates (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 19-7: 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%

Table 19-7: Impacts to Groundwater Discharge - Cambridge Model				
Reach	**Thermal Regime**	**Simulated Discharge (% Reduction)**		
		G1 Base	**G2 Base**	**G3 Base**
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

In this assessment, the predicted changes in groundwater level elevations beneath wetland complexes (see **Table 19-8**), 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 19-8.**

The changes in groundwater level elevations between the model simulated groundwater level elevations under existing land use and municipal pumping (Scenario C) and existing land use and future pumping rates (Scenario G2) were evaluated and are summarized in **Table 19-8**. 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 19-8**. In all steady-state scenarios, no changes in gradients were predicted at any of the wetland complexes.

In general, under future municipal pumping rates (Scenario G2) reductions in water level elevations were predicted to be 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 largest change in water levels was predicted for the Mill Creek Wetland which had a decline of approximately 0.9 m. However it was still predicted to be a groundwater discharge feature despite this predicted degree of change.

The Laurentian West Wetland in Kitchener was simulated in the model as a perched wetland that lies above the 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.

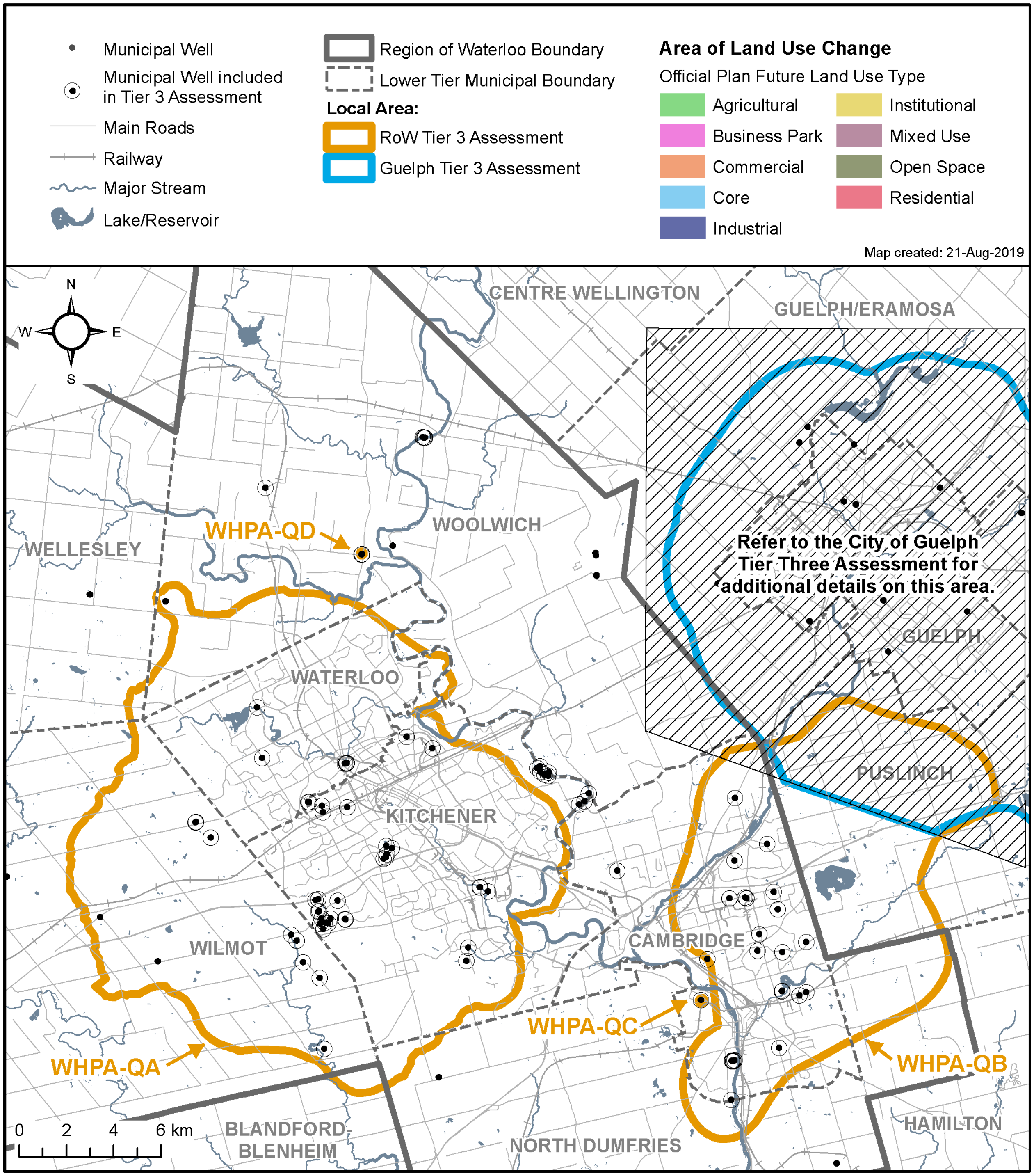
Table 19-8: Summary of Wetland Impacts for Steady-State Risk Assessment

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

Risk Level Circumstances

The conclusions of the Risk Assessment for the Region is that there is sufficient available water in the Region’s wells to meet future demand under increased development and reductions in precipitation. 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. Consequently, the four WHPA-Qs 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 future demand 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. The assignment of a low risk level means there are no significant water quantity threats.

Map 19-10: Vulnerable Area: WHPA-Q 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-Qs. 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-Qs within the Region was considered appropriate, and consequently, the uncertainty associated with the Risk Level was Low.

19.3.3 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 19-11** 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 19-12**. 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.

19.3.4 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.

19.4 Section Summary

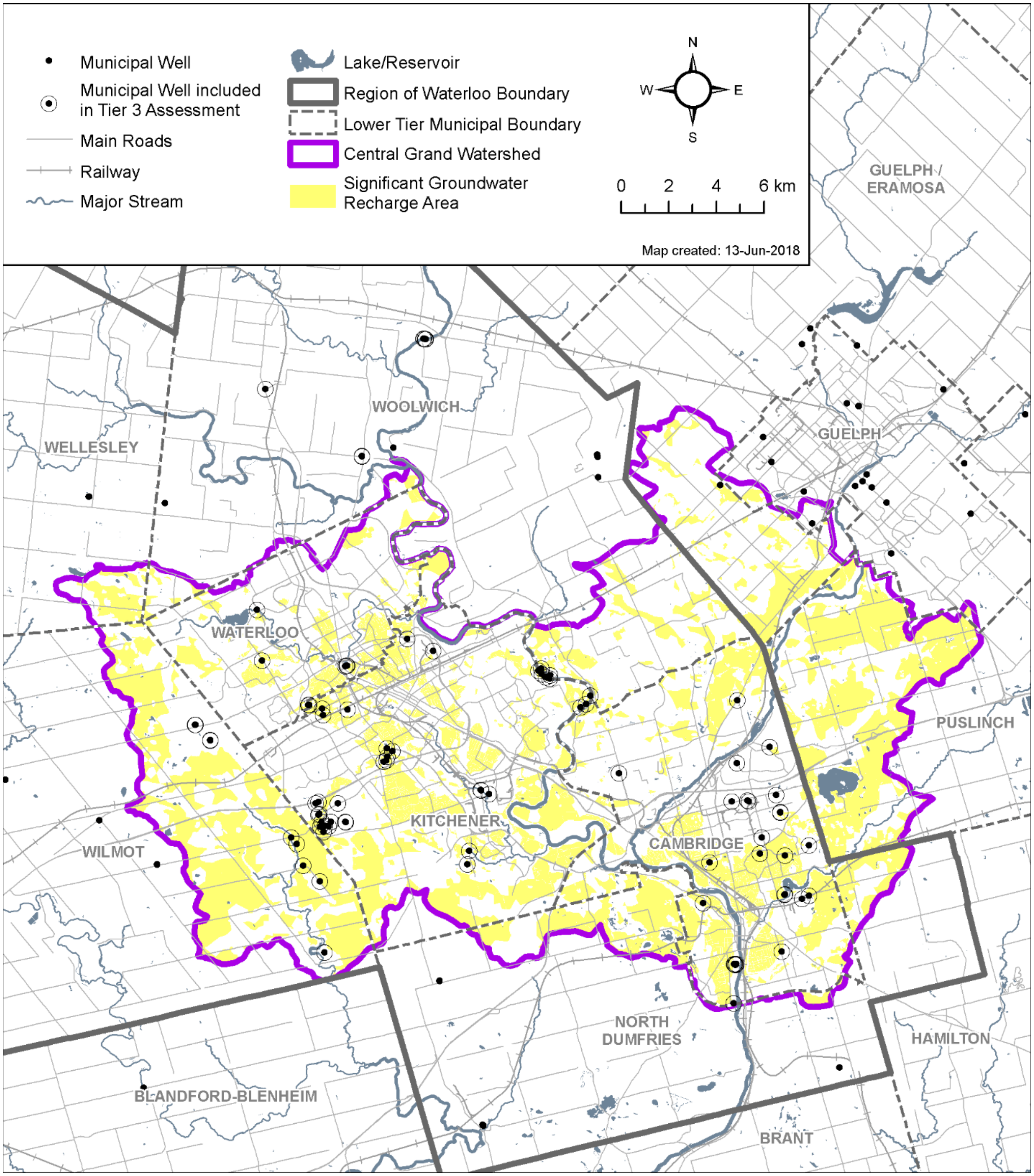
Four WHPA-Q's were delineated for the various municipal supply wells within the Tier 3 study area as shown on **Map 19-10**. The areas were delineated following the Province's Technical Rules (MOE, 2009), based on a combination of the drawdown of each municipal well, as well as land areas where reductions in recharge have the potential to have a measurable impact on the municipal wells. The additional drawdown due to increased development was considered negligible in relation to the seasonal water level fluctuations so the WHPA-Q was delineated based on the drawdown alone.

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-Qs within the Region of Waterloo as having a Low Risk Level. The Low Risk Level is considered appropriate for the WHPA-QA (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.

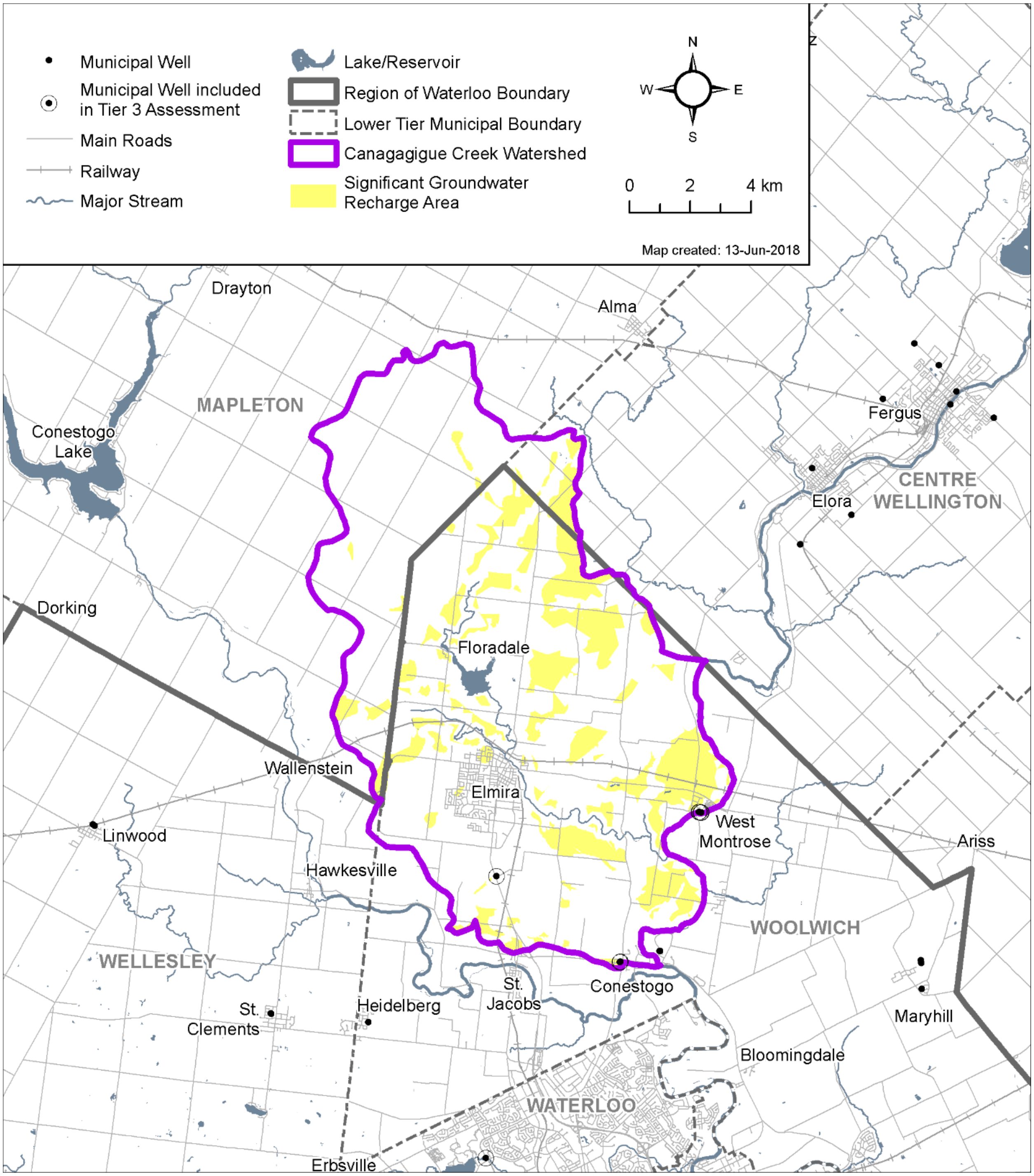
Similarly, the municipal wells located within WHPA-QB (i.e., Cambridge wells) are completed within productive overburden and bedrock units that are able to transmit volumes of water on a long-term basis that more than meet the 2031 demands, without causing negative impacts on other water uses. WHPA-QC and WHPA-QD (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-Qs 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 19-11: Spatial Mapping of Significant Groundwater Recharge Areas of Central Grand



Map 19-12: Spatial Mapping of Significant Groundwater Recharge Areas of Canagagigue Creek



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