Specific Purpose	Maximum Permitted Rate (m^3/day)	Percentage of Total Permitted Takings	Consumptive Demand (m^3/day)	Difference (Maximum Permitted - Consumptive; m^3/day)
Total	32,262	100	12,934	19,327

4 TIER THREE WATER BUDGET

The Tier Three Assessment aims to provide an improved estimate of the water budget components included in the hydrologic cycle within the Study Area. The surface water and groundwater flow models developed for the Tier Three Assessment were used to estimate average annual values for the various components of the hydrologic cycle. The GAWSER and FEFLOW models are separate and independent models linked through groundwater recharge; recharge is simulated by the GAWSER streamflow-generation model as a model output, and then is used as a model input parameter in the FEFLOW groundwater model.

The combined results of the water budget models produce an improved conceptualization of the hydrologic and hydrogeologic flow systems. The following sections quantify and outline the water budget components within the Study Area.

4.1 Groundwater Flow

The following section outlines the water budget model results relating to groundwater in the Study Area.

4.1.1 Groundwater Recharge

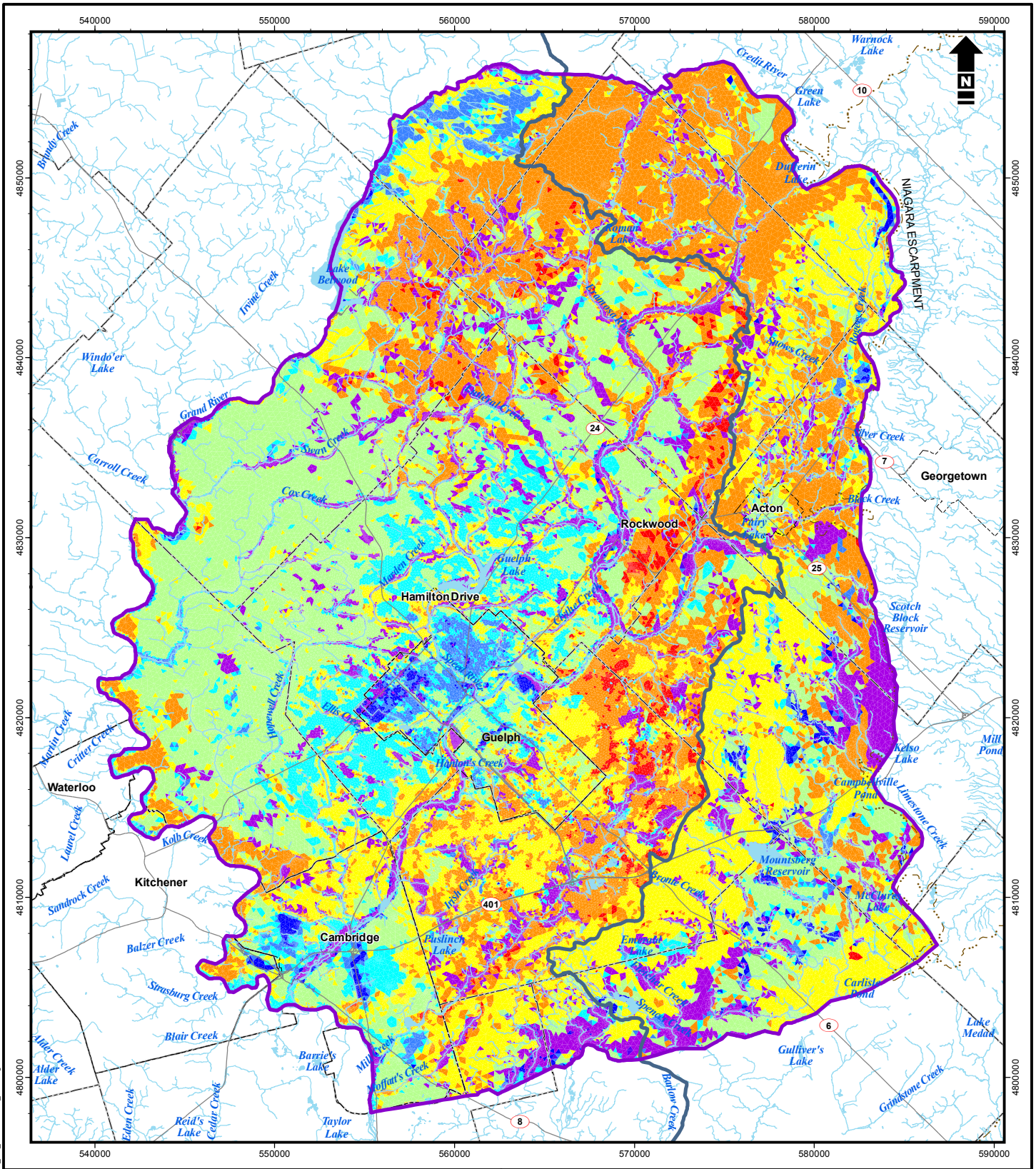
Figure 4-1 illustrates groundwater recharge rates applied in the FEFLOW groundwater flow model as specified flux boundary conditions. Groundwater recharge is greatest (533 mm/year) on hummocky regions associated with the Paris and Galt moraines (which are underlain by sands and gravels) and recharge is least (0 mm/year) where groundwater discharges to some wetlands. Groundwater recharge is also lower within the urban areas where there is a greater percent imperviousness associated with roads, parking lots, and buildings.

4.1.2 Water Table Surface

Figure 4-2 illustrates the elevation of the water table surface simulated by the calibrated steady-state groundwater flow model. The water table generally mimics the ground surface topography and is strongly influenced by surface water features. The shallow groundwater divide along the boundary with the Credit River Watershed generally coincides with the surface water divide. The shallow groundwater

divide along the Grand River Watershed boundary south of Mill Creek is not coincident with the surface water boundary, and this is consistent with previous modelling efforts and interpretations.

Figure 4-3 illustrates the simulated water table surface near the City of Guelph, Rockwood, and Hamilton Drive. This figure illustrates the significant impact that surface water features play on the shallow groundwater flow system within the City of Guelph and near Rockwood and Hamilton Drive. The effects of the Glen Collector system in the Arkell Spring Grounds are observed on Figure 4-3 where the water table contours are influenced by both the injection and collection of water.



Tier Three Model Boundary (Study Area)

Grand River Watershed Boundary

Community

Water Body

Watercourse

Major Road

Niagara Escarpment

Average Annual Groundwater Recharge (mm/yr)

- 0 - 5
- 5 - 10
- 10 - 20
- 20 - 50
- 50 - 100
- 100 - 200
- 200 -300
- 300 - 400
- > 400

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1:300,000

2 0 2

Kilometres

NAD 1983 UTM Zone 17N

I:\City of Guelph\15072\Figures and Tables\GHG\2013\Report\Risk Assessment\Figure_4-1_Groundwater_Recharge.mxd

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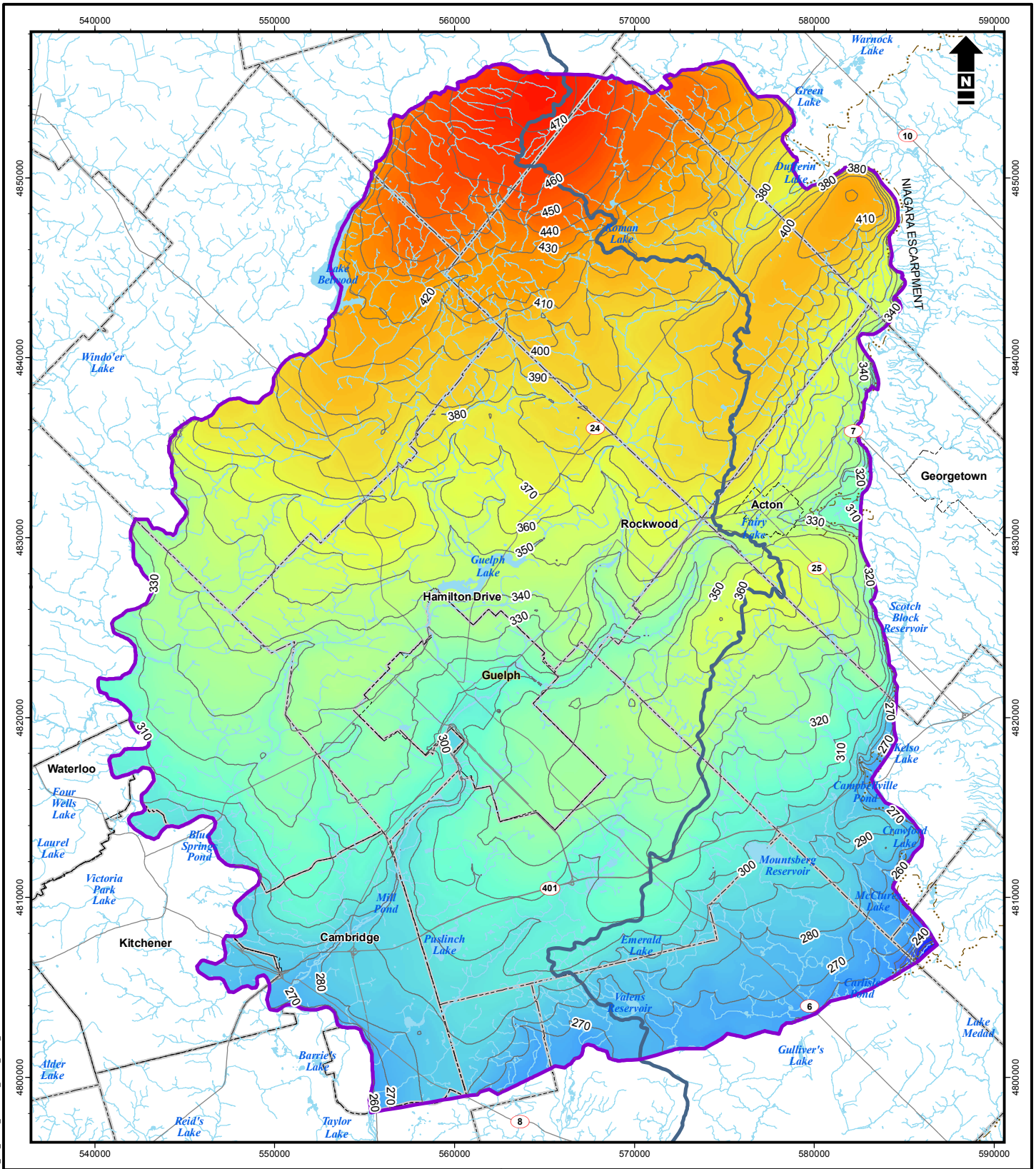
City of Guelph and Township of Guelph/Eramosa

Tier 3 Water Budget and Local Area Risk Assessment

Groundwater Recharge

Date:	Project:	Technical:	Reviewer:	Drawn:
21 Dec 2016	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 4-1



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Water Body
Watercourse
Major Road
Niagara Escarpment
Water Table Contour (10m)

Water Table (m asl)
High : 475
Low : 200

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1:300,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

I:\City of Guelph\15072\Figures and Tables\GHG\2013\Report\Risk Assessment\Figure_4-2_Model_Predicted_Water_Table_Elevation.mxd

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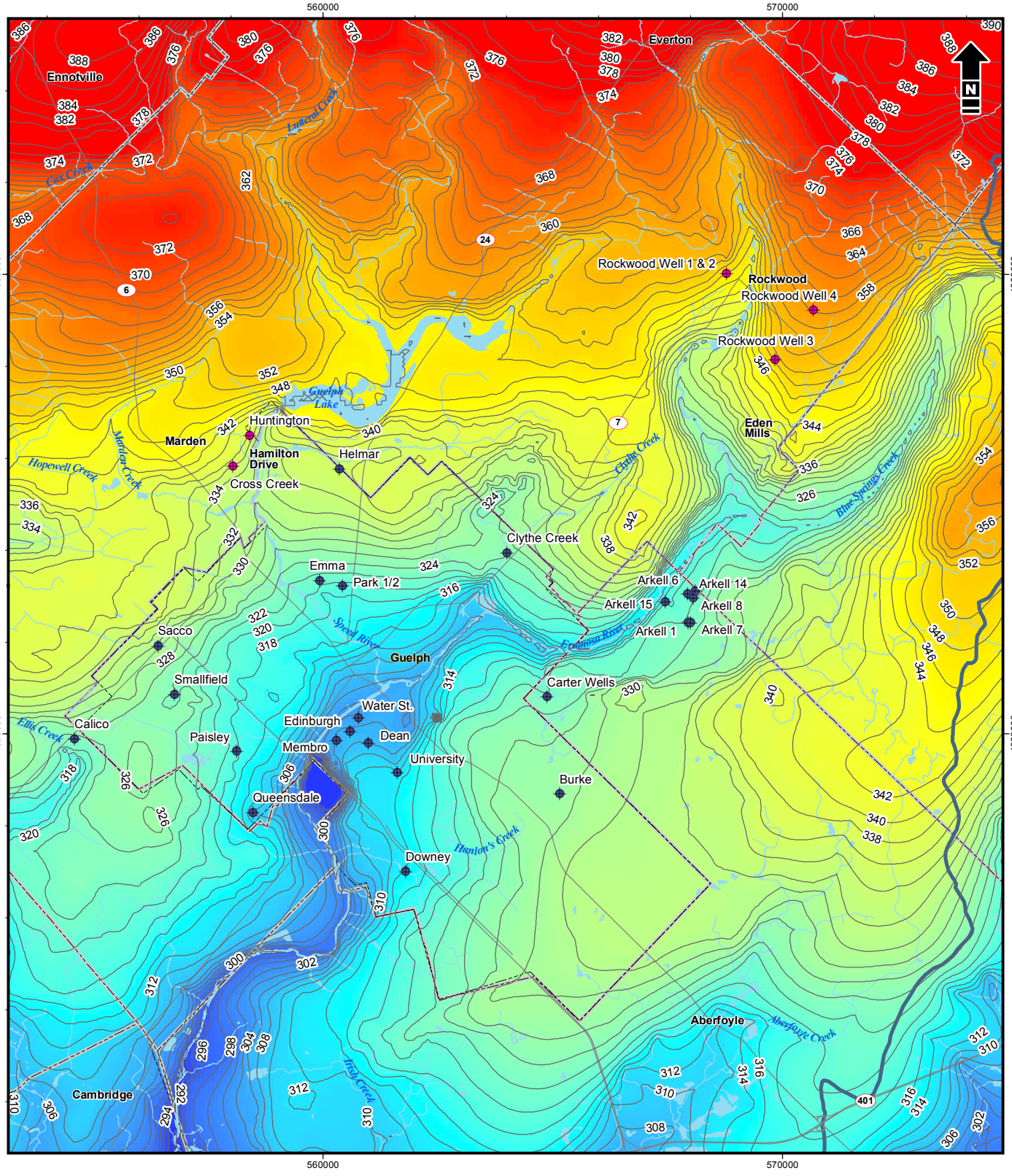
City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Model Predicted Water Table Elevation

Date: 21 Dec 2016	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

Figure 4-2



Grand River Watershed Boundary
Community
Water Body
Watercourse
Major Road
Water Table Contour (2m)
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

Water Table (m asl)
High : 375
Low : 285

1:120,000
1 0 1
Kilometres

NAD 1983 UTM Zone 17N

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I:\City of Guelph\15072\Figures and Tables\GHG\2013\Report\RiskAssessment\Figure_4-3_Model_Predicted_Water_Table_Elevation_CityofGuelph.mxd

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Model Predicted Water Table Elevation (Area of Interest)

Date:	Project:	Technical:	Reviewer:	Drawn:
23 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

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Figure 4-3

4.1.3 Bedrock Water Level Contours

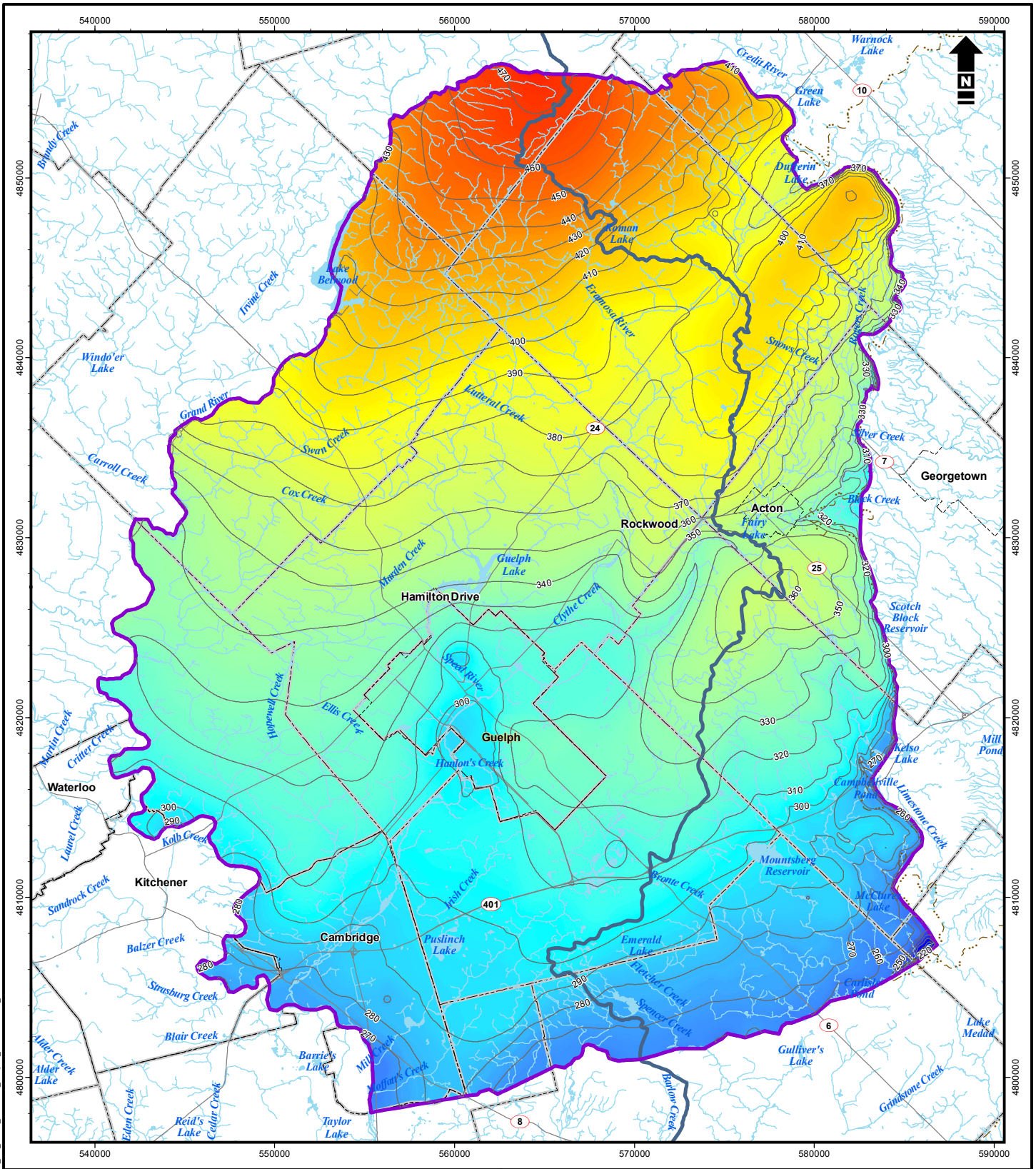
Figure 4-4 and Figure 4-5 illustrate the simulated steady-state potentiometric surface in the Middle Gasport Formation model layer for the entire Study Area and within the area of interest, respectively. In general, the groundwater divide in the Gasport Formation aquifer appears to follow the surface water divide between the Grand River and Credit River watersheds. This is not the case along the divide between Grand River Watershed and the Halton and Hamilton Region Conservation Authority jurisdiction to the south.

As shown on Figure 4-4, the deeper aquifer is influenced by some of the regional groundwater discharge features (i.e., the Eramosa River and Blue Springs Creek) where ground surface topography is incised into the deeper bedrock system. The smaller streams have very little influence on the deep groundwater flow system. In general, the simulated potentiometric surface contours generally compare well with the observed deep aquifer potentiometric surface contours illustrated on Figure 2-9 of Appendix B.

Within the area of interest (Figure 4-5) there appears to be limited interaction between the deep aquifer and surface water bodies, although interaction can be seen along the Eramosa River upstream of Eden Mills near Rockwood and along Blue Springs Creek. The effects of municipal and non-municipal wells pumping from the Gasport Formation aquifer are seen as depressions in the potentiometric surface around various well fields, and through the middle of the City of Guelph's higher permeability aquifer zones.

4.1.4 Vertical Hydraulic Head Difference

Figures 4-6 and 4-7 illustrate the model-predicted hydraulic head difference between the Contact Zone at the top of bedrock and the Gasport Formation layers for the Study Area and the area of interest, respectively. The maps are shaded to highlight areas having the strongest upwards (green) and downwards (dark blue) directed bedrock gradients of potential. The figures also show the interpreted extent of the Vinemount Member of the Eramosa Formation. Within this area the aquitard impedes the flow of groundwater as shown by the presence of large vertical gradients of potential. Vertical head differences east of the Vinemount Member aquitard boundary are minimal given that the Gasport Formation aquifer is generally present at the top of bedrock.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Water Body
Watercourse
Major Road
Niagara Escarpment
Potentiometric Surface Contour Interval 10m

Potentiometric Surface (m)
High : 480
Low : 215

1:300,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Model Predicted Gasport Potentiometric Surface

Date: 27 Jan 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

Figure 4-4

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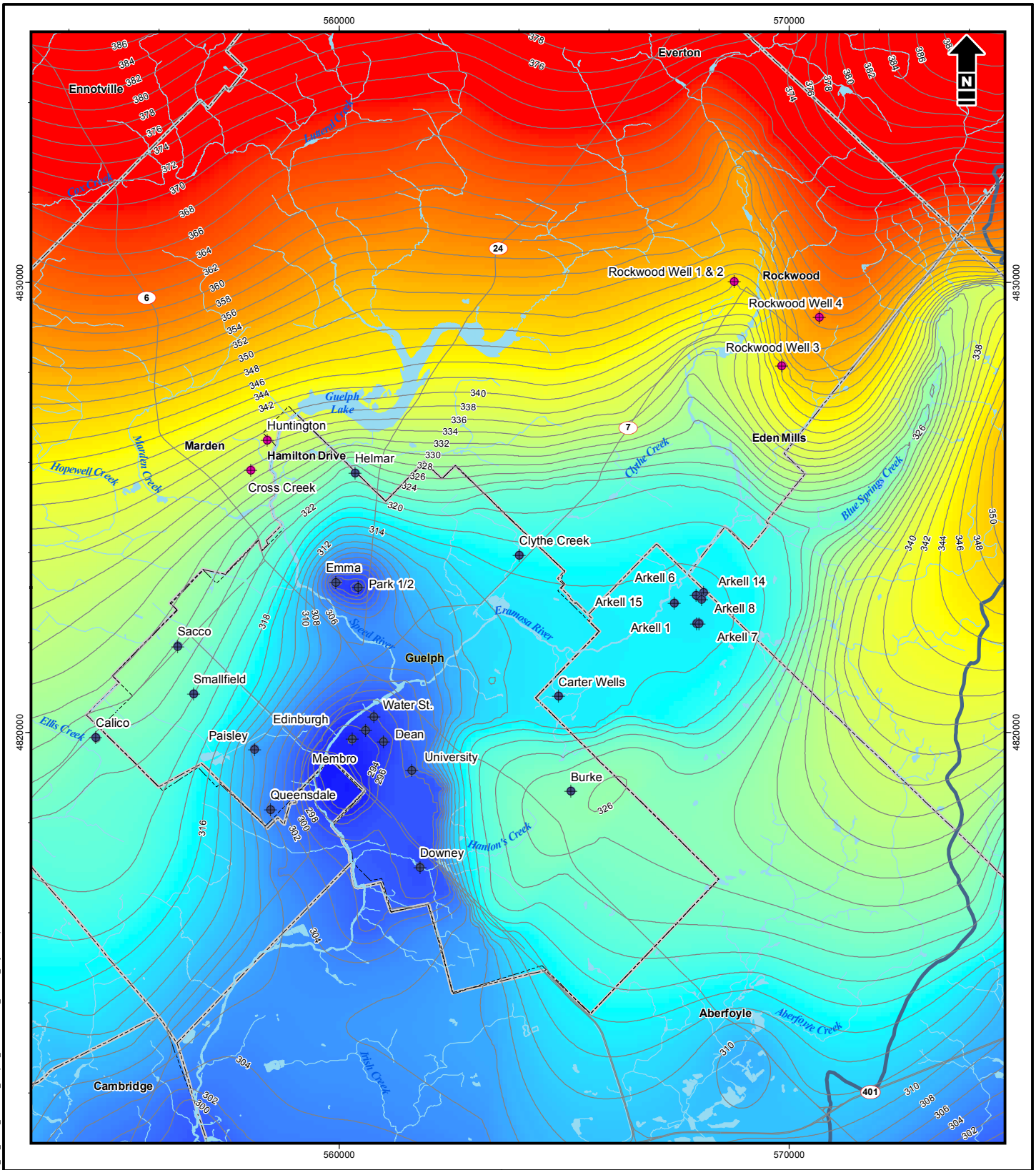

Grand River Watershed Boundary
Community
Water Body
Watercourse
Major Road
Potentiometric Surface Contour (2m)
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

Potentiometric Surface (m)
High : 370
Low : 290

1:120,000
1 0 1
Kilometres

NAD 1983 UTM Zone 17N

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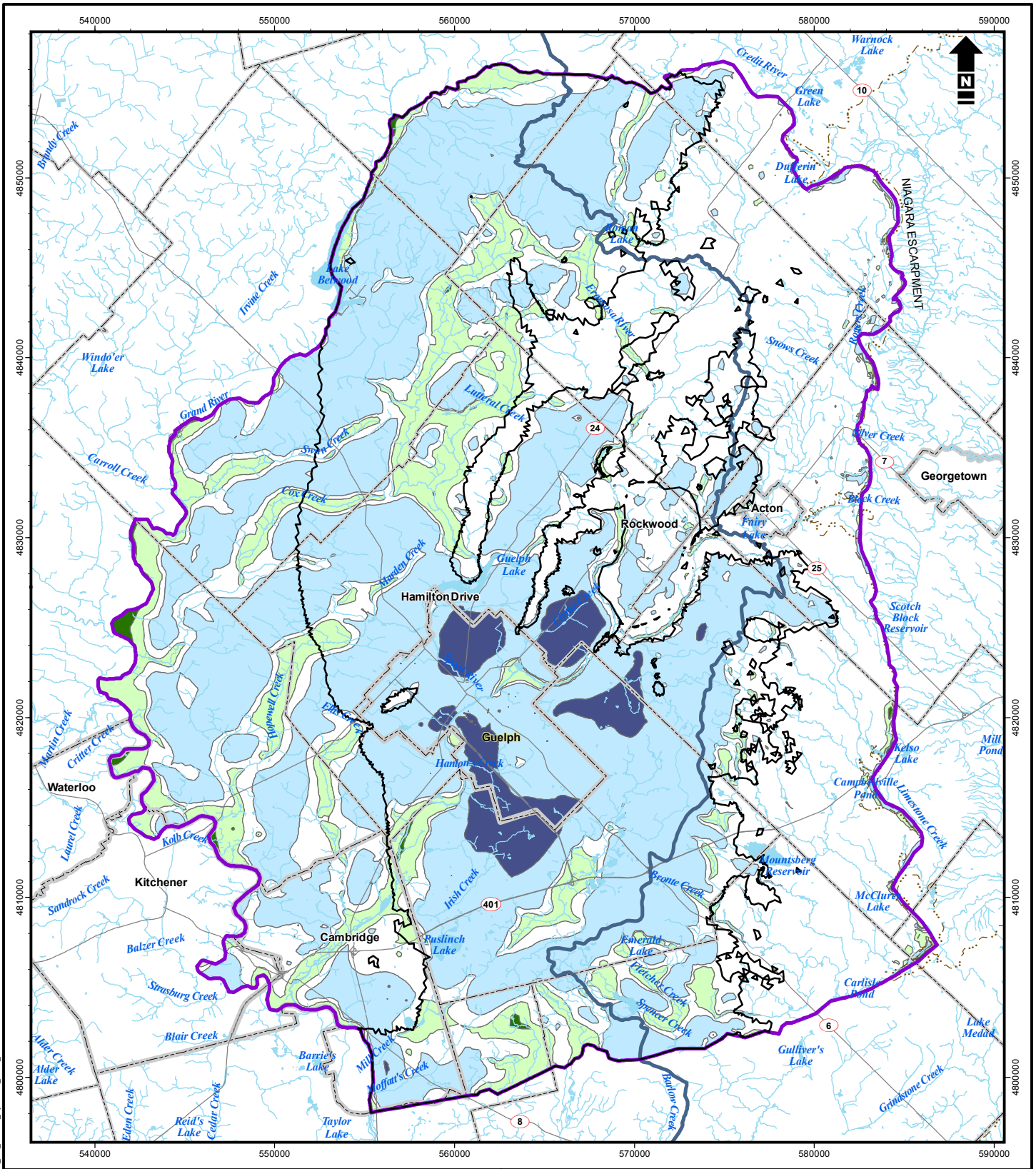
City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Model Predicted Gasport Potentiometric Surface (Area of Interest)

Date: 06 Mar 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

Figure 4-5



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Vinemount Formation
Community
Water Body
Watercourse
Major Road
Niagara Escarpment

Vertical Hydraulic Head Difference

Strong Downwards Potential
Downwards Potential
Upwards Potential
Strong Upwards Potential

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1:300,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

I:\City of Guelph\15072\Figures and Tables\GHG\2013\Report\RiskAssessment\Figure_4-6_Vertical_Hydraulic_Head_Difference.mxd

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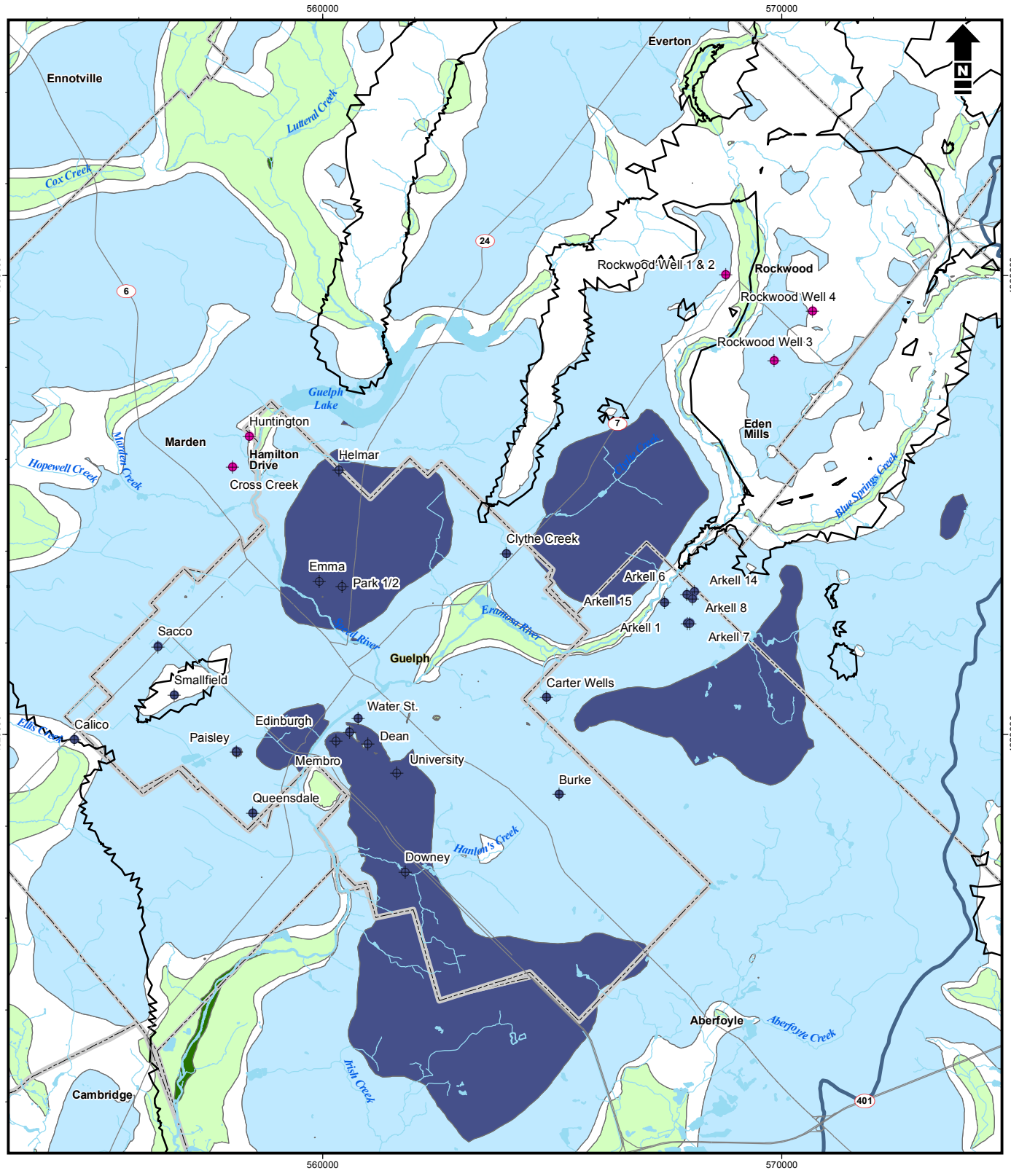
City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Vertical Hydraulic Head Difference

Date: 04 Jan 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

Figure 4-6



Grand River Watershed Boundary
Vinemount Formation
Community
Water Body
Watercourse
Major Road
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

Vertical Hydraulic Head Difference

Strong Downwards Potential
Downwards Potential
Upwards Potential
Strong Upwards Potential

1:120,000
1 0 1
Kilometres

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Vertical Hydraulic Head Difference (Area of Interest)

Date:	Project:	Technical:	Reviewer:	Drawn:
06 Mar 2017	15072-527	P. Chin	D. VanVliet	M.Urtheil

Figure 4-7

I:\City of Guelph\15072\Figures and Tables\GHG\2013\Report\Risk Assessment\Figure_4-7_Vertical_Hydraulic_Head_Difference_CityofGuelph.mxd

In general, the map illustrates that there are small downwards potentials into the Gasport Formation across a large amount of the Study Area, and that there are upwards potentials near surface water features. The largest head differences are highlighted on the figures as dark blue areas and correspond to areas in the Gasport Formation aquifer that experience significant drawdown due to the municipal supply wells.

4.2 Water Budget

Estimates of the water budget components for the Upper Speed Assessment Area for the period of 1960 to 2005 are summarized in Table 4-1 for the complete hydrologic system including surface and groundwater components. The table summarizes area inflows including precipitation, wastewater influent, and cross-boundary groundwater inflow. Outflows include evapotranspiration, streamflow (Speed River), groundwater pumping, and cross-boundary groundwater outflow. The water budget parameters are calculated based on information derived from both the surface water and groundwater flow models and are presented in units of m^3/day, mm/year, and as a percentage of precipitation. Figure 4-8 illustrates the estimated cross-boundary groundwater flow between the Upper Speed Assessment Area and adjacent areas. These values are referenced in the following discussion.

TABLE 4-1 Water Balance - Upper Speed Assessment Area (Complete System)

Water Budget Component	Flow (m^3/day)	Flow (mm/year)	Percent of Precipitation
Inflows			
Precipitation	1,553,000	923	100%
Guelph Wastewater Treatment Plant Effluent	56,000	33	4%
Groundwater Flow In	11,600	7	1%
Total Inflow	1,620,600	963	105%
Outflows			
Evapotranspiration	985,500	585	63%
Average Streamflow	568,000	338	37%
Permitted Groundwater Takings	62,700	37	4%
Groundwater Flow Out	4,400	3	0%
Total Outflow	1,620,600	963	105%

As shown in Table 4-1 and described in Appendix A, average annual precipitation in the Upper Speed Assessment Area is 923 mm/year as measured at the Guelph Arboretum climate station. As the region has an area of approximately 614 km^2, this translates to a rate of 1,553,000 m^3/day. The Guelph Wastewater Treatment Plant (WWTP) contributes approximately 56,000 m^3/day (2006 Average; CH2MHill 2009). Groundwater modelling results indicate that approximately 7 mm/year or 11,600 m^3/day of groundwater flows into the area across the boundaries from adjacent areas.

Outflows include evapotranspiration, streamflow, groundwater pumping, and groundwater flow out of the area. Average annual evapotranspiration is approximately 585 mm/year. Average annual streamflow consisting of the flow from the WWTP plus the flow as measured at the WSC Speed River Below Guelph Station (WSC 02GA015) is 568,000 m^3/day or 338 mm/year across the area. Groundwater takings simulated in the groundwater model are 62,700 m^3/day, or 37 mm/year, and 4,400 m^3/day of groundwater flows out of the area.

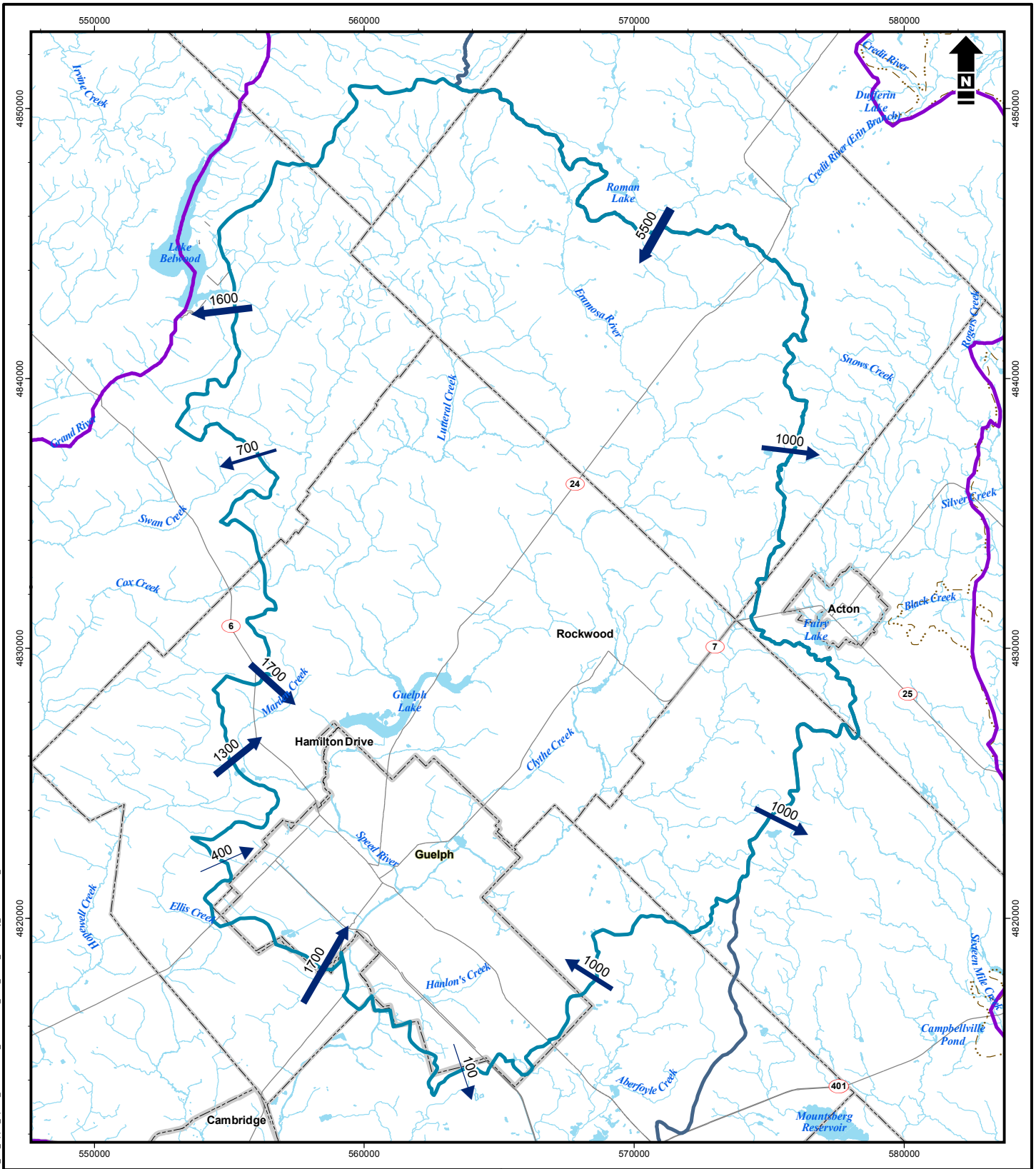
The water balance for the groundwater portion of the hydrologic cycle is summarized in Table 4-2. The water budget models predict an average annual groundwater recharge rate of 185 mm/year or 311,600 m^3/day into the Upper Speed Assessment Area. Groundwater flow into the area is approximately 7 mm/year or 11,600 m^3/day, representing approximately 4% of the recharge. The Arkell Recharge System contributes on average 3,000 m^3/day to the groundwater system from the Eramosa River Intake under Existing (2008) conditions.

TABLE 4-2 Water Balance - Upper Speed Assessment Area (Groundwater Model)

Water Budget Component	Flow (m^3/day)	Flow (mm/year)	Percent of Recharge
Inflows			
Groundwater Recharge	311,600	185	100%
Groundwater Flow In	11,600	7	4%
Contribution from Recharge System	3,000	2	1%
Total Groundwater Inflow	326,200	194	105%
Outflows			
Surface Water Discharge	259,100	154	83%
Permitted Groundwater Takings	62,700	37	20%
Groundwater Flow Out	4,400	3	2%
Total Groundwater Outflow	326,200	194	105%

Groundwater outflows include discharge to surface water (streams and wetlands), groundwater wells, and groundwater flow out of the subwatershed. Total groundwater discharge to surface water is approximately 259,100 m^3/day or 154 mm/year. Groundwater takings simulated in the model are 62,700 m^3/day, or approximately 20% of the groundwater recharge. Groundwater flow out of the subwatershed is 4,400 m^3/day or 2% of recharge.

A full summary of the water budget components for each subwatershed within the model domain is provided on Figure 4-9. The magnitude and direction of cross-boundary flows, both into and out of each subwatershed, are also provided.



- Tier Three Model Boundary (Study Area)
- Grand River Watershed Boundary
- Upper Speed Assessment Area
- Community
- Water Body
- Watercourse
- Major Road
- Niagara Escarpment
- Cross Boundary Groundwater Flow

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2 0 2
Kilometres
NAD 1983 UTM Zone 17N

I:\City of Guelph\15072\Figures and Tables\GHG\2013\Report\RiskAssessment\Figure_4-8_Upper_Speed_Groundwater_Assessment_Area_Cross_Boundary_Groundwater_Flow.mxd

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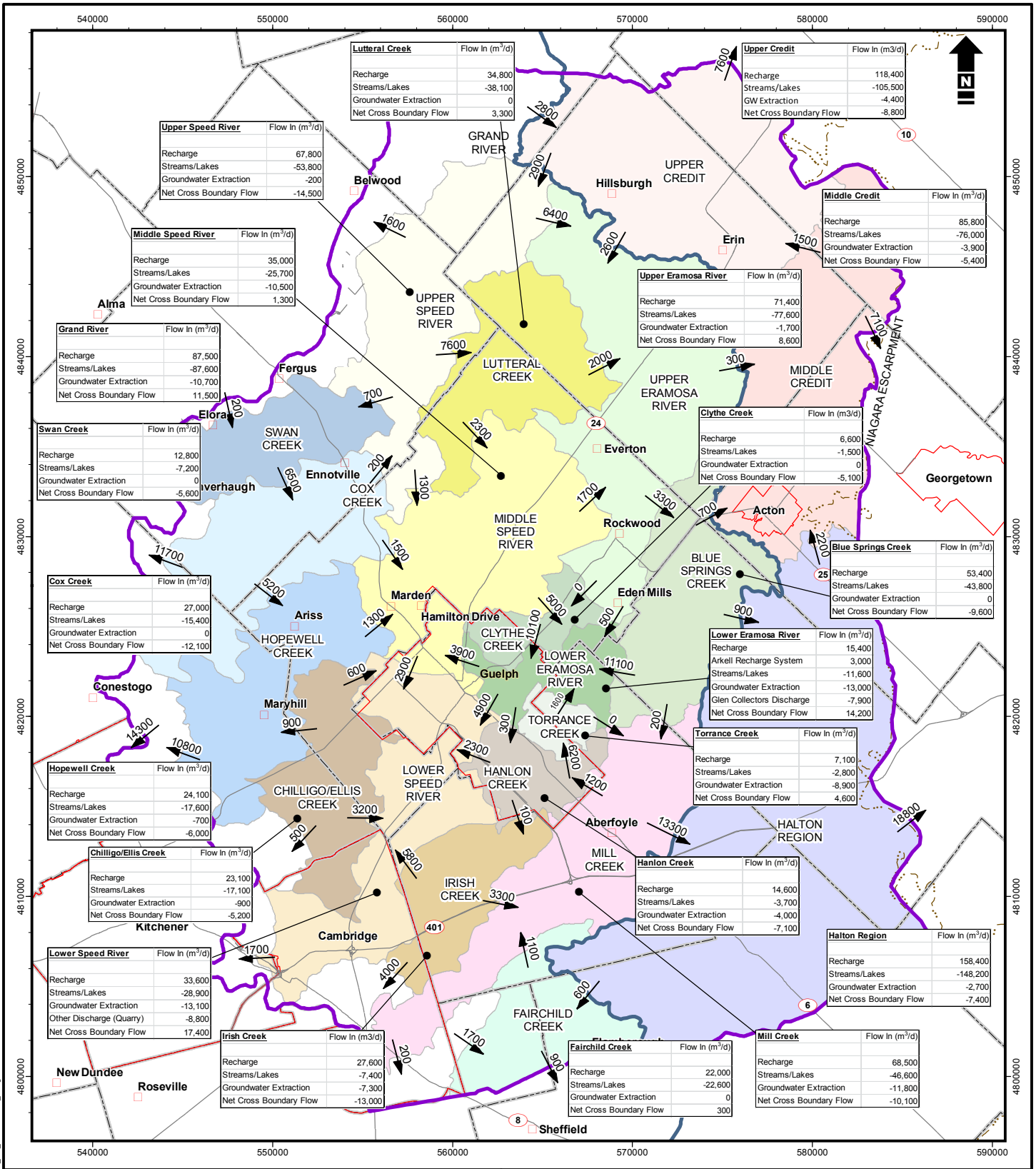
City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Upper Speed Groundwater Assessment Area Cross-Boundary Groundwater Flow

Date: 26 Jan 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M.Urtheil

Figure 4-8



Tier Three Model Boundary (Study Area)

Grand River Watershed Boundary

Community

Major Road

Niagara Escarpment

150 Cross Subwatershed Boundary Groundwater Flow (m^3/d)

Lower Eramosa River	Flow In (m^3/d)
Recharge	15,400
Arkell Recharge System	3,000
Streams/Lakes	-11,600
Groundwater Extraction	-13,000
Glen Collectors Discharge	-7,900
Net Cross Boundary Flow	14,200

Note: Flow In (m^3/d):
> 0 - Volume Entering Subwatershed Groundwater System
< 0 - Volume Leaving Subwatershed Groundwater System

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1:300,000

2 0 2 Kilometres

NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Groundwater Budget

Date: 26 Jan 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

Figure 4-9

I:\City of Guelph\15072\Figures and Tables\GHG\2013\Report\Risk Assessment\Figure_4-9_Groundwater_Budget.mxd

4.3 Subwatershed Stress Assessment

As described previously in the Grand River Watershed Tier Two Integrated Water Budget and Subwatershed Quantity Stress Assessment reports (AquaResource 2009a; 2009b), the municipal wells for the City of Guelph and the Township of Guelph/Eramosa (Rockwood and Hamilton Drive) are located in the Upper Speed Assessment Area, which is classified as having *Moderate* potential for subwatershed stress for groundwater sources in the Stress Assessment. While there are no documented issues with respect to the municipal sources meeting demand, the municipalities with wells located within this subwatershed are required to complete a Tier Three Assessment. In this section, the subwatershed stress is recalculated for the Upper Speed Assessment Area using the Tier Three Assessment water budget results.

4.3.1 Stress Assessment Methodology

The approach for conducting a Subwatershed Stress Assessment is outlined in the Province's *Water Budget & Water Quantity Risk Assessment Guide* (Risk Assessment Guide; AquaResource 2011a). The Risk Assessment Guide prescribes an approach for estimating subwatershed stress based on estimates for water supply, water reserve, and water demand in each subwatershed. While estimated values for water supply and water reserve are calculated using the water budget model results, the water demand is estimated using municipal and non-municipal wells.

A subwatershed's potential for stress is estimated by comparing the amount of water consumed with the amount of water available. As outlined in the Risk Assessment Guide (AquaResource 2011a), the Percent Water Demand is calculated using the following formula:

$$\textit{Percent Water Demand} = \frac{Q_{DEMAND}}{Q_{SUPPLY} - Q_{RESERVE}} \; x\ 100\%$$

The terms are defined below:

- Q_{DEMAND} is equal to the consumptive demand calculated as the estimated rate of locally consumptive takings. (Note: only groundwater demands are considered here).

- Q_{SUPPLY} is the water supply term, calculated for groundwater supplies as the estimated annual recharge rate plus the estimated groundwater inflow into a subwatershed.

- $Q_{RESERVE}$ is the water reserve, defined as the specified amount of water that does not contribute to the available water supply. Groundwater reserve is calculated as 10% of the total estimated groundwater discharge within a subwatershed.

The Stress Assessment calculation is carried out for the average annual demand conditions and for the monthly maximum demand conditions. The stress level for groundwater systems is categorized into three levels (*Significant, Moderate,* or *Low*) according to the thresholds listed in Table 4-3.

TABLE 4-3 Groundwater Potential Stress Thresholds

Groundwater Potential Stress Level Assignment	Average Annual	Monthly Maximum
Significant	> 25%	> 50%
Moderate	> 10%	> 25%
Low	0 to 10%	0 to 25%

Subwatersheds are classified as having a S*ignificant* or *Moderate* potential for hydrologic stress so the subwatersheds with a higher probability of experiencing water quantity related environmental impacts can be studied in greater detail (Tier Three) than those with a lower probability of impact. The Tier Three studies are more detailed to improve the local understanding of the potential impacts on municipal drinking water sources from various Drinking Water Threats. Subwatersheds identified as having a *Low* potential for stress are not likely to be affected by water takings under the current water taking regimes; therefore, a more detailed level of study is unnecessary unless increased, or additional water takings move the subwatershed into a higher stress category (e.g., a S*ignificant* or *Moderate* potential for hydrologic stress).

4.3.2 Groundwater Stress Assessment Calculations

4.3.2.1 Existing conditions

The Percent Water Demand is calculated using estimated groundwater supply, reserve, and consumptive demand in the Upper Speed Assessment Area. These estimated components of the Groundwater Stress Assessment are summarized on Table 4-4 and calculated as follows:

- Groundwater supply is calculated as the average annual groundwater recharge plus the amount of groundwater flow into the area plus groundwater contributions from the Arkell Recharge System. Groundwater recharge and the lateral groundwater flow were estimated using the FEFLOW model.

- Groundwater reserve is calculated as 10% of the estimated groundwater discharge in the Upper Speed Assessment Area as calculated by the FEFLOW model.

- The average consumptive water demand values are estimated in Section 3. Under existing conditions, the average demand consists of 41,181 m^3/day for the City of Guelph's municipal wells and 6,500 m^3/day for the Glen Collector for a total of 47,681 m^3/day. Existing municipal demand rates for the Township of Guelph/Eramosa (Rockwood and Hamilton Drive wells) are provided in Table 3-6 and are 967 m^3/day and 179 m^3/day, respectively for a total of 1,146 m^3/day. An additional 12,934 m^3/day for non-municipal demand gives a total of 61,761 m^3/day for the area.

- The monthly maximum consumptive water demand for the City of Guelph, determined from historical records, was 52,914 m^3/day. The Glen Collector contribution was held constant at 6,500 m^3/day. This resulted in a monthly maximum demand of 59,414 m^3/day for the City of Guelph. The maximum monthly demand for the Township of Guelph/Eramosa (Rockwood and Hamilton Drive wells) was 1,733 m^3/day; for non-municipal demands, it was 16,436 m^3/day. These give a total of 77,583 m^3/day for the area.

TABLE 4-4 Stress Assessment - Upper Speed Groundwater Assessment Area

Supply (m^3/day)	Flow In		11,600
	Recharge		311,600
	Arkell Recharge System		3,000
	TOTAL		326,200
Reserve (m^3/day)			25,900
Existing Conditions	Demand (m^3/day)	Average	61,761
		Maximum Monthly	77,583
	% Water Demand	Average	21%
		Maximum Monthly	26%
Planned Conditions	Demand (m^3/day)	Average	88,476
		Maximum Monthly	104,298
	% Water Demand	Average	29%
		Maximum Monthly	35%

Using the Tier Three water budget models, under Existing conditions the Upper Speed Assessment Area had an estimated percent water demand of 21% under average demand and 26% under maximum monthly demand. These estimates result in a classification of *Moderate* potential for stress under average demand conditions and a *Moderate* potential for stress under maximum monthly demand conditions. Under the Tier Two Stress Assessment (AquaResource 2009b), the Assessment Area had estimated percent water demands of 20% and 23% under average demand and maximum monthly demand conditions, respectively.

4.3.2.2 Planned Conditions

The Planned Conditions Stress Assessment evaluates the impact of increased municipal demand on the potential for subwatershed stress. The Planned conditions average demand for the City of Guelph was taken as the Allocated rate estimated for 2031 as given in Table 3-7 consisting of 66,550 m^3/day for the municipal wells and 6,900 m^3/day for the Glen Collector for a total of 73,450 m^3/day. This is an increase of 25,769 m^3/day over the Existing conditions demand.

The Planned conditions average demand for Rockwood was estimated as 1,907 m^3/day and for Hamilton Drive was 185 m^3/day as shown on Table 3-8. This is an increase of 946 m^3/day over the Existing conditions demands.

Future non-municipal water demand estimates are assumed equal to current estimates and thus are held constant at 12,934 m^3/day. The total Planned conditions average demand for the subwatershed is 88,476 m^3/day.

The monthly maximum consumptive water demand under Planned conditions for the area was determined by adding the increased average demands of 25,769 m^3/day and 946 m^3/day to the maximum demand under Existing conditions giving a total of 104,298 m^3/day. Table 4-4 also summarizes the Stress Assessment calculation for the subwatershed under Planned conditions.

Under Planned conditions, the Upper Speed Assessment Area has an estimated percent water demand of 29% under average demand and 35% under maximum monthly demand. Based on the thresholds established by the Risk Assessment Guide (AquaResource 2011a; Table 4-3) these estimates result in a classification of *Significant* potential for stress under average demand conditions and a *Moderate* potential for stress under maximum monthly demand conditions. Under the Tier Two Stress Assessment (AquaResource 2009b), the Assessment Area was found to have estimated percent water demands under Planned conditions of 24% and 26% under average demand and maximum demand conditions, respectively. These resulted in a classification of *Moderate* potential for stress under both average and maximum demand conditions.

5 LOCAL AREA RISK ASSESSMENT

A Tier Three Assessment is completed to estimate the likelihood a municipality's drinking water wells or surface water intakes will be able to supply their Allocated rates without negatively impacting other water uses. According to the Technical Rules (Part III.2; MOECC 2016) a Tier Three Assessment must be completed for all Type I, II, and III drinking water systems where

- there have been historical issues with water sources meeting demand
- the Tier Two Assessment classified the subwatershed containing one or more municipal well as having a *Moderate* or *Significant* potential for hydrologic stress

As described previously, the municipal wells for the City of Guelph and the Township of Guelph/Eramosa (Rockwood and Hamilton Drive) are located in the Upper Speed Assessment Area, which was classified as having *Moderate* subwatershed stress levels for groundwater sources in the Tier Two Stress Assessment (AquaResource 2009b). This circumstance required a Tier Three Assessment for the municipal wells of these three communities. There are no documented issues with respect to the municipal well sources meeting their past or current municipal demands.

The City of Guelph operates a surface water intake on the Eramosa River. The Eramosa River subwatershed, which contributes water to the river at the intake, was classified as having a *Moderate*

subwatershed stress level for surface water sources. This circumstance required the City of Guelph to undergo a Tier Three Assessment for the Eramosa Intake.

As part of the Tier Three Assessment, water budget models are used to delineate water quantity Vulnerable Areas, including the "Local Area" for groundwater wells or surface water intakes; these Vulnerable Areas form the basis for the Local Area Risk Assessment. The term "Local Area" is introduced in the MOECC Director's Rules (Part III.2; MOECC 2016) to focus the water budget assessment around drinking water wells or intakes and in this study the Local Areas are represented by the groundwater Vulnerable Areas (WHPA-Q1/WHPA-Q2) and Surface Water Vulnerable Area (IPZ-Q). In this assessment, the water budget models are used to assess the potential impact of proposed increases in water demand, changes in land use and climatic variability on the municipal water wells and surface water intakes. Where these scenarios identify a potential that wells or intakes will not be able to supply their Allocated rates, the Vulnerable Area is assigned a *Significant* Water Quantity Risk Level, and the consumptive water uses and reductions in groundwater recharge within those Vulnerable Areas will be identified as *Significant* Drinking Water Threats. The risk scenarios also consider the need to meet the water demand requirements of other surrounding uses, particularly those that are required to be maintained by provincial or federal law such as wastewater assimilation flows or the ecological flow requirements of cold-water fish habitat. When these other water uses are impacted beyond prescribed thresholds, a *Moderate* or *Significant* Risk Level is assigned to the Vulnerable Areas and the consumptive water uses and reductions in groundwater recharge within those areas will be identified as *Moderate* or *Significant* Drinking Water Threats.

Municipalities typically implement physical solutions (e.g., storage reservoirs, peaking / backup intakes) and demand management/water conservation measures to reduce the instantaneous water demand required from drinking water sources or to reduce the community's peak water demand. These types of measures are implemented to increase a municipality's "tolerance" to short-term water shortages. Tolerance effectively reduces the potential that a municipality will face short- or long-term water quantity shortages.

5.1 Methods

The following steps are required when completing a Local Area Risk Assessment:

1. Delineate Vulnerable Areas for Groundwater: The Groundwater Quantity Vulnerable Areas (WHPA-Q1 and WHPA-Q2) are delineated using the Tier Three Water Budget Model (see definitions in Section 5.2 below).

2. Delineate Vulnerable Areas for Surface Water: As a portion of the City of Guelph's water supply is indirectly sourced from surface water, the Surface Water Vulnerable Area (IPZ-Q) is delineated as the drainage area contributing to the Eramosa River Intake and the area that provides recharge to an aquifer that contributes groundwater discharge to the drainage area.

3. Define the Local Areas based on the water quantity Vulnerable Areas: WHPA-Q1, WHPA-Q2, and IPZ-Q.

4. Evaluate risk scenarios: A series of predictive model scenarios are run to examine the potential impact on the municipal wells, intakes, and other water uses of increased pumping at the Allocated rates, average and drought conditions, and future land use (as specified in the municipality's Official Plan). The scenarios are evaluated in terms of the ability of the wells or intakes to pump water as well as the impact to other water uses.

5. Assign Risk Level: A Risk Level (*Low*, *Moderate*, or *Significant*) is assigned to the Vulnerable Area(s) based on the results of the risk scenarios. An uncertainty level (e.g., *High* or *Low*) is also applied to the Vulnerable Areas.

6. Identify *Significant* and *Moderate* Drinking Water Quantity Threats and areas: Drinking Water Quantity Threats include all consumptive water uses and any reductions in recharge within the Vulnerable Areas.

5.2 Delineation of Vulnerable Areas for Groundwater Wells

Similar to water quality Vulnerable Areas, the water quantity Vulnerable Areas for Groundwater (Wellhead Protection Area for Quantity: WHPA-Q1 and WHPA-Q2) are delineated to protect the quantity of water required by a municipality to meet their current or future (Allocated) water supply needs. The Technical Rules (MOECC 2016) require that WHPA-Q1 and WHPA-Q2 areas be delineated for all municipal water supply wells that extract water from a subwatershed assigned a groundwater stress level of *Moderate* or *Significant* in the Tier Two Water Budget and Subwatershed Stress Assessment.

The WHPA-Q1 is delineated as the combined area that is the cone of influence of the well and the whole of the cones of influence of all other wells that intersect that area (MOECC 2016). The cone of influence for the well(s) was estimated by calculating the difference in the potentiometric heads in the main bedrock aquifer under Existing plus Committed municipal demands and current land use versus the potentiometric heads in the aquifer with no pumping. The extent of the cone of influence is determined by selecting an appropriate drawdown threshold, which considers several factors including observed seasonal aquifer water level fluctuations (e.g., 1.0 to 2.0 m) and available field observations of pumping induced drawdown around the municipal wells.

The WHPA-Q2 is delineated as the WHPA-Q1 plus any area where a future reduction in recharge would have a measurable impact on the cone of influence of the municipal wells. Areas where future reductions in recharge are expected to occur were identified using the Official Plans, and the maximum recharge reductions that may result from the land use development were considered.

5.2.1 WHPA-Q1

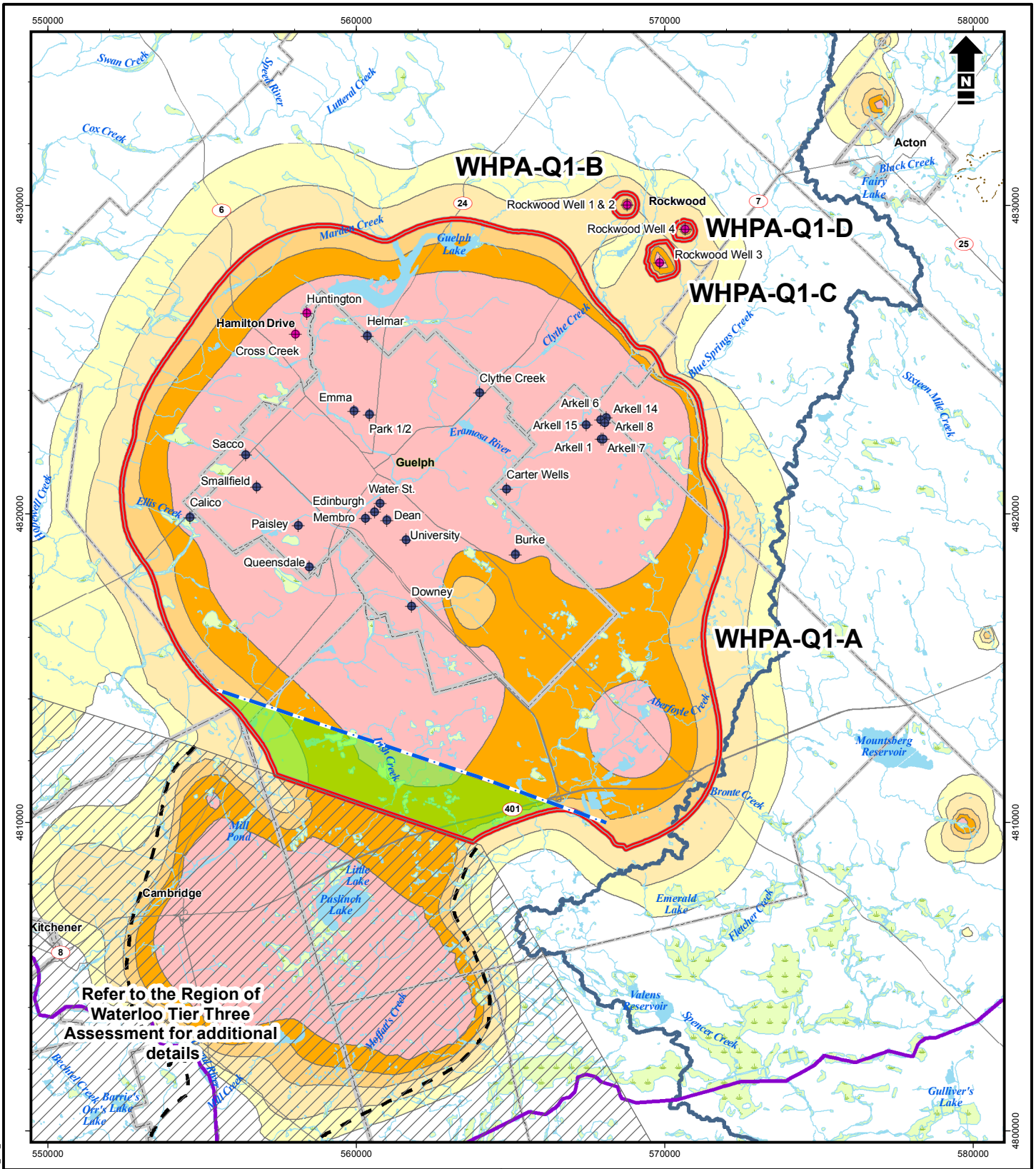
The WHPA-Q1 Vulnerable Areas for Groundwater were delineated by examining the change in model predicted heads within the production aquifers between two model scenarios:

1. Steady-state model simulating existing land use, and no municipal or non-municipal pumping. This scenario establishes water levels that would exist without pumping.

2. Steady-state model simulating existing land use and the municipal wells of the City of Guelph; and those in Rockwood, Hamilton Drive, and Cambridge are simulated to pump at their Allocated rates (i.e., Existing plus Committed; Risk Assessment Scenario G[2]).

The model predicted heads in the Gasport Formation for each of the above scenarios were subtracted from one another. Simulated drawdown was greatest and extended furthest in this production aquifer and thus it was used to delineate the WHPA-Q1 areas. The average seasonal water level fluctuation within wells monitoring heads in the Gasport Formation is +/- 2.0 m; therefore, the 2.0 m drawdown contour was used as the boundary of the WHPA-Q1 areas as shown on Figure 5-1 (Appendices A and C provide hydrographs of high quality wells).

WHPA-Q1-A is derived from the 2.0 m drawdown contour surrounding the City of Guelph and Hamilton Drive wells. WHPA-Q1-B, WHPA-Q1-C, and WHPA-Q1-D are derived from the 2.0 m drawdown contours surrounding the Rockwood wells 1 and 2, Rockwood Well 3, and Rockwood Well 4, respectively (Figure 5-1). The WHPA-Q1-A extends toward Cambridge and is truncated 2 km southwest of the modelled groundwater divide in the Gasport Formation aquifer. This divide was used to mark a separation between the WHPA-Q1-A delineated in this Tier Three Assessment from the WHPA-Q1 derived for the Cambridge wells as part of the Region of Waterloo Tier Three Assessment (Matrix and SSPA 2014). The groundwater divide between the Vulnerable Areas has been buffered by 2 km to represent seasonal variation and this leads to a 4 km wide overlap between the Vulnerable Areas. This is described in more detail in Appendix H.



Tier Three Model Boundary (Study Area)
Grand River Watershed Regulatory Boundary
Community
Wetland
Water Body
Watercourse
Major Road
Niagara Escarpment
WHPA-Q1
WHPA-Q1 - ROW Tier Three

Groundwater Divide Between Guelph and Cambridge WHPA-Q1
2 km Buffer South of Groundwater Divide
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

Drawdown (m)
0.50 - 1.00
1.00 - 2.00
2.00 - 3.00
3.00 - 5.00
> 5.00

1:175,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

WHPA-Q1

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-1

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5.2.2 WHPA-Q2

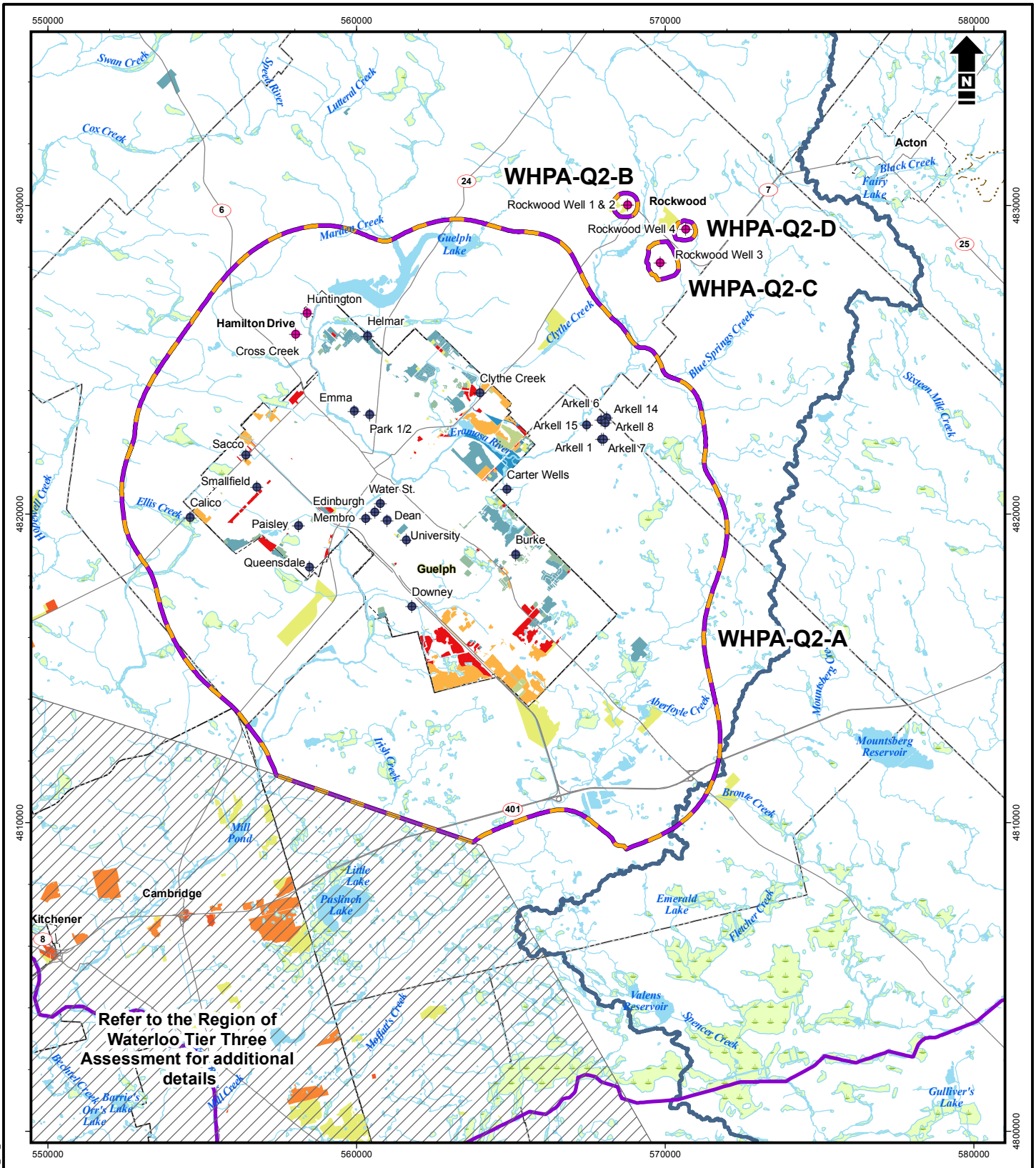
The WHPA-Q2 Vulnerable Area for groundwater is defined in the Technical Rules (MOECC 2016) as the WHPA-Q1 area, plus any area where a future reduction in recharge, as defined in the Official Plans, may have a measurable impact on that area. Figure 5-2 illustrates the proposed land development areas in relation to WHPA-Q1 determined above.

All of the areas that have the potential to reduce the available drawdown in a municipal well, such that the well may have difficulty pumping at its Allocated rate, are already included within the WHPA-Q1-A. The closest area of potential recharge reduction outside of the WHPA-Q1-A is over 10 km from the closest municipal well (Burke) and was found to have no impact on water levels at that well.

In Rockwood, areas of proposed land use change fall outside WHPA-Q1-B, WHPA-Q1-C, and WHPA-Q1-D; however, the amount of modelled drawdown caused by the reduction of recharge in these areas was considered negligible. The WHPA-Q2 Vulnerable Areas for the City of Guelph wells and Township of Guelph/Eramosa wells in Rockwood and Hamilton Drive are therefore the same the WHPA-Q1 areas and are designated: WHPA-Q2-A, WHPA-Q2-B, WHPA-Q2-C, and WHPA-Q2-D (Figure 5-2).

5.2.3 Groundwater Vulnerable Areas

The final groundwater Vulnerable Areas (A, B, C, and D) are represented by the WHPA-Q1/WHPA-Q2 areas (Figure 5-3) and will be used to identify Water Quantity Threats in Section 6.



Tier Three Model Boundary (Study Area)
Grand River Watershed Regulatory Boundary
Community
Wetland
Water Body
Watercourse
Major Road
Niagara Escarpment

WHPA-Q2
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

Percent Imperviousness Increase

< 10%
10% - 20%
20% - 30%
30% - 40%
40% - 50%
50% - 60%
60% - 70%
70% - 80%
80% - 90%
> 90%

1:175,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

Referenece: Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008. Produced using information under License with the Grand River Conservation Authority. Copyright © Grand River Conservation Authority, 2013 Produced using information provided by the Ministry of Natural Resources, Copyright © Queen's Printer, 2013

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

WHPA-Q2

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

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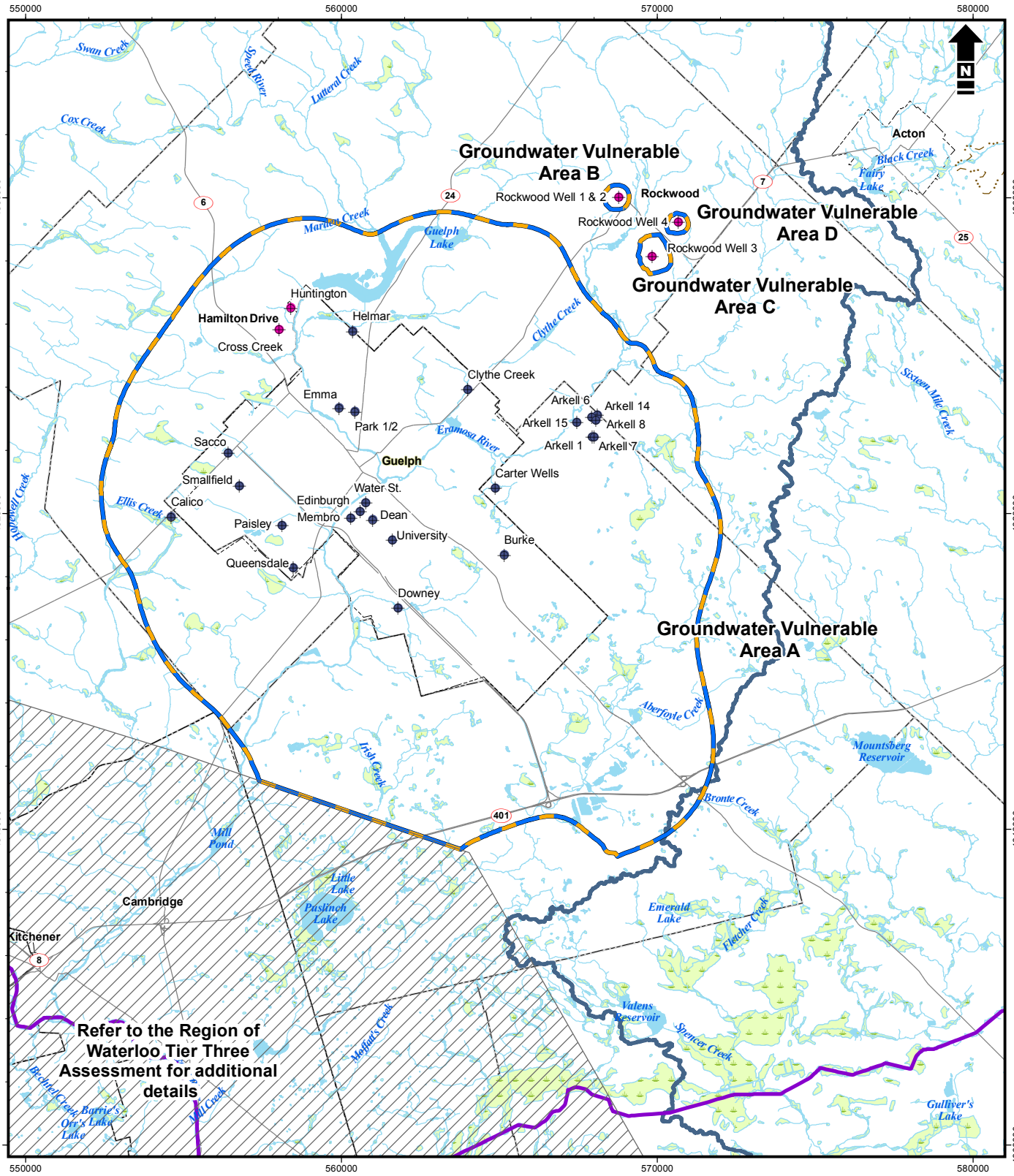
Figure 5-2



Tier Three Model Boundary (Study Area)
Grand River Watershed Regulatory Boundary
Community
Wetland
Water Body
Watercourse
Major Road
Niagara Escarpment
Groundwater Vulnerable Area
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

1:175,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Groundwater Vulnerable Areas

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-3

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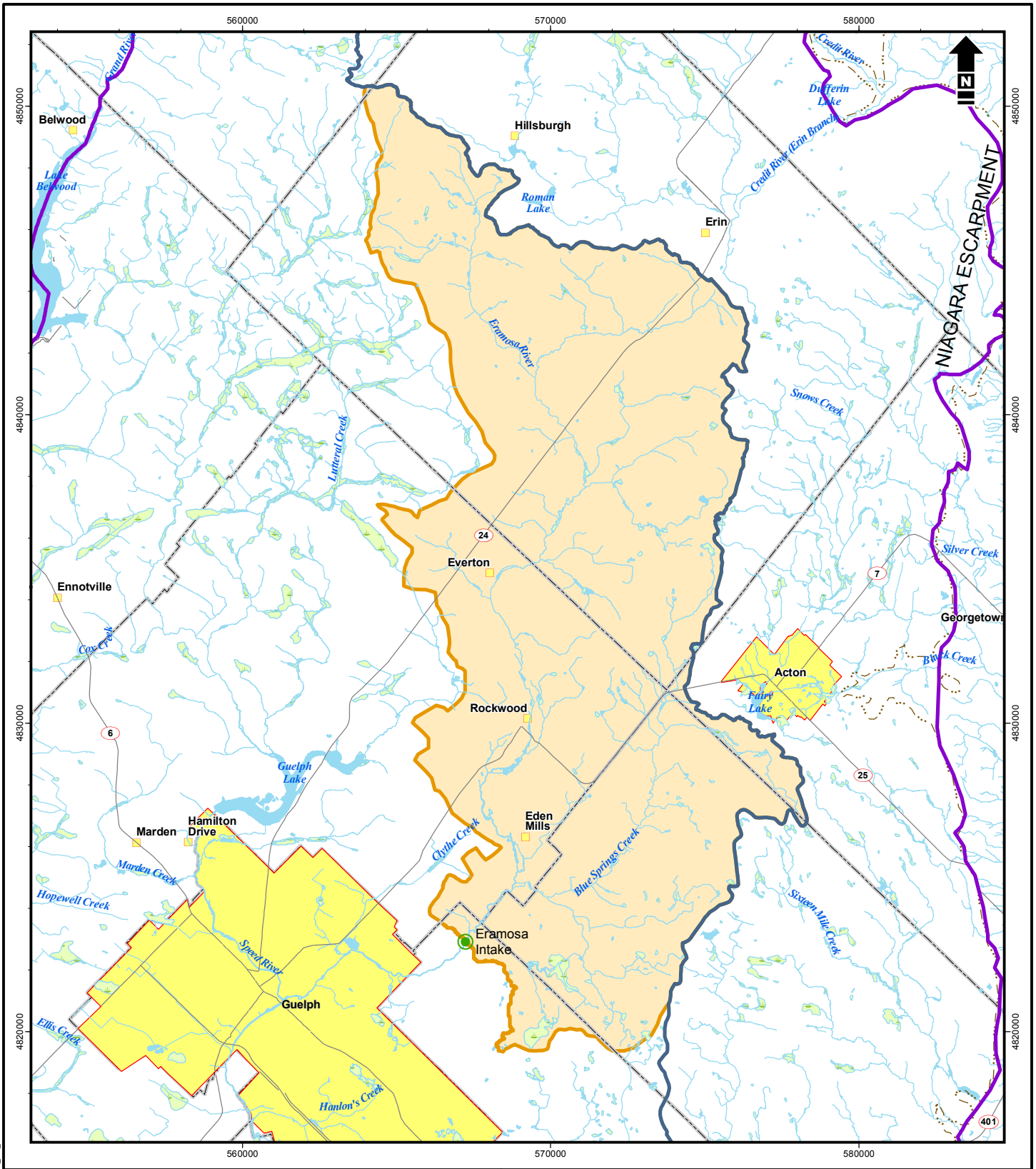
5.3 Delineation of Vulnerable Areas for Surface Water Intakes

For surface water intakes, the Surface Water Quantity Vulnerable Area (IPZ-Q; Intake Protection Zone - Quantity), corresponds to the drainage area that contributes surface water to the intake and the area that provides recharge to aquifers that contribute groundwater discharge to the drainage area (Figure 5-4). Part VI.7 of the Technical Rules (MOECC 2016) specifies the rules with respect to the delineation of IPZ-Q.

For this Tier Three Assessment, the drainage area that contributes surface water to the Eramosa River Intake was delineated as the Eramosa River found upstream of the intake and tributaries that supply the Eramosa River (e.g., Blue Springs Creek). Areas that lie outside of this drainage area, but still provide recharge to an aquifer that contributes groundwater discharge to the drainage area, were delineated using particle tracking tools in the groundwater flow model.

Areas where simulated particle tracking indicated that the IPZ-Q may extend slightly (less than 1.5 km) east of the Grand River Watershed boundary and into the Credit River and Halton Region watersheds were removed from the IPZ-Q. These areas were removed in recognition that there is uncertainty in the determination of the groundwater divide between the watersheds and small changes in simulated local recharge could shift the divide. Similarly, an area was removed from the IPZ-Q, which was found just inside (west) of the Grand River Watershed boundary, but was located so far north that it was subject to boundary effects by being too close to the northern model boundary.

The removed areas contributed an insignificant amount of recharge to the aquifer that contributes groundwater discharge to the drainage area and thus were removed to constrain the IPZ-Q to the Grand River Watershed. Figure 5-4 illustrates the final IPZ-Q.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
IPZ-Q
Community
Wetland
Watercourse
Water Body
Major Road
Niagara Escarpment
River Intake

Referenece: Base Data - City of Guelph, 2009; GRCA, 2008, CVC, 2008, Ministry of Natural Resources, 2008. Produced using information under License with the Grand River Conservation Authority. Copyright © Grand River Conservation Authority, 2013 Produced using information provided by the Ministry of Natural Resources, Copyright © Queen's Printer, 2013

1:175,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

IPZ-Q

Date: 27 Jan 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

Figure 5-4

5.4 Description of Risk Assessment Scenarios

The scenarios to be evaluated, as listed in the Technical Rules (MOECC 2016), are summarized in Table 5-1. As there is no Planned quantity of water, only the demands associated with the Allocated rates will be described in the following sections.

TABLE 5-1 Summary of Risk Assessment Scenarios (MOECC 2016)

Scenario	Supply	Time Period	Data Restrictions
A	SW	The period for which climate and streamflow data are available for the Local Area	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the Study Period.
B	SW	10-year drought period	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the Study Period.
C	GW	The period for which climate and streamflow data are available for the Local Area	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the Study Period.
D	GW	10-year drought period	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the Study Period.
E	SW	The period for which climate and streamflow data are available for the Local Area	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the year in which the existing system with a Committed demand is operating at its Allocated quantity.
F	SW	10-year drought period	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the year in which existing system with a Committed demand is operating at its Allocated quantity.
G	GW	The period for which climate and streamflow data are available for the Local Area	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the year in which the existing system with a Committed demand is operating at its Allocated quantity.
H	GW	10-year drought period	Data related to average monthly pumping rates for water takings and land cover reflect conditions during the year in which the existing system with a Committed demand is operating at its Allocated quantity.

Notes:
SW - Scenario for Surface Water Supplies
GW - Scenario for Groundwater Supplies

5.4.1 Groundwater Supplies

In the above table, scenarios A, B, C, and D correspond to Existing pumping rates and land use under average climate and drought conditions, respectively. Scenarios E, F, G, and H correspond to future land use and Allocated rates for existing wells under average climate and drought conditions, respectively. Scenarios A, B, E, and F are evaluated to assess the Risk Level for the surface water Vulnerable Areas, and scenarios C, D, G, and H are evaluated to assess the Risk Level for the groundwater Vulnerable Areas. The Risk Assessment scenarios for groundwater were interpreted as follows:

- Scenarios representing average climate (i.e., C and G) can be simulated in the groundwater flow model using steady-state conditions.

- Scenarios representing drought conditions (i.e., D and H) can be simulated in the groundwater flow model using a transient model representing the drought period of the 1960s.

- Multiple versions of scenarios G and H may be required to evaluate the impact of Allocated pumping rates separate from impacts of land cover and the cumulative impact of both using the groundwater flow model.

- Impacts to other uses (e.g., wetlands and cold-water fisheries) are not evaluated for the drought scenarios (D and H). The drought scenarios only serve to identify the potential for water levels to fall beneath a safe water elevation for each municipal well.

Table 5-2 below summarizes the groundwater flow model scenarios evaluated for this Tier Three Assessment. These scenarios were designed primarily to assist in identifying the potential impacts from each of the water takings, land use, and drought on current hydrogeological conditions. The data required for each of the model scenarios are outlined in Section 5.

TABLE 5-2 Groundwater Risk Assessment Model Scenarios

Scenario	Time Period	Model Scenario Details			
		Land Cover	Municipal Pumping	Model Simulation	
C	Period for which climate and streamflow data are available for the Local Area (1960-2005)	Existing	Existing	Steady-state, Average Annual Recharge	
D	10 year drought period	Existing	Existing	Transient (1960 to 1970); Monthly recharge rates (GAWSER)	
G(1)	Period for which climate and streamflow data are available for the Local Area (1960-2005)	Planned (Official Plan)	Existing plus Committed	Groundwater Recharge Reduction and Increase in Demand	Steady-state, Average Annual Recharge
G(2)		Existing	Existing plus Committed	Groundwater Discharge Reduction from Increase in Demand	
G(3)		Planned (Official Plan)	Existing	Groundwater Recharge Reduction	
H(1)	10 year drought period	Planned (Official Plan)	Existing plus Committed	Groundwater Recharge Reduction and Increase in Demand	Transient (1960 to 1970); Monthly recharge rates (GAWSER)
H(2)		Existing	Existing plus Committed	Groundwater Discharge Reduction from Increase in Demand	
H(3)		Planned (Official Plan)	Existing	Groundwater Recharge Reduction	

5.4.2 Surface Water

As described in Section 3.1.4, water pumped from the Eramosa River Intake is not fed directly into the City of Guelph's drinking water system. Pumped water is discharged into an artificial recharge system, which feeds the Glen Collector. Water pumped from the Glen Collector is treated and made available to the drinking water system.

The City of Guelph's PTTW for the Eramosa River Intake requires that the river discharge be maintained at 0.43 m^3/s at the intake and flow downstream at the wastewater treatment plant must also be maintained at a specified value for the intake to operate. The permit also constrains the maximum pumping rate depending on the date between April 15 and November 15.

In recent years, discharge at the Eramosa Intake has fallen below 0.43 m^3/s for at least 1 day between April 15 and November 15 in 2001, 2003, 2005, and 2007 resulting in a condition where the City of Guelph could not operate the intake. However, these conditions did not directly result in a risk to the City of Guelph's drinking water quantity. During lower water periods the Glen Collector continued to discharge stored water that was derived from both the artificial recharge system and the natural groundwater flow system. Regardless, the City of Guelph relies upon the Glen Collector to supply its

Allocated rate (as discussed in Section 3.2.3), which is impacted by the City of Guelph's ability to pump from the Eramosa Intake. If the flow conditions in the Eramosa River change such that there are more days during the summer when the City of Guelph cannot pump from the Eramosa Intake, the yield of the Glen Collector could be impacted.

Considering that water pumped from the Eramosa Intake is not fed directly into the drinking water system, and that the Glen Collector was included in the Risk Assessment for groundwater, a Risk Assessment for the surface water supply was not completed. However, to ensure the sustainability of the Glen Collector and the Eramosa Intake, the Surface Water Vulnerable Area (IPZ-Q) was assigned the same Risk Level as the Groundwater Vulnerable Area that contains the Glen Collector.

5.5 Risk Assessment - Groundwater

5.5.1 Development of Risk Assessment Scenarios

The following sections describe the approach followed to develop and evaluate each Risk Assessment scenario.

5.5.1.1 Scenario C - Existing Conditions, Average Climate

Scenario C evaluates hydrogeologic conditions under Existing pumping rates and average climate conditions. This scenario was simulated in steady-state using the FEFLOW model and 2008 typical pumping rates for City of Guelph wells, 2009 to 2010 average pumping rates for the Township of Guelph/Eramosa wells in Rockwood and Hamilton Drive (Appendix F; Table F-2), and the calibrated average annual groundwater recharge distribution.

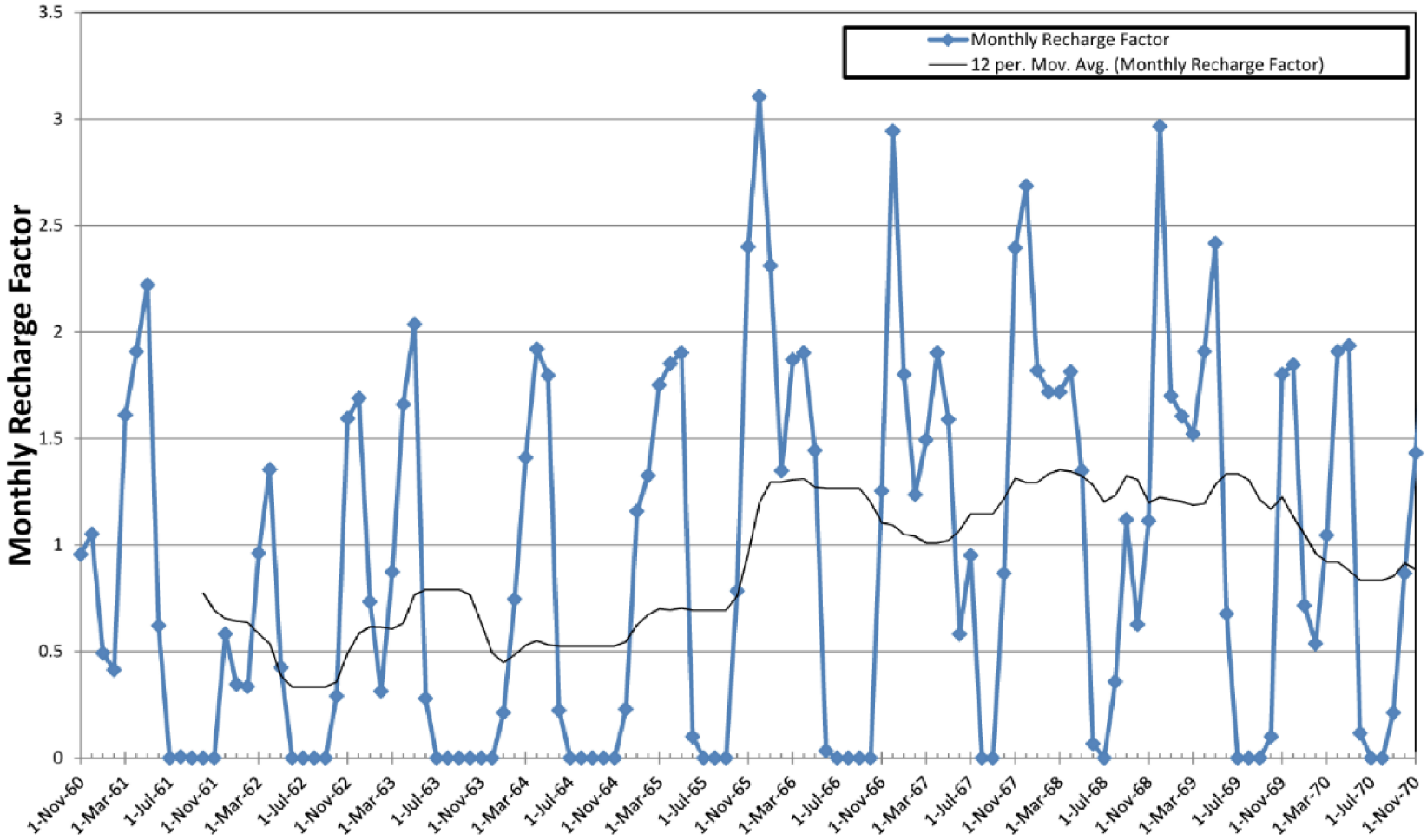
Scenario C differs from the steady-state model calibration results for four City of Guelph municipal wells due to the use of different pumping rates. During steady-state model calibration, the average 2008 pumping rate was used for Carter, Emma, Helmar, and Park 1 and 2 wells. These rates were significantly lower than the typical pumped rate because the wells were offline for significant periods during 2008. The typical pumped rates (Appendix F; Table F-2) used in Scenario C simulated the in-well water levels during typical pumped conditions.

5.5.1.2 Scenario D - Existing Conditions, Drought

Scenario D evaluates the impact of drought conditions on the ability for existing wells to pump Existing rates. This scenario was simulated using the calibrated Tier Three Groundwater Flow Model in continuous transient mode over a 10-year drought period (1960 to 1970). Figure 5-5 illustrates the variability of average monthly groundwater recharge rate, referred to as a monthly recharge factor, from 1960 to 1970 as estimated by the GAWSER model. Figure 5-5 also illustrates the 12-month moving average of the groundwater recharge rates, which highlights the lowest groundwater recharge rates during the drought period of the 1960s. For the drought scenario, the average recharge rates across the

model were multiplied by the monthly recharge factor over the period of the scenario to follow the trend predicted during the drought period.

Monthly pumping rates from 2008 were applied in the groundwater flow model to be representative of Existing pumping for the City of Guelph wells. Average pumping rates from 2009 to 2010 were used for the Township of Guelph/Eramosa municipal wells in Rockwood and Hamilton Drive. As outlined in the Technical Rules (MOECC 2016), the impacts of municipal pumping on other uses were not considered in this drought scenario. As a result, the main output parameters for this scenario are water levels at each of the municipal wells.



I:\City of Guelph\15072\Figures and Tables\GHG2013\Report\Risk Assessment\Figure_5-5_Long_Term_Monthly_Average_Groundwater_Recharge_Factor.mxd

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City of Guelph and Township of Guelph/Eramosa

Tier 3 Water Budget and Local Area Risk Assessment

Long-Term Monthly Average Groundwater Recharge Factor

Date:	Project:	Technical:	Reviewer:	Drawn:
07 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-5

5.5.1.3 Scenario G - Existing Plus Committed Demand, Future Land Development, Average Climate

Scenario G evaluates the ability for existing wells to maintain Allocated rates (Existing plus Committed) under average climate conditions and reductions in recharge. This scenario was simulated using the calibrated Tier Three Groundwater Flow Model in steady-state conditions using groundwater recharge rates that reflect long-term average climate conditions. Scenario G is subdivided into three scenarios: G(1), G(2), and G(3). This is to evaluate the impacts of recharge reductions and pumping, pumping, recharge reductions, respectively. The purpose of subdividing these scenarios is to isolate the impacts of municipal pumping from recharge reductions. Only Scenario G(2) is considered when evaluating the impact of the scenarios on wetlands and cold-water streams.

Scenario G(1)

This scenario evaluated the cumulative impact of increased municipal pumping rates (Allocated rates; Existing plus Committed) and reductions in recharge (assuming increased imperviousness) due to future land use changes defined in the Official Plans, on the municipal wells and other uses. Tables 3-7 and 3-8 list the Existing plus Committed water demands applied to evaluate this scenario (average day). Section 2.6 describes how recharge reductions were estimated based on potential land use changes (Figure 2-13). The recharge rates assigned for these areas were calculated by adjusting Existing recharge by the recharge reduction assumed for each land use. The scenario does not include the impacts of mitigation measures (e.g., Low Impact Development) on maintaining Existing recharge rates.

Scenario G(2)

This scenario evaluates the impact of increased municipal pumping rates (Allocated rates; Existing plus Committed) on the municipal wells and other water uses. The existing conditions land use was simulated in this scenario to isolate the influence of municipal pumping from land development. This scenario is used to evaluate the impact of the scenarios on wetlands and cold water streams. Baseflow reductions arising from land use development are independent from increased groundwater pumping, and only those impacts associated with groundwater pumping (i.e., Scenario G[2]) should be used to evaluate the Water Quantity Risk Level relating to the impact to other uses.

Scenario G(3)

This scenario evaluates the impact of reductions in recharge (due to increases in imperviousness) resulting from land use changes defined in the Official Plans on the municipal wells and other water uses. Existing municipal pumping rates were used in this scenario to isolate the influence of land development from a pumping increase to Existing plus Committed demand.

5.5.1.4 Scenario H - Existing Plus Committed Demand, Future Land Development, Drought Conditions

Scenario H evaluates the ability for existing wells to maintain Allocated rates (Existing plus Committed) through the 10-year drought period. The groundwater flow model was run transiently to examine the combined impact of drought conditions, land use development, and additional municipal pumping on water levels at the municipal wells. Impacts to other water uses are not considered in Scenario H. As described in Section 3.2.3 variable monthly pumping rates were applied in the Groundwater Flow Model for the City of Guelph wells with an objective to always achieve the Allocated rate of 73,450 m^3/day from the system. The Glen Collector is a key component of the supply, but its yield varies seasonally according to climate and the amount of water discharged into the artificial recharge system. When the simulated collector yield falls below the Allocated rate of 6,900 m^3/day, the pumping rates at other wells are increased to make up the loss in supply from the collector. Table 3-7 identifies those wells that were assigned a higher pumping rate under drought conditions.

For the Township of Guelph/Eramosa wells in Rockwood and Hamilton Drive, the Allocated rates applied to evaluate this scenario (average day) are listed in Table 3-8.

Similar to Scenario G, this scenario was subdivided into scenarios H(1), H(2), and H(3) to evaluate the relative contribution of municipal water takings and land use development at each municipal well under drought conditions. For these scenarios, the impact is only evaluated as in-well drawdown at the municipal wells. Consideration of impacts to other water uses (i.e., baseflow reductions) is not required under the Technical Rules.

Scenario H(1)

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

Scenario H(2)

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

Scenario H(3)

This scenario evaluates the impact of reductions in recharge (from increases in imperviousness) due to future land use developments defined in the Official Plans and drought conditions on the municipal wells. As noted above, the impact is only evaluated at the municipal wells as drawdown and not on other water uses (i.e., baseflow impacts).

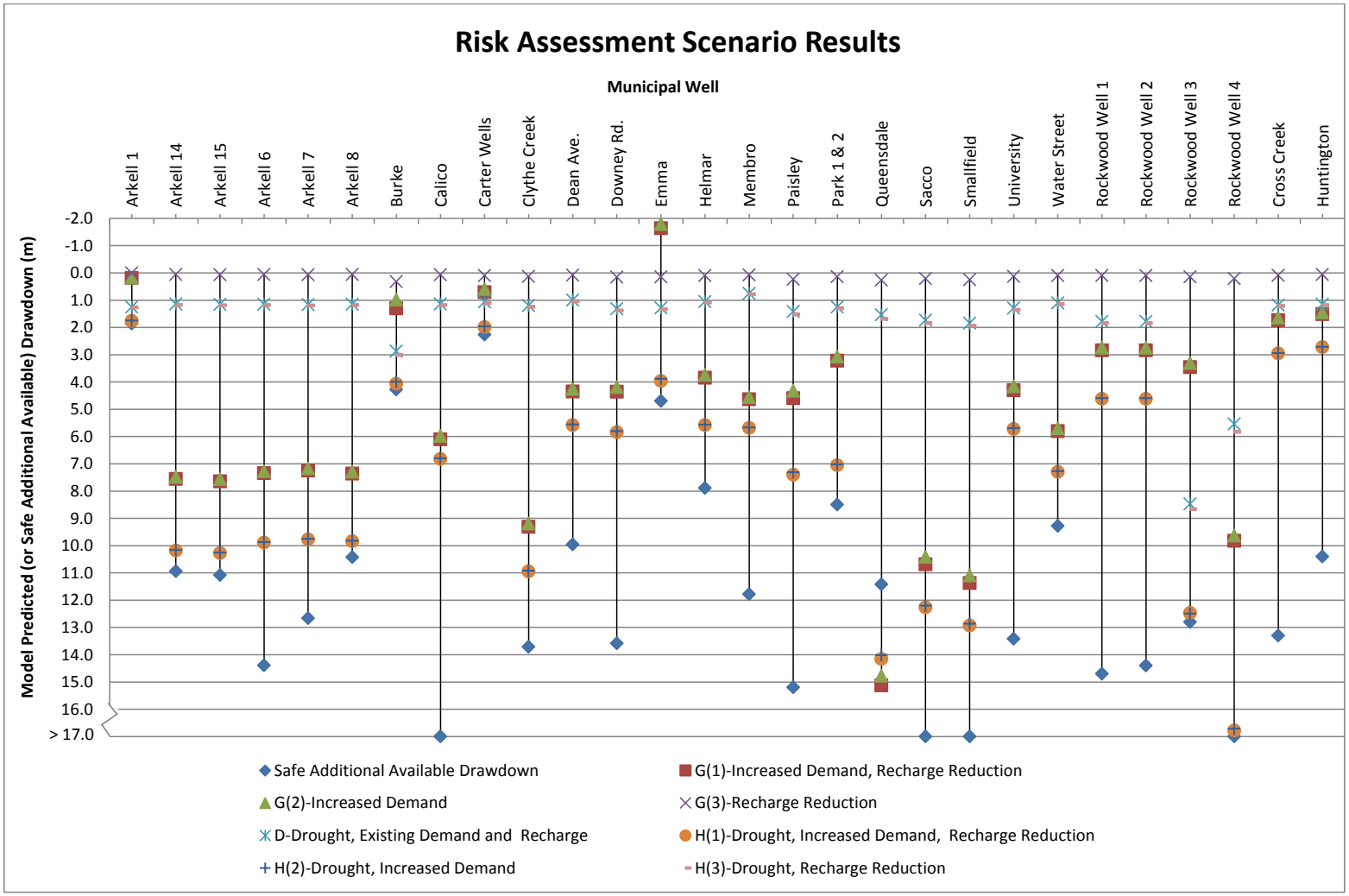
5.5.2 SCENARIO RESULTS - GROUNDWATER

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

5.5.2.1 Drawdown

The drawdown under each of the Risk Assessment groundwater model scenarios was calculated and compared to the safe additional available drawdown at each municipal well. The drawdown at each well is calculated relative to Scenario C (i.e., 2008 average pumped conditions for the City of Guelph wells and operating low water conditions for the Township of Guelph/Eramosa wells in Rockwood and Hamilton Drive [Burnside 2015b]) and is summarized in Table 5-3 and compared to the safe additional drawdown including well losses for each municipal well. As Rockwood Well 4 is a new municipal supply well with no historical pumping data, the 2015 static head recorded following well completion (355.1 m asl; Burnside 2015a) was used in the calculation of the safe additional drawdown at this well instead of the operating low water level. For the transient scenarios D and H, the maximum drawdown (relative to Scenario C) over the entire drought simulation is presented. The model simulated drawdown was then compared to the safe additional available drawdown to identify municipal wells where there is a potential that the wells will be unable to pump at their Allocated rates.

Figure 5-6 summarizes the predicted maximum drawdown in each municipal well for each of the Risk Assessment scenarios.



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City of Guelph and Township of Guelph/Eramosa

Tier 3 Water Budget and Local Area Risk Assessment

Model Predicted Drawdown in Risk Assessment Scenarios

Date:	Project:	Technical:	Reviewer:	Drawn:
3 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-6

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TABLE 5-3 Risk Assessment Drawdown Results

Well Name	Safe Additional Available Drawdown (inc. Well Losses)	FEFLOW Groundwater Model Scenario Drawdown (m)						
		Average Climate			Drought			
		G(1)	G(2)	G(3)	D	H(1)	H(2)	H(3)
		Recharge Reduction, Increased Demand	Increased Demand	Recharge Reduction	Existing Recharge, Demand	Recharge Reduction, Increased Demand	Increased Demand	Recharge Reduction
City of Guelph								
Arkell 1	1.9	0.2	0.2	0.0	1.3	1.8	1.8	1.3
Arkell 6	14.4	7.3	7.3	0.1	1.1	9.9	9.9	1.2
Arkell 7	12.7	7.2	7.2	0.1	1.2	9.8	9.8	1.2
Arkell 8	10.4	7.4	7.3	0.1	1.2	9.8	9.8	1.2
Arkell 14	10.9	7.6	7.5	0.1	1.1	10.2	10.2	1.2
Arkell 15	11.1	7.6	7.6	0.1	1.2	10.3	10.3	1.2
Burke	4.3	1.3	1.0	0.3	2.9	4.1	4.0	3.0
Calico	17.3	6.1	6.0	0.1	1.1	6.8	6.8	1.2
Carter Wells	2.3	0.7	0.6	0.1	1.1	2.0	2.0	1.1
Clythe Creek	13.7	9.3	9.2	0.1	1.2	10.9	10.9	1.2
Dean Ave.	10.0	4.3	4.3	0.1	1.0	5.6	5.6	1.0
Downey Rd.	13.6	4.4	4.2	0.2	1.3	5.8	5.8	1.4
Emma	4.7	-1.6[1]	-1.8[1]	0.1	1.3	4.0	3.9	1.3
Helmar	7.9	3.8	3.7	0.1	1.1	5.6	5.6	1.1
Membro	11.8	4.6	4.6	0.1	0.8	5.7	5.7	0.8
Paisley	15.2	4.6	4.3	0.2	1.4	7.4	7.3	1.5
Park 1 & 2	8.5	3.2	3.1	0.1	1.3	7.1	7.0	1.3
Queensdale	11.4	15.1	14.8	0.3	1.5	14.2	14.0	1.7
Sacco	29.4	10.7	10.4	0.2	1.7	12.3	12.2	1.8
Smallfield	39.9	11.4	11.1	0.2	1.8	12.9	12.9	1.9
University	13.4	4.3	4.2	0.1	1.3	5.7	5.7	1.4
Water Street	9.3	5.8	5.7	0.1	1.1	7.3	7.3	1.1
Rockwood								
Rockwood Well 1	14.7	2.8	2.7	0.1	1.8	4.6	4.6	1.8
Rockwood Well 2	14.4	2.8	2.7	0.1	1.8	4.6	4.6	1.8
Rockwood Well 3	12.8	3.5	3.3	0.1	8.5	12.5	12.5	8.7
Rockwood Well 4	32.7	9.8	9.6	0.2	5.5	16.8	16.7	5.8
Hamilton Drive								
Cross Creek	13.3	1.7	1.6	0.1	1.2	3.0	2.9	1.2
Huntington	10.4	1.5	1.4	0.1	1.2	2.7	2.7	1.2

Note:
[1]Negative drawdown indicates water level had risen from the existing conditions (Scenario C) due to decreased pumping in the future scenarios.

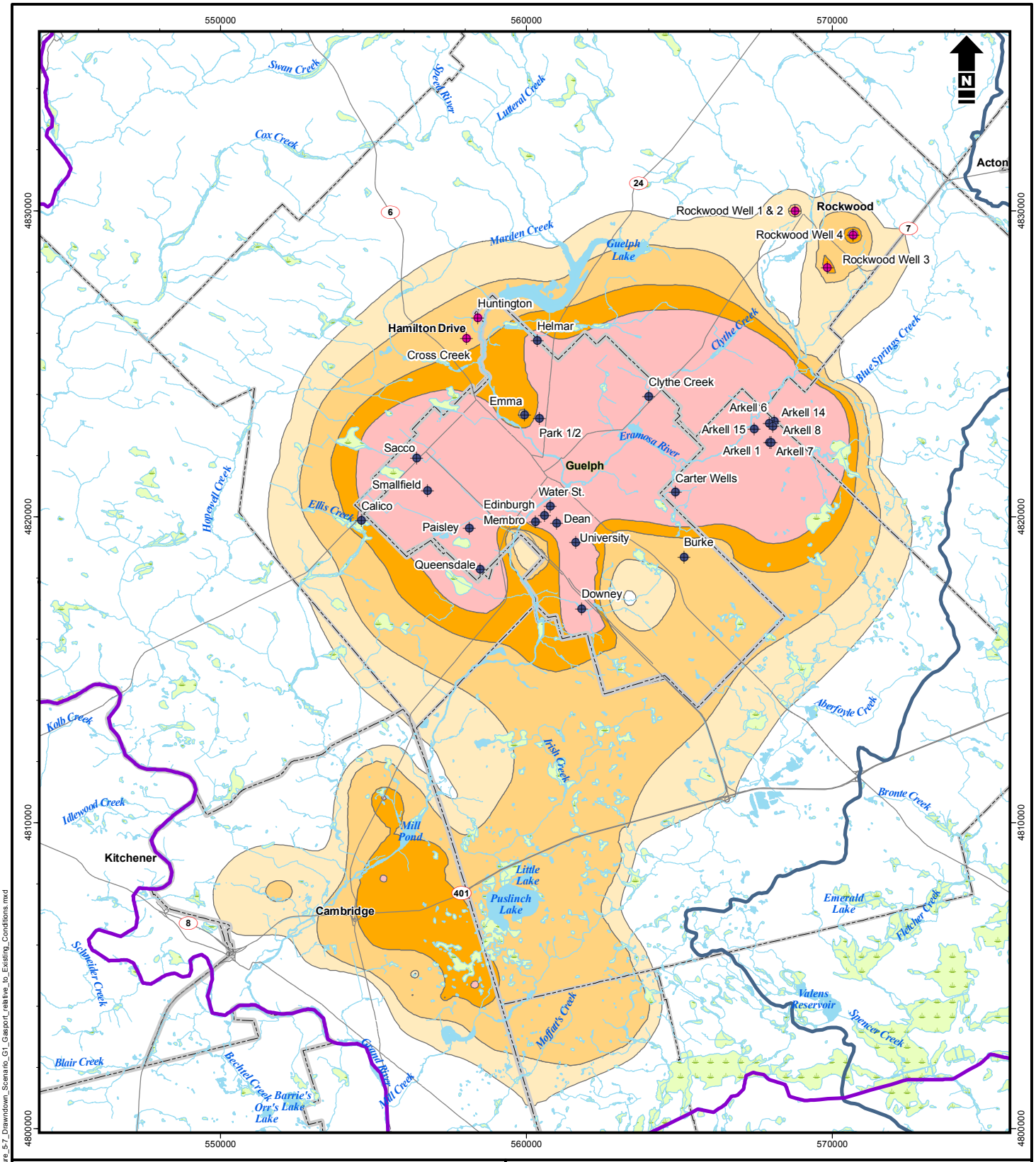
Scenario G

Table 5-3 shows the model simulated drawdown under scenarios G(1), G(2), and G(3) at the municipal wells. The model predicted drawdown arising from the increase in pumping at the Allocated rats and the reductions in recharge (Scenario G[1]) is less than the safe additional drawdown in all municipal wells, except at the Queensdale Well where it is exceeded by 3.7 m. Figure 5-7 illustrates the drawdown contours for Scenario G(1) compared to existing conditions (Scenario [C]) in the Gasport Formation, while Figure 5-8 shows the drawdown in the Guelph Formation/Contact Zone. Areas that show drawdown in the shallow system where there is no corresponding drawdown in the underlying Gasport Formation highlight areas that are influenced by shallow pumping, or areas impacted only by reductions in recharge and not increases in pumping at depth. Model predicted drawdown under Scenario G(2) is shown on Figure 5-9 and Figure 5-10 for the Gasport and Guelph/Contact Zone Formations, respectively, relative to existing (current) conditions. The figures illustrate the reduction in water level due to increase in pumping relative to existing conditions.

For all municipal wells except the Queensdale Well, the drawdown is within the safe additional drawdown. At the Queensdale Well, drawdown exceeds the safe level by 3.4 m. The Emma Well had a negative drawdown for scenarios G(1) and G(2) as the average conditions Allocated pumping rate for the Emma Well (2,100 m^3/day; Table 3-7) was less than the Scenario C (2008 typical pumped conditions) pumping rate of 2,600 m^3/day (Section 5.5.1.1).

Figures 5-11 and 5-12 illustrates the model predicted reduction in water levels within the Gasport and Guelph/Contact Zone Formations, respectively, under Scenario G(3), relative to existing (current) conditions. The figures illustrate the reduction in water level relative to existing conditions due to reductions in recharge arising from land use development outlined in the Official Plans. Water level reductions are predicted to be greater in the shallow groundwater flow system (i.e., Contact Zone and Guelph Formation) than in the Gasport Formation. This can be seen when comparing Figures 5-11 and 5-12. When compared to the drawdown contours for Scenario G(1; Figures 5-7 and 5-8), there is more drawdown due to increases in pumping (Scenario G[1]) than from changes in land use (Scenario G[3]). Under average climatic conditions, the model predicted drawdown is less than the safe additional drawdown at all wells. This suggests that if only reductions in recharge were to take place (Scenario G[3]), all municipal wells would be able to pump sustainably under average climatic conditions.

Although these scenarios account for non-linear in-well losses that accompany increased pumping, they do not account for potential changes to the wells or aquifers (e.g., loss of yield due to fouling or collapse), mechanical problems with the pumps, or other infrastructure limitations.



- Tier Three Model Boundary (Study Area)
- Grand River Watershed Boundary
- Community
- Wetland
- Water Body
- Watercourse
- Major Road
- Niagara Escarpment
- Municipal Well (City of Guelph)
- Municipal Well (Guelph/Eramosa Township)

Drawdown (m)

- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- > 3.00

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1:175,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

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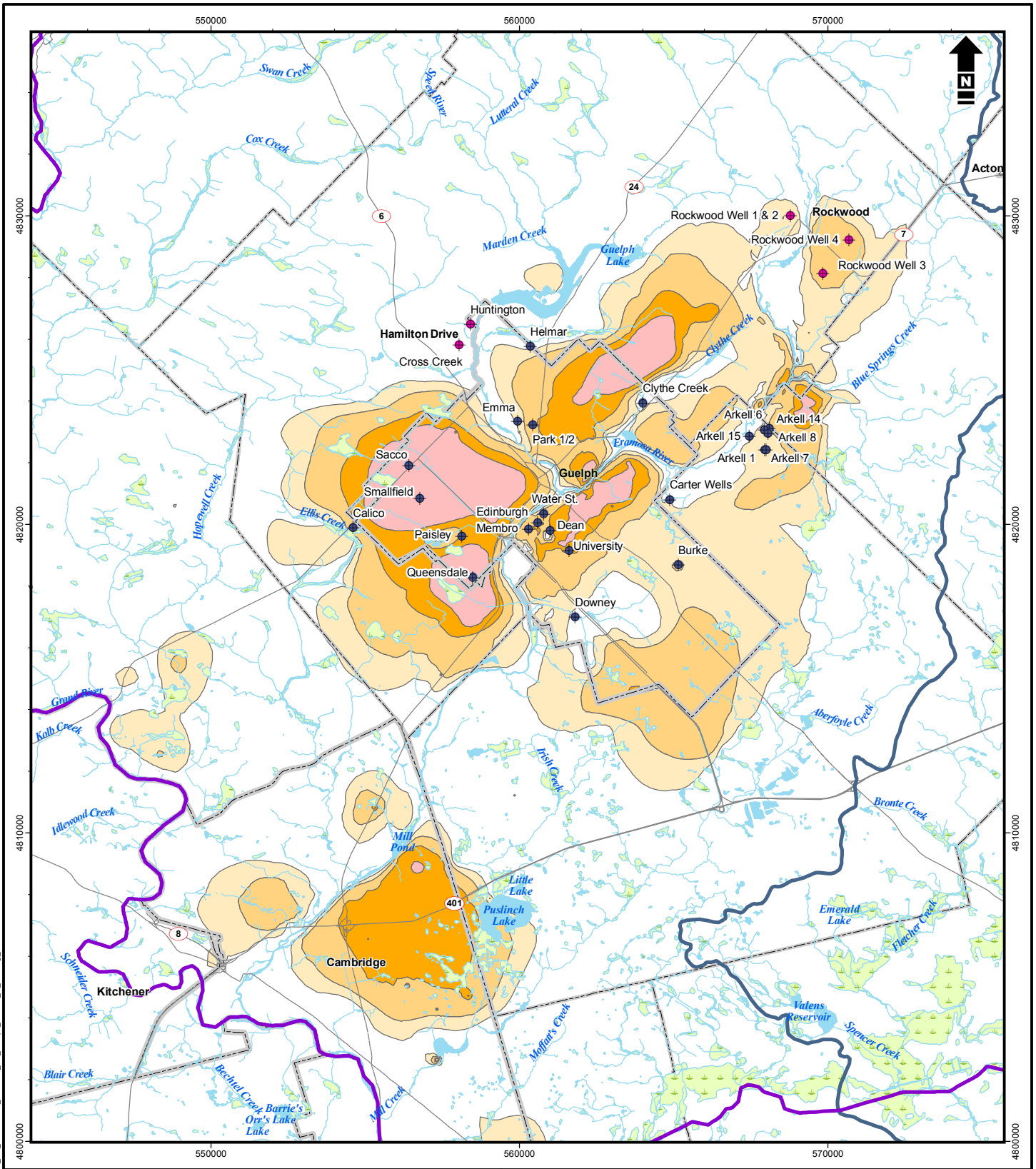
City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Drawdown Scenario G(1) (Gasport Fm.; relative to existing conditions)

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-7



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Wetland
Water Body
Watercourse
Major Road
Niagara Escarpment
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

Drawdown (m)
0.50 - 1.00
1.00 - 2.00
2.00 - 3.00
> 3.00

1:175,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

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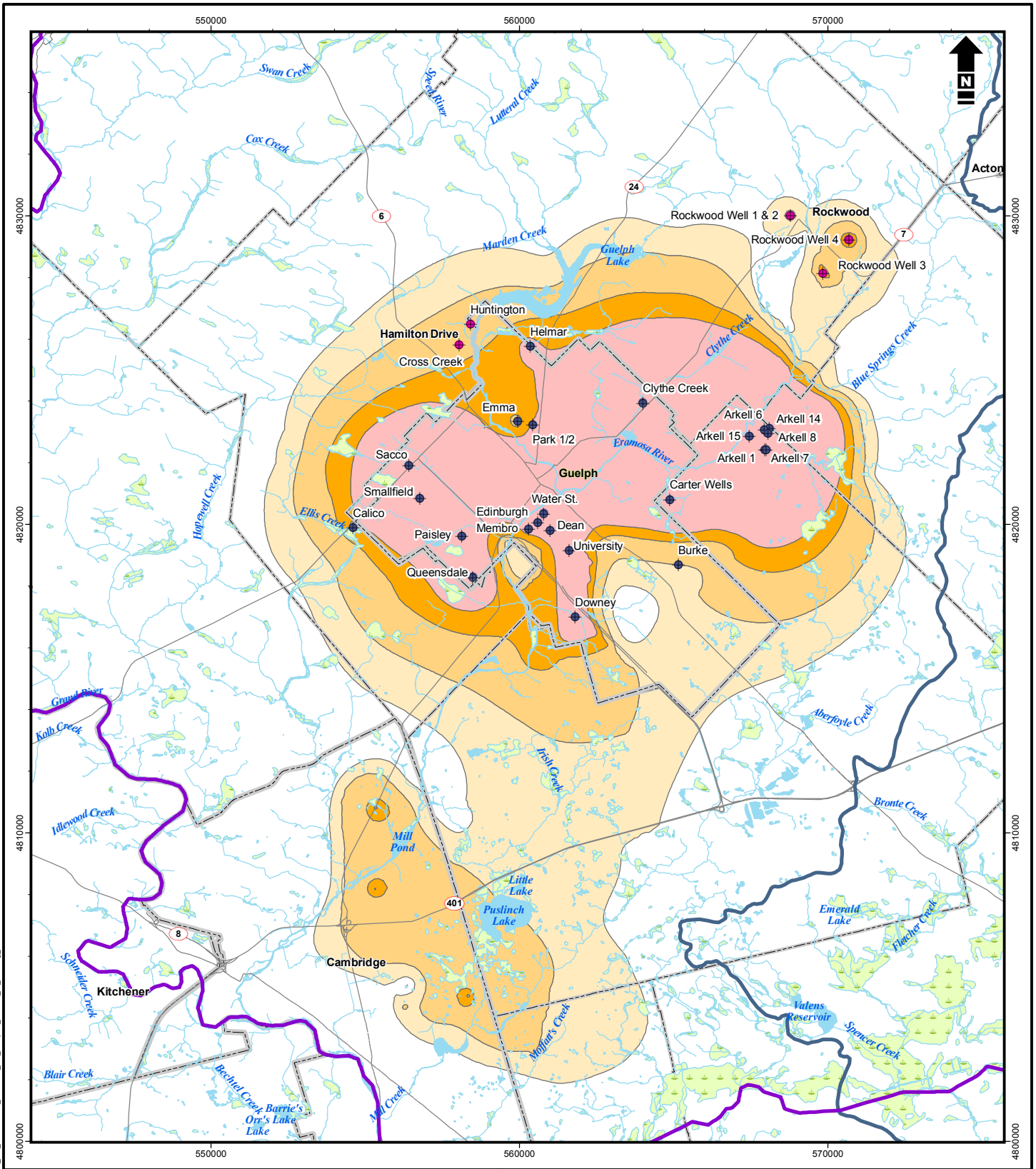
City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Drawdown Scenario G(1) (Guelph Fm.; relative to existing conditions)

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-8



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Wetland
Water Body
Watercourse
Major Road
Niagara Escarpment
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

Drawdown (m)
0.50 - 1.00
1.00 - 2.00
2.00 - 3.00
> 3.00

1:175,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

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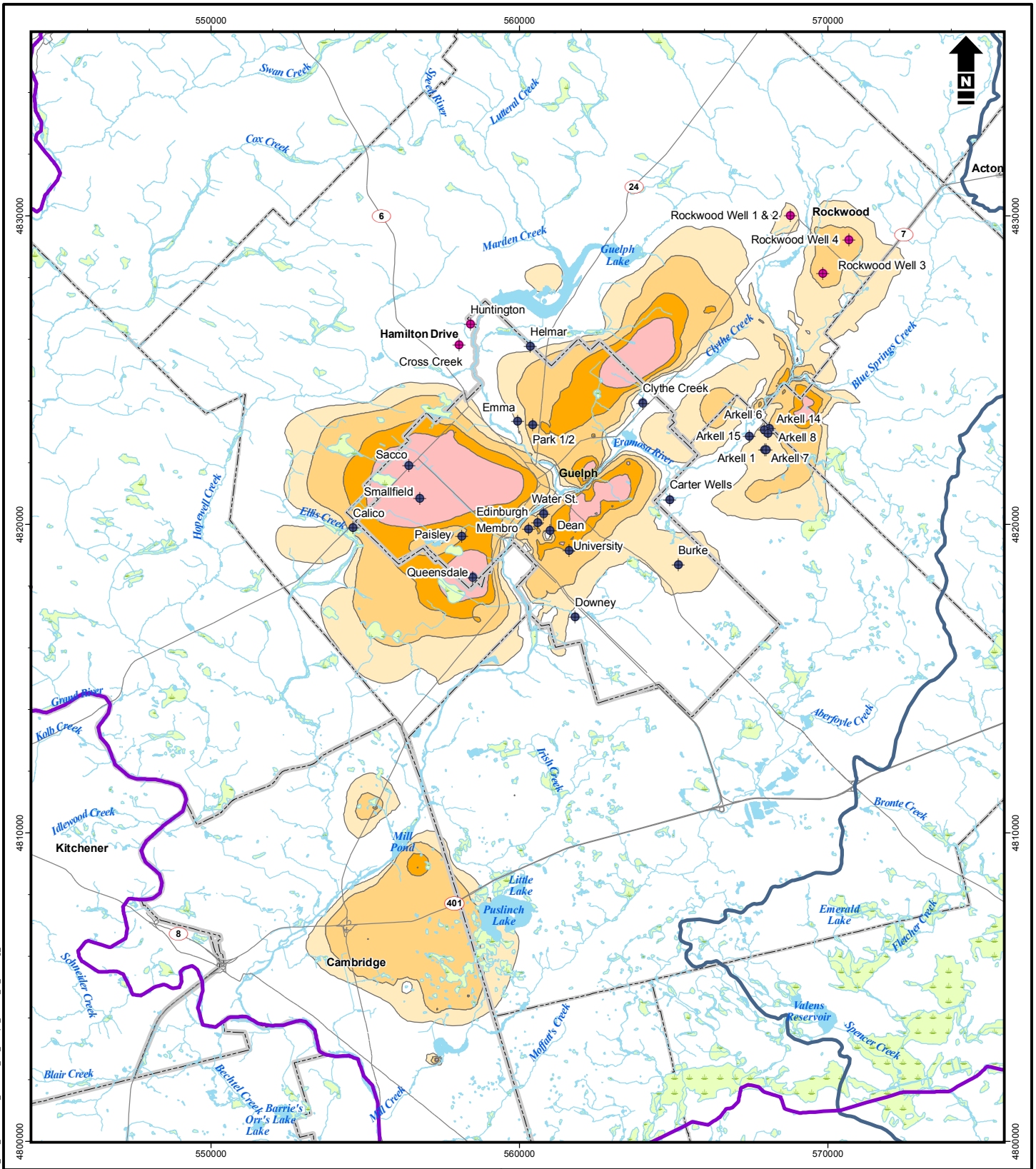
City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Drawdown Scenario G(2) (Gasport Fm.; relative to existing conditions)

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-9



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Wetland
Water Body
Watercourse
Major Road
Niagara Escarpment
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

Drawdown (m)
0.50 - 1.00
1.00 - 2.00
2.00 - 3.00
> 3.00

1:175,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

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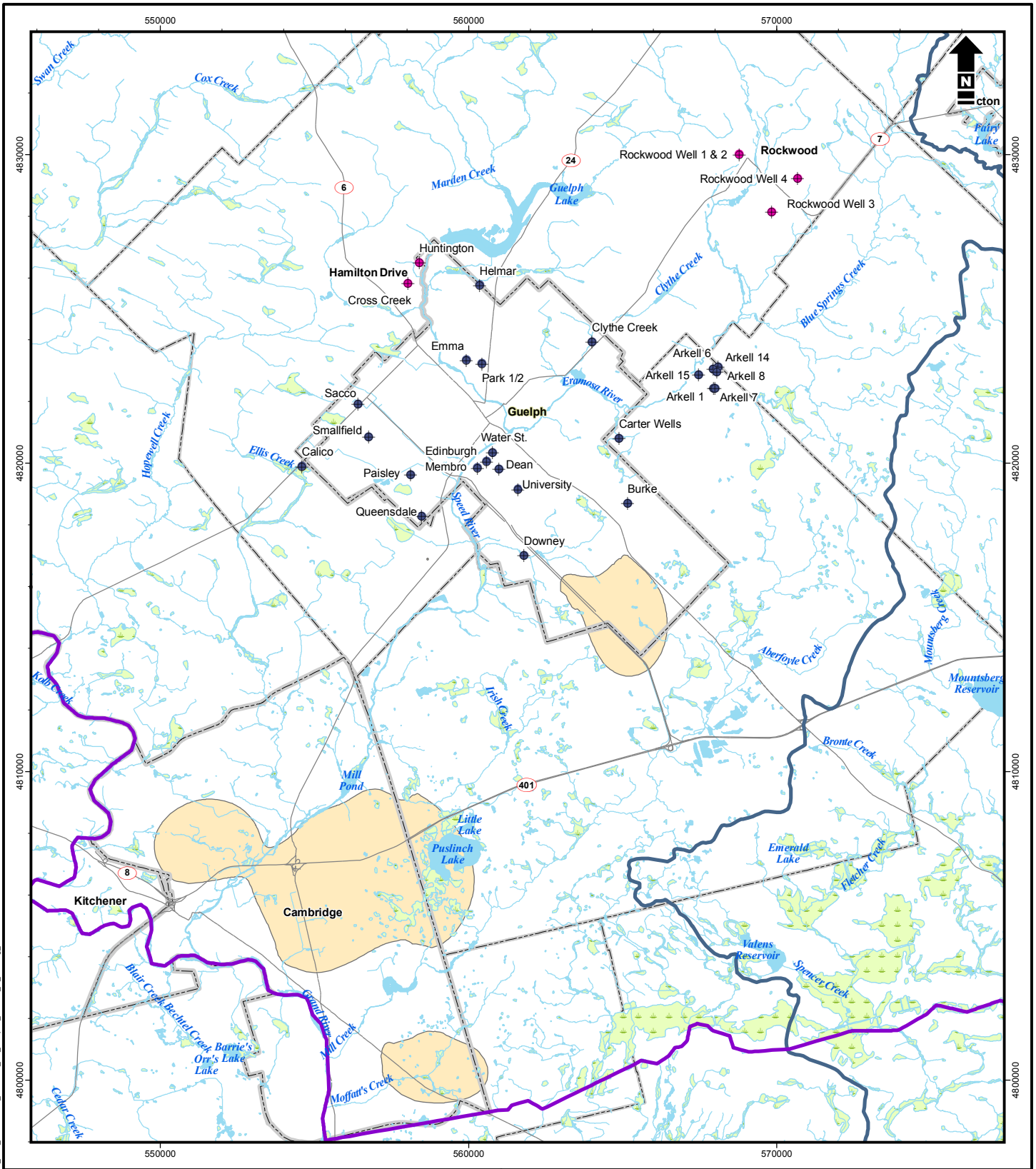
Tier 3 Water Budget and Local Area Risk Assessment

Drawdown Scenario G(2) (Guelph Fm. ; relative to existing conditions)

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-10



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Wetland
Water Body
Watercourse
Major Road
Niagara Escarpment
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

Drawdown (m)
0.50 - 1.00
1.00 - 2.00
2.00 - 3.00
> 3.00

1:175,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Drawdown Scenario G(3)
(Gasport Fm.; relative to existing conditions)

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-11

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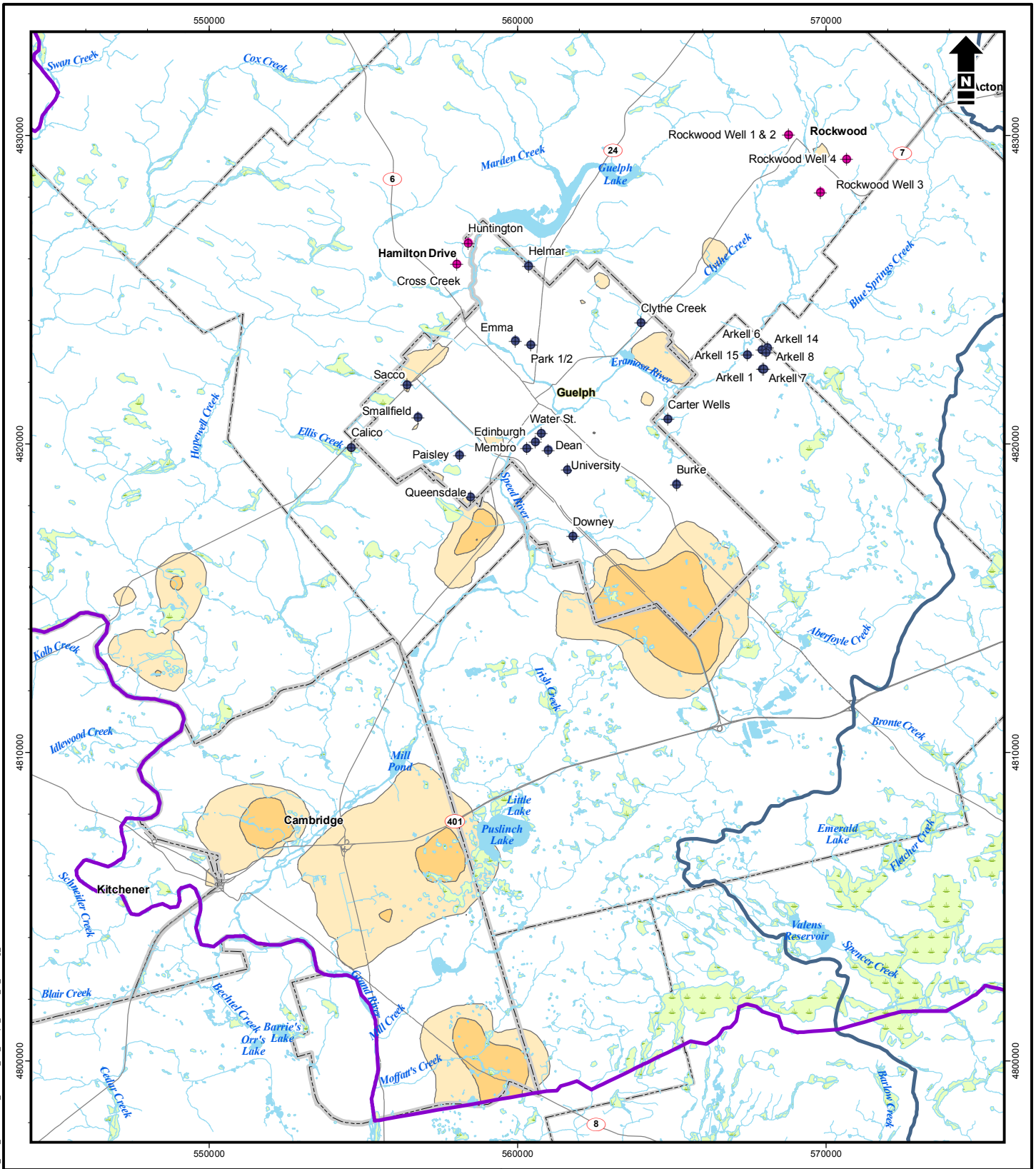

Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Wetland
Water Body
Watercourse
Major Road
Niagara Escarpment
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

Drawdown (m)
0.50 - 1.00
1.00 - 2.00
2.00 - 3.00
> 3.00

1:175,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Drawdown Scenario G(3) (Guelph Fm. ; relative to existing conditions)

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-12

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Scenario D

Scenario D examines the model-predicted fluctuations in hydraulic head at each of the municipal wells using existing land use, Existing municipal pumping rates, and variable climatic conditions including short- and long-term drought. The lowest hydraulic head elevation predicted by the model during the scenario (in the aquifer at each municipal well) was recorded. The difference (drawdown) between this elevation and the head elevation in the aquifer at each well under Scenario C was tabulated and compared to the safe additional available drawdown estimated at each municipal well (Table 5-3).

As shown in Table 5-3, the model predicted drawdown in the aquifers at each municipal well is less than the estimated safe additional drawdown at each of the wells. As such, the wells can meet Existing rates through the 10-year drought periods.

Scenario H

Scenario H examines the model predicted fluctuations in hydraulic head measurements at each of the municipal wells under drought conditions. Scenario H(1) evaluated the cumulative impact of increased municipal pumping at the Allocated rates and reductions in recharge, while Scenario H(2) evaluated the impact from increased pumping only, and Scenario H(3) evaluated the impacts from reductions in recharge only.

The amount of drawdown in Scenario H(1) is not equal to the sum of the drawdowns resulting from scenarios H(2) and H(3). This is because scenarios H(2) and H(3) both include the drawdown related to climate variation (i.e., Scenario D - drought conditions). Therefore, if scenarios H(2) and H(3) are added together, the impact of climate variation is counted twice.

The maximum drawdown (in the aquifer at each municipal well) predicted by the model during each of the model scenarios is recorded in Table 5-3.

The Queensdale Well is the only municipal well with drawdown predicted to exceed the safe additional drawdown threshold for scenarios H(1) and H(2; Figure 5-13). Drawdown exceeds the threshold (11.4 m) for the majority of the transient drought simulations. Maximum water level decline occurs 5 years into the transient scenario, during the maximum drought period, where safe drawdown is exceeded by a maximum of 2.7 m and 2.5 m for scenarios H(1) and H(2), respectively.

All other municipal wells, for all other scenarios, have predicted drawdown that is less than the safe additional drawdown. However, there are eight municipal wells that have predicted drawdown approaching the safe additional drawdown threshold. These wells include Arkell Well 1, Arkell Well 14, Arkell Well 15, Arkell Well 8, Burke Well, Carter Well, Emma Well, and Rockwood Well 3 where the difference between the maximum drawdown for Scenario H(1) and the safe additional available well drawdown is less than 1.0 m (Figure 5-6; Table 5-3).

- Arkell Well 1: As illustrated on Figure 5-14, the maximum drawdown for Scenario H(1) is 1.8 m, which occurs from January to March 1964. This corresponds to a period following 6 months of drought in July to December 1963 as shown on the chart of monthly groundwater recharge used in the simulations (Figure 5-5). As Arkell Well 1 draws water from a shallow overburden aquifer, the influence of the longest period of drought is immediate and the pattern of drawdown mimics the pattern of simulated flow from the Glen Collector (Figure 3-5). Although the majority of the 10-year simulation has drawdown that is 1 m or more above the safe water elevation, the maximum drawdown leaves approximately 0.1 m of available drawdown during the winter of 1964.

- Arkell Well 14: Figure 5-15 shows the maximum drawdown for Scenario H(1) is 10.2 m, which occurs from January to March 1964. During this time, 0.8 m of available drawdown remains. While Arkell 14 is open across the Upper to Middle Gasport Formation instead of across the overburden at Arkell 1, it still responds rapidly to the preceding 6 months of drought from July to December 1963.

- Arkell Well 15: The maximum drawdown of 10.3 m occurs from January to March 1964 as shown on Figure 5-16. The drawdown response is almost identical to that of Arkell Well 14, and similarly leaves just 0.8 m of available drawdown. Arkell Well 15 is open across the Upper to Lower Gasport Formation.

- Arkell Well 8: As illustrated on Figure 5-17, the maximum drawdown is 9.8 m, which occurs from February to March 1964. At that time, 0.6 m of available drawdown remains. The variation in predicted drawdown is similar to that at Arkell wells 14 and 15. Arkell Well 8 draws water from the Upper to Middle Gasport Formation aquifer.

- Burke Well: Figure 5-18 shows the maximum drawdown for Scenario H(1) of 4.1 m, which occurs from December 1964 to January 1965 and leaves only 0.2 m of available drawdown for a short period. This is nearly 1 year later than the Arkell wells and the Glen Collector, which source water from the shallow overburden and deeper bedrock units. Burke Well is screened across the Guelph Formation down to the Gasport Formation and thus draws from both the shallow and deep bedrock systems with longer flow paths from the sources of recharge leading to a delayed response to the lengthy drought period.

- Carter Wells: The maximum drawdown of 2.0 m occurs in December 1964 and January 1965 as shown on Figure 5-19. Carter Wells are screened in the shallow bedrock aquifer only (Guelph Formation and Contact Zone) and partially draw from the same aquifer system as Burke Well. There is 0.3 m of remaining available drawdown when Carter Wells reach their maximum drawdown under Scenario H(1).

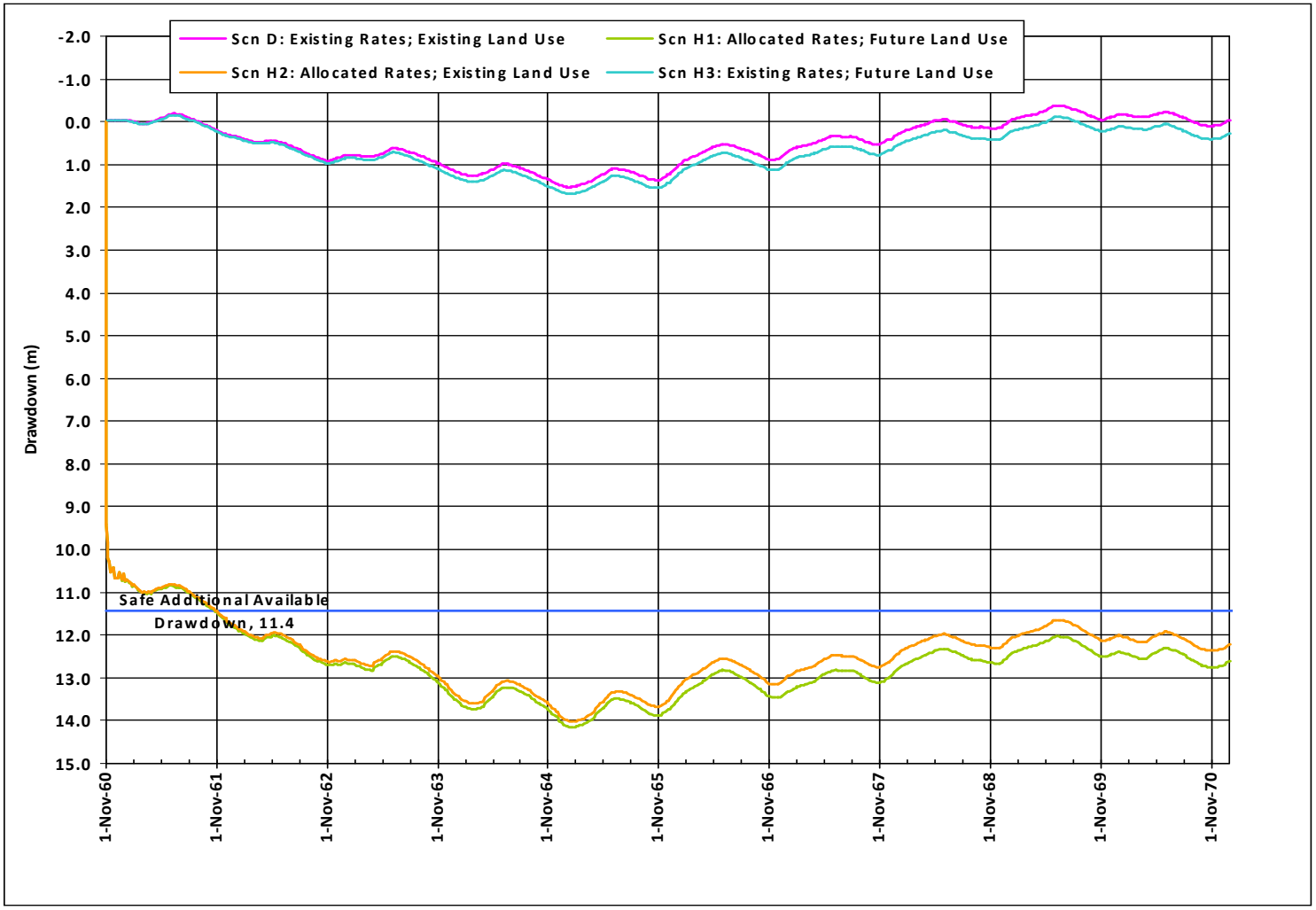
- Emma Well: Figure 5-20 illustrates the timing of the maximum drawdown of 4.0 m for Scenario H(1) to be in late February 1964. The remaining available drawdown is 0.7 m when Emma Well reaches the lowest level, but this is only simulated to occur for a few days. Even though the safe water level

was determined to be at a depth of 40.0 m below ground surface (bgs), the major water producing zone of the well is below a depth of 44.2 m. Therefore, there is 4.2 m of additional room in the well to accommodate additional drawdown during extreme drought conditions. The patterns of simulated drawdown are different when comparing scenarios H(2) and H(1) to scenarios D and H(3). The former two scenarios use pumping that varies between the average and drought Allocated rates (2,100 to 2,400 m^3/day), while the latter two use a constant, 2008 pumping rate (2,600 m^3/day). Emma Well draws its water supply from the Gasport Formation, the deeper confined aquifer, and there is little influence by variable recharge on the water levels in this well (as seen in scenarios D and H[3]). The influence of the variable pumping rates on the drawdown is evident with scenarios H(2) and H(1) where maximum pumping rates are used during periods of low flow at the Glen Collector leading to maximum drawdown in the well.

- Rockwood Well 3: Figure 5-21 shows the maximum drawdown of 12.5 m is predicted to occur in scenarios H(1) and H(2) for a few days at the end of December 1964 and start of January 1965. At this time, there is 0.3 m of available drawdown remaining. Rockwood Well 3 draws its water from the Middle Gasport Formation, but the absence of a lower conductivity confining layer allows the drought impacts to be transmitted to the bedrock aquifer relatively quickly.

The rest of the municipal supply wells in the Risk Assessment have greater than 1 m of remaining available drawdown when the maximum drawdown in each well is predicted for Scenario H(1). The results for all the City of Guelph and the Township of Guelph/Eramosa (Rockwood and Hamilton Drive) municipal wells are provided in Appendix G.

Because the predicted drawdown at the Queensdale Well exceeds the safe additional drawdown threshold for scenarios G(1), G(2), H(1), and H(2), the Risk Level for Groundwater Vulnerable Area A is *Significant*. Further, as described in Section 5.4.2, the associated Surface Water Vulnerable Area (IPZ-Q) will be assigned the same Risk Level as the Groundwater Vulnerable Area that contains the Glen Collector (i.e., Groundwater Vulnerable Area A). Therefore, the associated Surface Water Vulnerable Area is also assigned a *Significant* Risk Level.



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Tier 3 Water Budget and Local Area Risk Assessment

Drought Scenarios Predicted Drawdown - Queensdale

Date:	Project:	Technical:	Reviewer:	Drawn:
7 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

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Figure 5-13

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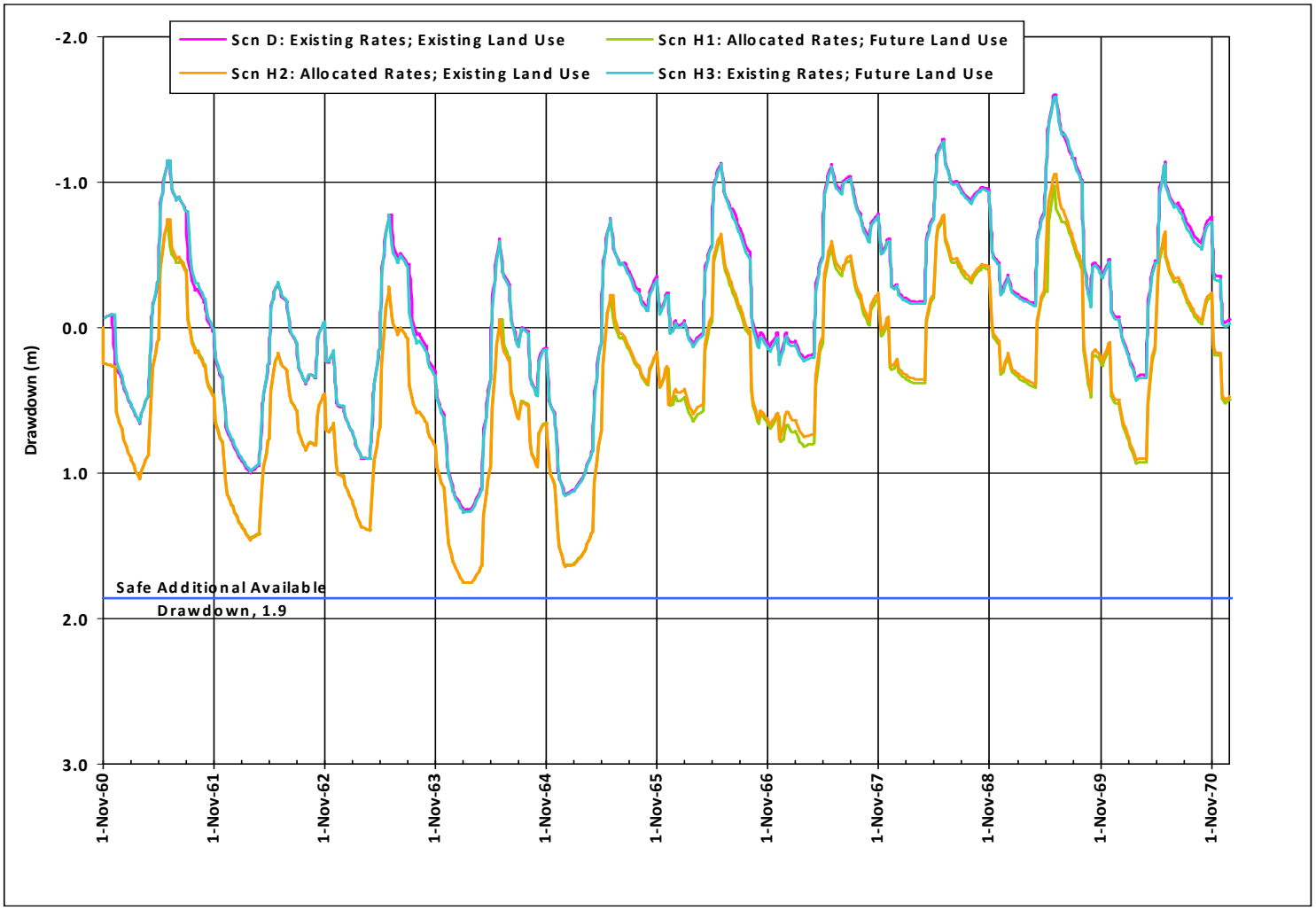

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Drought Scenarios Predicted Drawdown - Arkell 1

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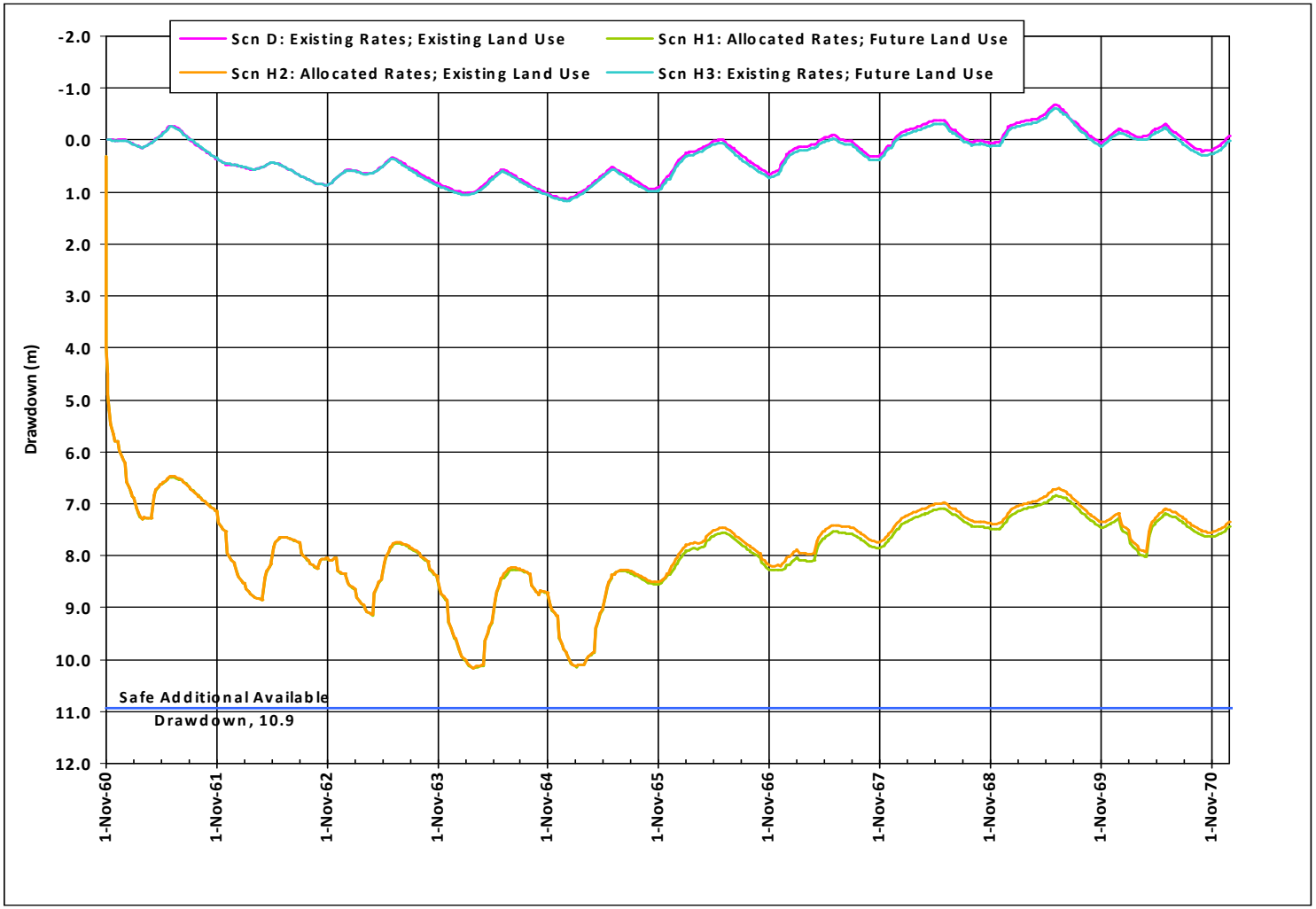
Figure 5-14



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Drought Scenarios Predicted Drawdown - Arkell 14

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Figure 5-15

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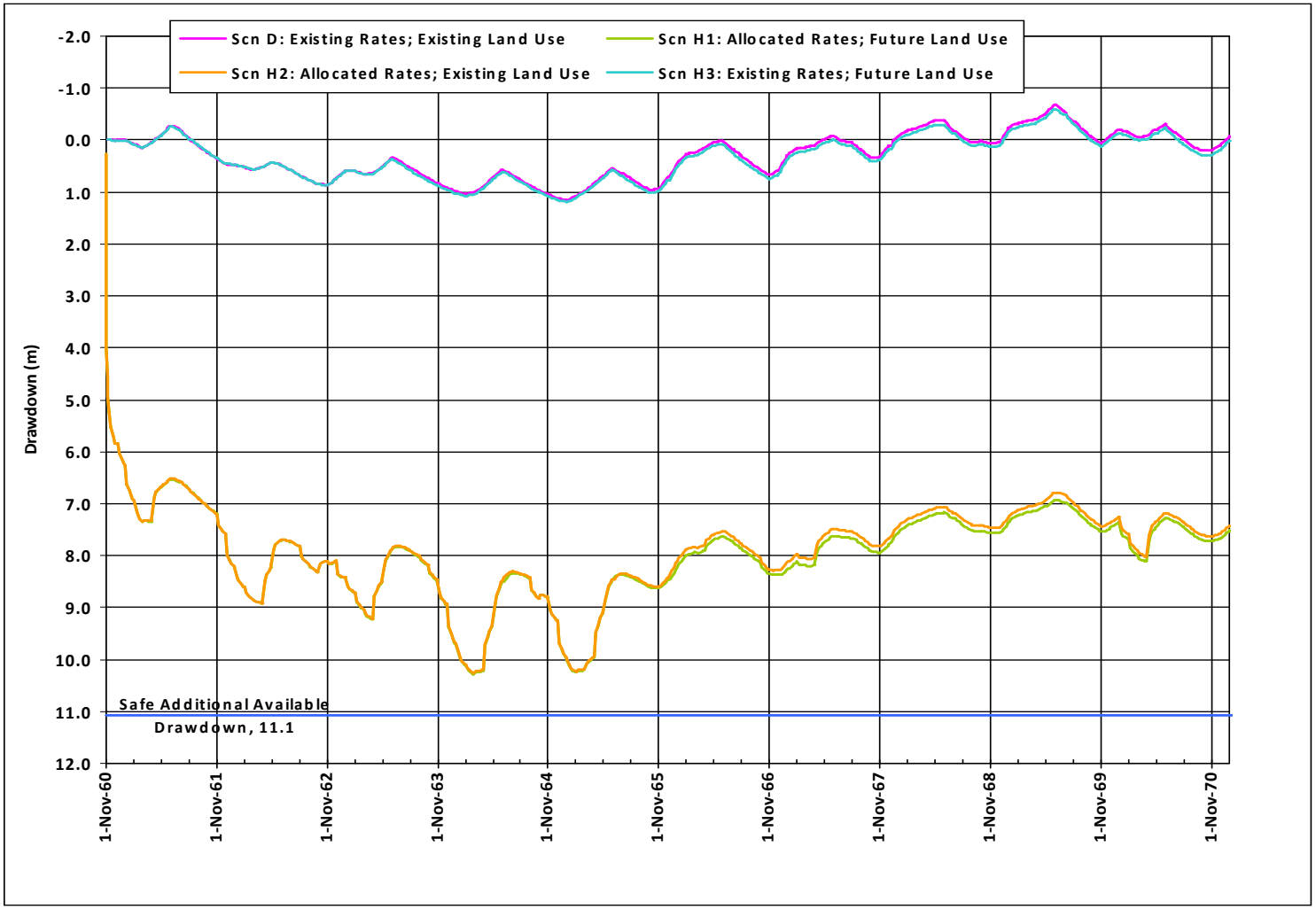

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Figure 5-16

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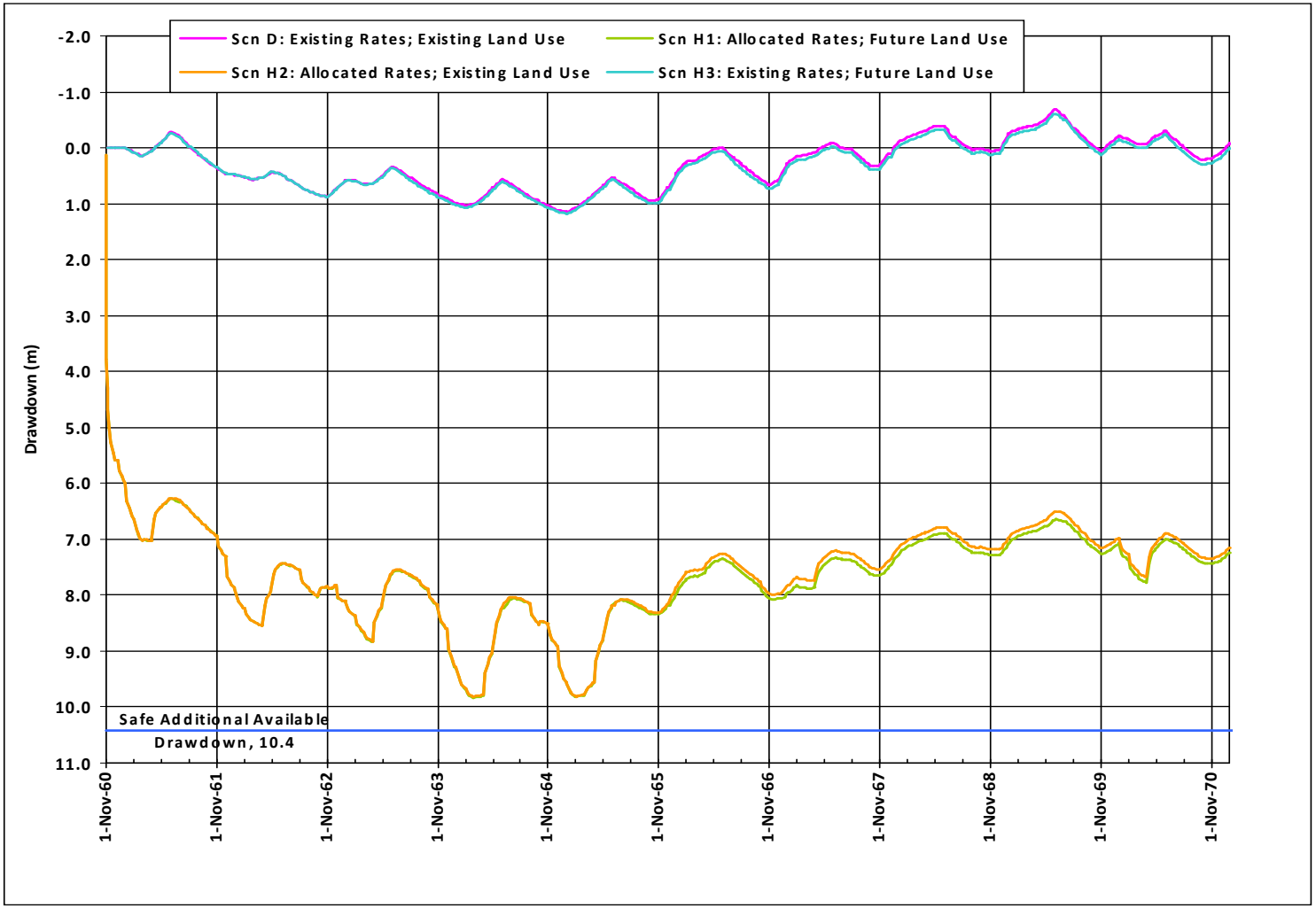

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Drought Scenarios Predicted Drawdown - Arkell 8

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Figure 5-17

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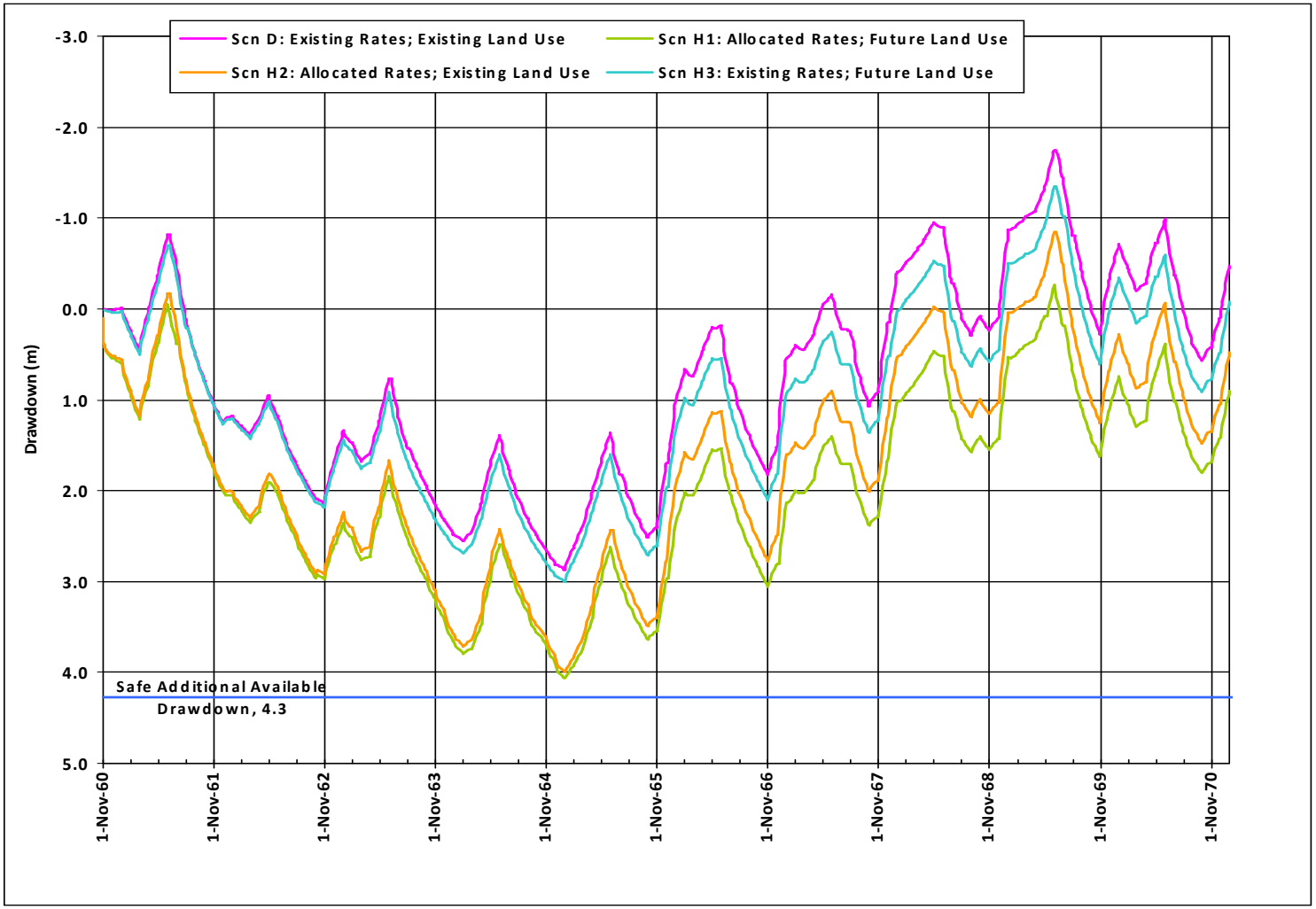

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Tier 3 Water Budget and Local Area Risk Assessment

Drought Scenarios Predicted Drawdown - Burke

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7 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-18

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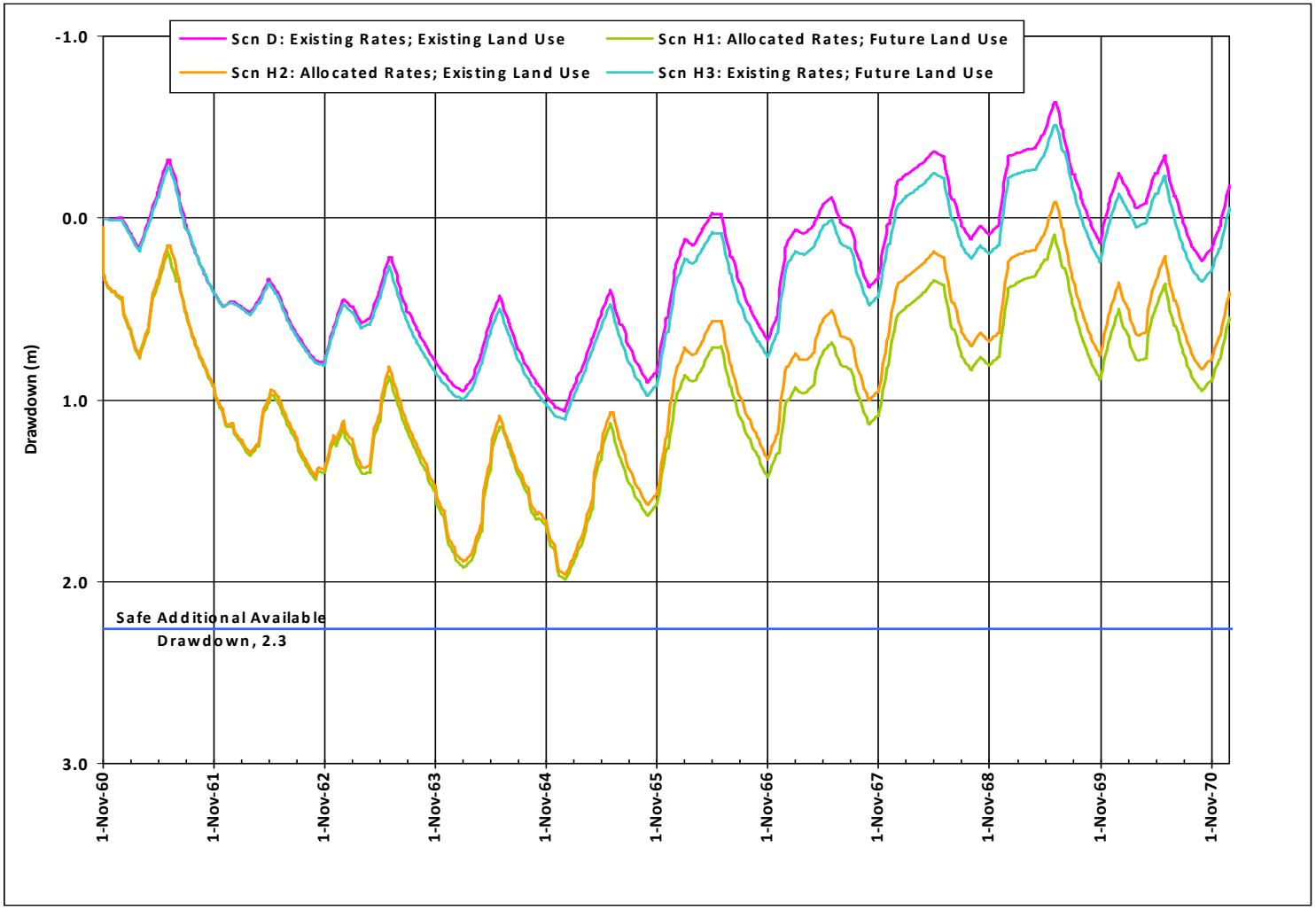

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Drought Scenarios Predicted Drawdown - Carter Wells

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7 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

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Figure 5-19

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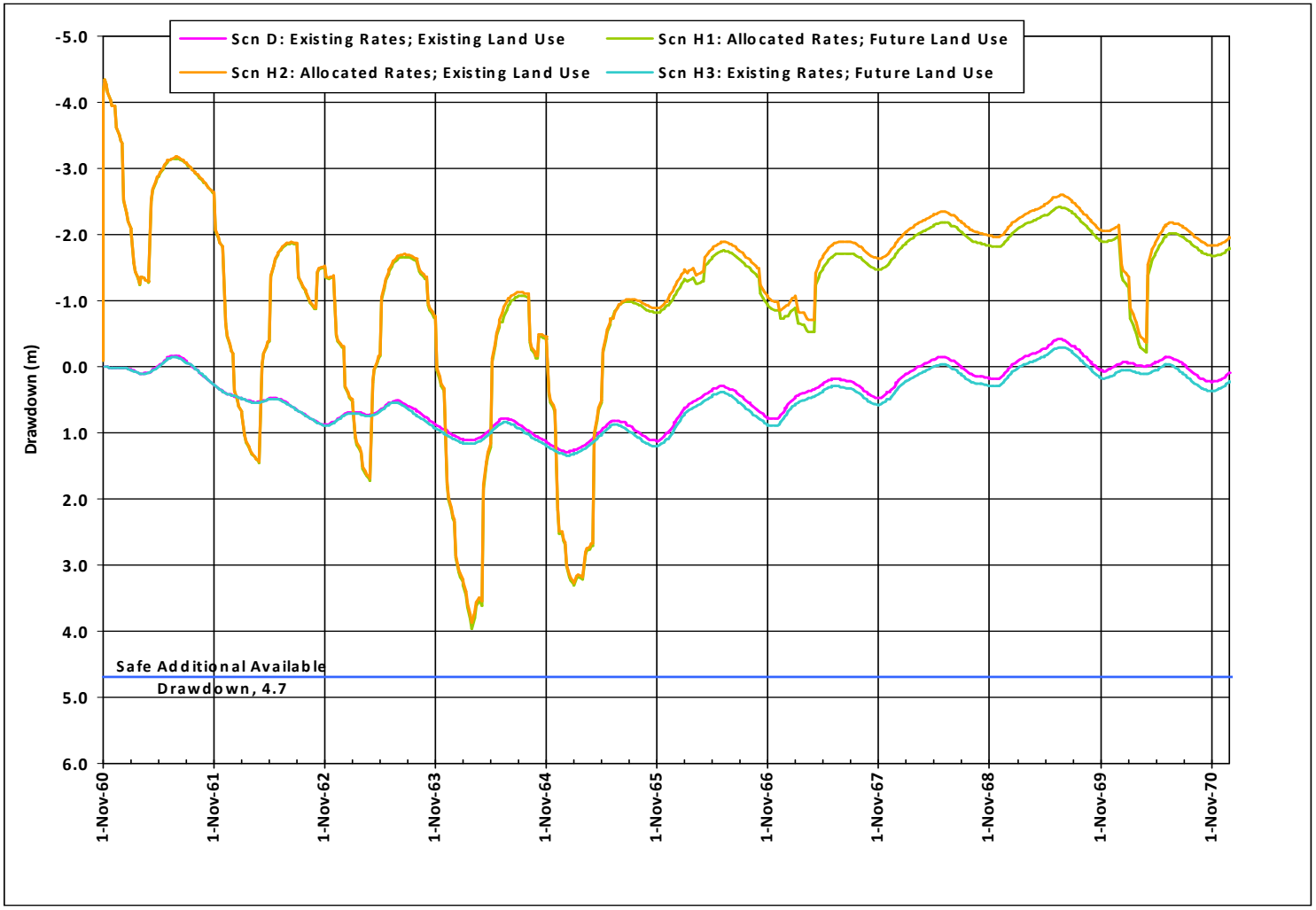

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Tier 3 Water Budget and Local Area Risk Assessment

Drought Scenarios Predicted Drawdown - Emma

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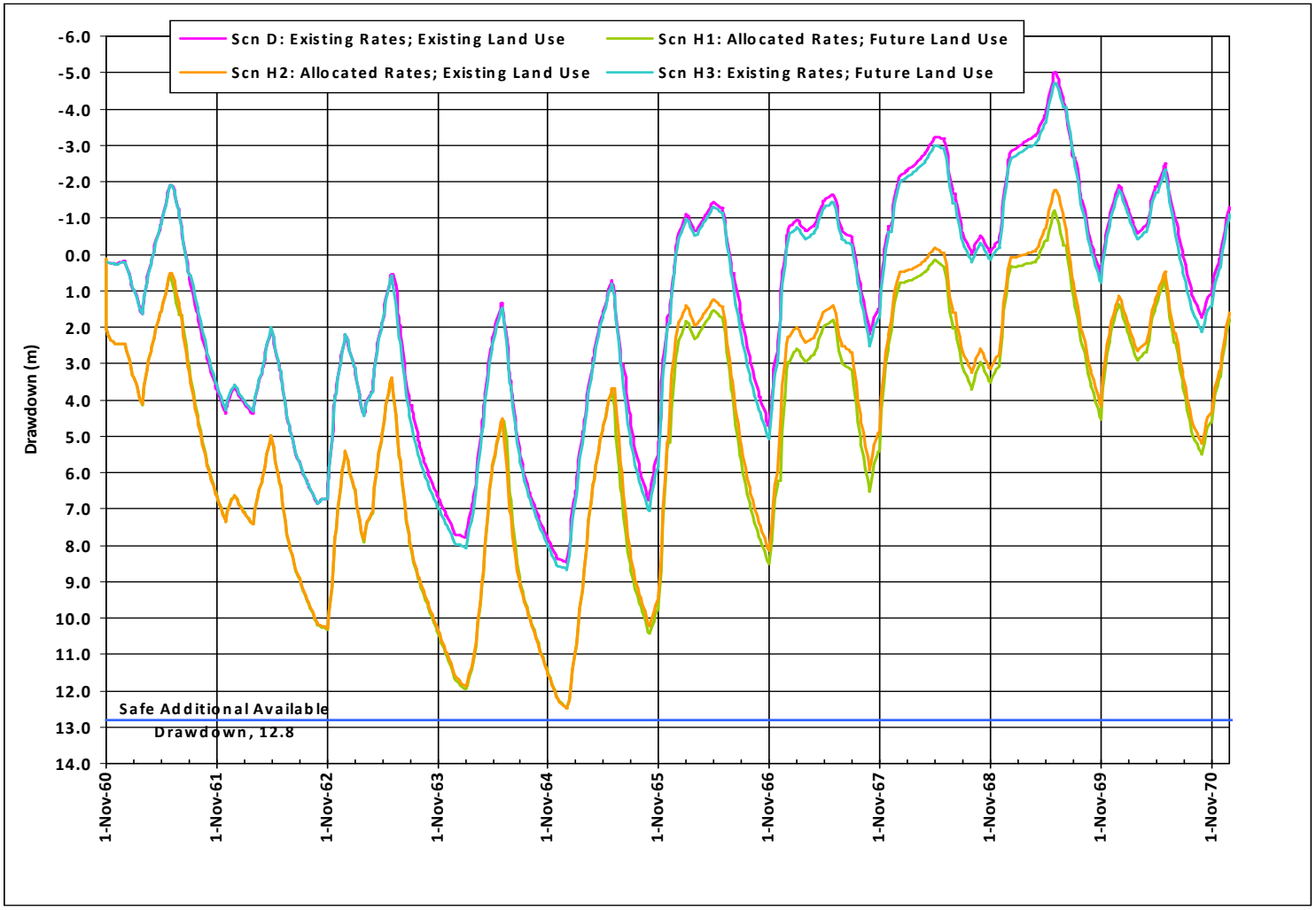
7 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-20



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Tier 3 Water Budget and Local Area Risk Assessment

Drought Scenarios Predicted Drawdown - Rockwood 3

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7 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-21

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5.5.2.2 Impacts of Groundwater Discharge to Cold Water Streams

In the Province of Ontario, streams are classified as being cold water, cool water, or warm water based on temperature measurements and habitat and species observations. Cold-water streams are of particular importance in that they support a diverse range of fish and plant life that exist in the natural thermal and water quality conditions. Cold-water streams exist primarily due to a large portion of baseflow sustained by groundwater discharge. This baseflow may be reduced by decreases in groundwater discharge due to pumping or reduction in recharge from land use changes.

Under the Tier Three Assessment, when considering only increased municipal pumping at the Allocated rates, any baseflow reductions to cold-water streams using Scenario G(2) of 10% or more would result in a Water Quantity Risk Level classification of *Moderate* for the Local Area (MOE 2013).

Figure 2-3 illustrates the location of surface water monitoring used in the calibration of the groundwater flow model and where impacts to groundwater discharge were assessed under each model scenario. The estimated average annual net groundwater discharge into various stream reaches in the model area is given in Table 5-4 along with the net groundwater discharge simulated for each of the future scenarios. The percentage reduction in groundwater discharge, as compared to existing conditions (Scenario C) is also shown in this table. The approach employed to represent streams in the groundwater model lumps groundwater discharge into adjacent riparian wetlands with the stream discharge.

The simulated impact on baseflow for rivers, streams and wetlands of interest within the Study Area was assessed for scenarios G(1), G(2), and G(3) by comparing the simulated groundwater discharge under each of the model scenarios to the net groundwater discharge simulated under 2008 (for the City of Guelph) and 2009 to 2010 (the Township of Guelph/Eramosa wells in Rockwood and Hamilton Drive) pumping conditions (Scenario C). The greatest impacts to groundwater discharge are occurring in Scenario G(1) under the influence of pumping and recharge reductions. The Risk Assessment only considers the impacts of pumping under Scenario G(2) when evaluating risk.

As shown in Table 5-4, simulated groundwater discharge reductions for Scenario G(2) are 10% or more at the following locations:

- Torrance Creek (41%)
- Chilligo/Ellis Creek at Wellington Road 32 (32%)
- Hanlon Creek South Tributary at Highway 6 (31%)
- Blue Springs Creek South Branch at 28th Side Road (27%)
- Hanlon Creek at Waterfowl Park (19%)
- Irish Creek at Townline Road (14%)
- Hanlon Creek at Highway 6 (11%)

TABLE 5-4 Impacts to Groundwater Discharge Scenario G

Surface Watercourse	ID	Description	Drainage Area (km^2)	Scenario C - Existing Conditions GW Discharge (L/s)	Scenario G(1) (Increased Demand and Recharge Reduction)		Scenario G(2) (Increased Demand)		Scenario G(3) (Recharge Reduction)	
					GW Discharge (L/s)	Percent Reduction (%)	GW Discharge (L/s)	Percent Reduction (%)	GW Discharge (L/s)	Percent Reduction (%)
Blue Springs Creek	BSC_30	At Camp Edgewood 1+2	76	508	468	7.8%	469	7.7%	507	0.1%
	SW4	At 2nd Line	46	442	436	1.4%	436	1.4%	442	0.0%
	2GA031	Near Eden Mills	42	379	376	0.9%	376	0.9%	379	0.0%
	BSC_10	At 5th Line	31	255	253	0.6%	253	0.7%	255	0.0%
	BSC_20	South Branch - At 28th SDRD	17	27	19	28.5%	20	27.4%	27	1.1%
Chilligo/Ellis Creek	ASF-5	At Maple Grove Rd	54	177	160	9.8%	163	8.3%	175	1.4%
	CGC_10	At Kossuth Rd	40	132	118	10.7%	119	9.4%	130	1.2%
	EC_10	At Wellington Rd 32	12	26	17	34.0%	18	31.6%	25	2.2%
Cox Creek	CCT_20	Cox Ck S Trib at 6th Line E	19	26	25	2.7%	25	2.5%	26	0.2%
Eramosa River	2GA029	Above Guelph	230	1,486	1,384	6.9%	1,389	6.6%	1,481	0.3%
	ER_40	At Wellington Rd 29	219	1,408	1,336	5.1%	1,341	4.8%	1,404	0.3%
	ER-99b	At Rockwood	127	788	784	0.6%	786	0.3%	786	0.3%
	ER_30	At Everton	105	695	693	0.3%	695	0.0%	693	0.2%
	ER_20	At Wellington Rd 125	85	616	614	0.3%	616	0.0%	614	0.3%
	ER_10	At 3rd Line	50	448	446	0.4%	448	0.0%	447	0.4%
Guelph Lake Tributary	GLT_10	Cold Trib. At 3rd Line	19	35	34	3.5%	34	3.3%	35	0.2%
	GLT_20	Trib. At Jones Baseline	18	75	74	1.1%	74	1.0%	75	0.0%
Hanlon Creek	HC	At Waterfowl Park	26	42	19	56.1%	34	18.9%	27	37.3%
	HC_10	At Hwy 6	18	32	20	37.8%	29	10.6%	23	27.2%
	HCT_20	South Trib. At Hwy 6	5	7	-2[1]	126.8%	5	31.2%	0	96.0%
Hopewell Creek	ASF-8	At Breslau Dam	76	202	185	8.4%	195	3.5%	192	5.0%
	HWC_50	Below Hwy 7	73	192	179	6.7%	185	3.6%	186	3.1%
	HP-1	At Greenhouse Rd	51	169	159	5.6%	162	4.0%	166	1.6%
	HWC_10	At Wellington Rd 32	33	103	97	5.7%	97	5.2%	102	0.4%
Irish Creek	IC_20	At Townline Rd	38	86	66	23.1%	74	13.7%	78	9.4%
	IC_10	At Wellington Rd 32	18	54	49	10.5%	52	5.3%	52	5.2%
Lutteral Creek	2GA033	Near Oustic	67	396	396	0.0%	396	0.0%	396	0.0%

Surface Watercourse	ID	Description	Drainage Area (km^2)	Scenario C - Existing Conditions GW Discharge (L/s)	Scenario G(1) (Increased Demand and Recharge Reduction)		Scenario G(2) (Increased Demand)		Scenario G(3) (Recharge Reduction)	
					GW Discharge (L/s)	Percent Reduction (%)	GW Discharge (L/s)	Percent Reduction (%)	GW Discharge (L/s)	Percent Reduction (%)
	LCT_20	Trib. At 6th Line	5	47	47	0.0%	47	0.0%	47	0.0%
Marden Creek	MDC_10	At Wellington Rd 30	14	35	34	3.8%	34	3.6%	35	0.1%
Mill Creek	2GAC19	At SR #10	82	446	426	4.5%	439	1.7%	434	2.8%
	MC-99a	At Paddock's Corners	71	371	353	5.0%	364	1.8%	359	3.2%
	3AQ131	Aberfoyle Ck at Twp Rd 7	43	198	187	5.7%	193	2.6%	192	3.1%
	MC_10	At Victoria Rd	13	73	69	6.5%	70	4.0%	72	2.5%
Moffat Creek	MOFC_20	At Hwy 24	18	25	25	1.2%	31	-23.4%[2]	19	24.6%
	MOFC_10	At Franklin Blvd	14	13	11	17.5%	15	-12.7%[2]	9	30.0%
Speed River	2GA015	Below Guelph	581	2,951	2,774	6.0%	2,792	5.4%	2,933	0.6%
	2GA040	Near Armstrong Mills	174	1,068	1,067	0.0%	1,067	0.0%	1,068	0.0%
	SR_40	Above Lutteral Creek	100	612	612	0.0%	612	0.0%	612	0.0%
	SR_30	At 3rd Line	90	553	553	0.0%	553	0.0%	553	0.0%
	SR_20	At 6th Line	48	361	360	0.0%	361	0.0%	360	0.0%
	SR_10	At Wellington Rd 26	38	261	261	0.0%	261	0.0%	261	0.1%
Swan Creek	ASF-13	At Sideroad 4	43	67	67	0.3%	67	0.1%	67	0.3%
Torrance Creek	TC_10	At Stone Rd	10	32	15	53.9%	19	41.2%	28	12.6%
West Credit River	02HB02	At 8th Line	35	355	339	4.4%	355	0.0%	339	4.4%

Notes:

1) Scenario G(2) used for assessing impacts. Other scenarios provide an indication of contribution to impacts from land use and pumping changes, and combined effects.

2) Highlighted cells indicate streams which have simulated groundwater discharge reductions which are 10% or more for Scenario G(2).

[1]Negative Groundwater Discharge indicates the stream reach is leaking (recharging) into the ground.

[2]Negative Percent Reduction indicated Groundwater Discharge has increased from the existing conditions (Scenario C) due to decreased pumping in the future scenario at Region of Waterloo wells affecting stream reach.

Even though Irish Creek at Townline Rd. was assessed to have discharge reduced by 14%, this watercourse is considered to be situated too close to the model boundary for an accurate assessment of impacts. Therefore, further interpretation or discussion of Irish Creek will not be provided in this Tier Three Assessment.

The locations of the remaining six catchments are shown on Figure 5-22 with the associated reduction in groundwater discharge under Scenario G(2). The results are discussed in the following sections:

Torrance Creek

Torrance Creek is a tributary of the Eramosa River and drains approximately 10.6 km^2 of land in the southern part of the City of Guelph. There are significant terrestrial features from an environmental perspective including the Torrance Creek PSW Complex and upland woodlots. The wetland areas buffer existing urban, rural, and recreational land use from the stream and augment base flows (TSH 1997).

The Torrance Creek Subwatershed Study (TSH 1997) describes the role of groundwater discharge in the subwatershed. The study mapped areas of groundwater discharge, but also found that in September the total flow decreased to a point where several reaches of the creek had little (e.g., < 2 L/s) or no flow. During the study, a series of online ponds may have masked the actual discharge contribution to the creek at several locations acting as local sources of groundwater recharge during periods of low flow. The MNRF has classified Torrance Creek as warm water. Monitoring of streambed piezometers identified upwards gradients within the creek bed in the headwaters and some of the wetlands and also identified the water table as being below the creek in others.

Regional hydrogeologic gradients indicate a downward movement of water from the shallow groundwater system to the deep groundwater system, and that the discharge to Torrance Creek appears to be locally derived from shallow sands and gravel.

Torrance Creek starts in the headwaters as a very short, cold-water reach; however, the MNRF has classified Torrance Creek as warm water, and this is consistent with groundwater discharge being locally derived and not of a sufficient rate and consistency to overcome the warming caused by the online ponds.

The simulated results for Scenario G(2) indicate that increasing municipal pumping to the Allocated rates may reduce groundwater discharge to Torrance Creek and its tributaries by approximately 41%. As Torrance Creek is not classified as a cold-water stream, this impact would not result in a level of risk assigned to the Vulnerable Areas.

Chilligo/Ellis Creek at Wellington Road 32

The Chilligo/Ellis Creek subwatershed is oriented north-south. The headwaters of Chilligo/Ellis Creek are northwest of the City of Guelph, and the creek flows south and discharges into the Speed River in Cambridge. The drainage area is approximately 56.6 km^2. The Chilligo/Ellis Creek subwatershed is

dominated by open agricultural land of various uses with few patches of forest and a golf course in the southern end.

The provincial classification of Chilligo/Ellis Creek is cold water with some of the upper reaches classified as cool water by the Fisheries and Oceans Canada (DFO). The GRCA fisheries monitoring data suggests that the creek supports a cool-water fish community.

The simulated results for Scenario G(2) indicate that increasing municipal pumping to the Allocated rates may reduce groundwater discharge to the upper reaches of the creek by approximately 32% at Wellington Rd. 32. As the creek is classified as a cold-water stream, this impact would result in a Risk Level of *Moderate* assigned to the Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area.

Blue Springs Creek South Branch at 28th Side Road

Blue Springs Creek is a tributary of the Eramosa River and is a perennial, cold-water stream that supports a resident brook trout population. Blue Springs Creek originates near the Town of Acton and flows southwesterly into the Eramosa River. The confluence of Blue Springs Creek with the Eramosa River is located about 2 km northeast of the Arkell Spring Grounds.

The South Branch of Blue Springs Creek drains approximately 17 km^2 of land and discharges into Blue Springs Creek east of Eden Mills. Much of the lands drained by the South Branch are occupied by the Arkell-Corwhin PSW Complex. The Arkell-Corwhin PSW Complex is located on the Paris Moraine at a considerably higher elevation than the Blue Spring Creek and Eramosa River valleys. The wetland complex is designated as a PSW and is made up of ten individual wetlands, composed of two wetland types (90% swamp, 3% marsh; Stantec 2012).

The City of Guelph implemented the Arkell Adaptive Management Plan, designed to monitor and manage groundwater pumping from the Arkell Springs well field (Stantec 2012, 2013, 2015). This work included water quantity, quality, and ecological monitoring of the South Branch of Blue Springs Creek. Monitoring results indicated that there were not significant groundwater contributions into the South Branch. Brook trout and brown trout were not identified within the South Branch. All results indicated that the South Branch was marginal in terms of supporting a trout population and would not be a preferred spawning location relative to other reaches of Blue Springs Creek. However, redd surveys indicated that spawning was low with 1 to 3 redds identified in 2006, 2007, and 2011 data. In all, 21 redds were counted in the lower portion of the South Branch in 2010 (Stantec 2012). In spite of this, Stantec Consulting Ltd. (2012) concluded that the South Branch was not conducive for trout spawning activity and likely does not provide adequate habitat or groundwater upwelling to maintain successful spawning over time.

The simulated results for Scenario G(2) indicate that increasing municipal pumping to the Allocated rates may reduce groundwater discharge to the South Branch of Blue Springs Creek by approximately 27%. As this creek is classified as a cold-water stream, this impact would result in a Risk Level of *Moderate* assigned to Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area.

Hanlon Creek at Waterfowl Park, Hanlon Creek South Tributary at Highway 6 and Hanlon Creek at Highway 6

The Hanlon Creek Subwatershed is located in the south part of the City of Guelph, with a total drainage area of approximately 26.4 km^2. The highest elevation of the subwatershed is approximately 360 m at the northeastern boundary of the subwatershed, while the central wetland area has an elevation of approximately 320 m, forming the headwaters of the Hanlon Creek.

For the most part, soils are well-drained and composed of loam till to the southeast and stony, sandy loam till in the west. The exception is around the central wetland area, where poorly drained gravel soil can be found bordering the wetland to the north and south, while the wetland itself is organic matter with very poor drainage.

The land in this subwatershed is principally covered by built-up residential and commercial areas, particularly to the north and west. The Hanlon Industrial Park is located within the subwatershed at Clair Road West and the Hanlon Expressway. A major conservation area protects wetland and dense forest around the headwaters of the creek. Much of the land otherwise is used for agricultural purposes, but some dense and sparse forest is located to the west end of the subwatershed.

There are two significant wetlands in the Hanlon Creek Subwatershed, which are connected by a heavily vegetated corridor. The Hanlon Creek Swamp is regionally significant and the Hall's Pond Wetland is Provincially Significant. These wetlands provide habitat for some rare and uncommon bird and plant species, as well as for deer and other wildlife (PEIL et al. 2004).

Most of Hanlon Creek is classified as a cold-water stream. Planning and Engineering Initiatives Ltd. et al. (2004) indicate that the presence of online ponds and broad creek sections in the lower portion of Hanlon Creek tend to offset the cooling potential of groundwater inflows in the area. Brook trout are present upstream of the Hanlon Parkway but not downstream and similarly, brook trout spawning locations were found in the upper reaches and central wetland area, but not in the lower reaches (PEIL et al 2004).

The simulated results for Scenario G(2) indicate that increasing municipal pumping to the Allocated rates may reduce groundwater discharge to Hanlon Creek at Waterfowl Park, Hanlon Creek South Tributary at Highway 6 and Hanlon Creek at Highway 6 by approximately 19%, 31%, and 11%, respectively. As this creek is classified as a cold-water stream, these impacts would result in a Risk Level of *Moderate* assigned to Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area.

Due to a lack of predicted impacts of groundwater discharge to cold-water streams in Groundwater Vulnerable Area B, C, and D, a *Low* Risk Level would be assigned to these areas.

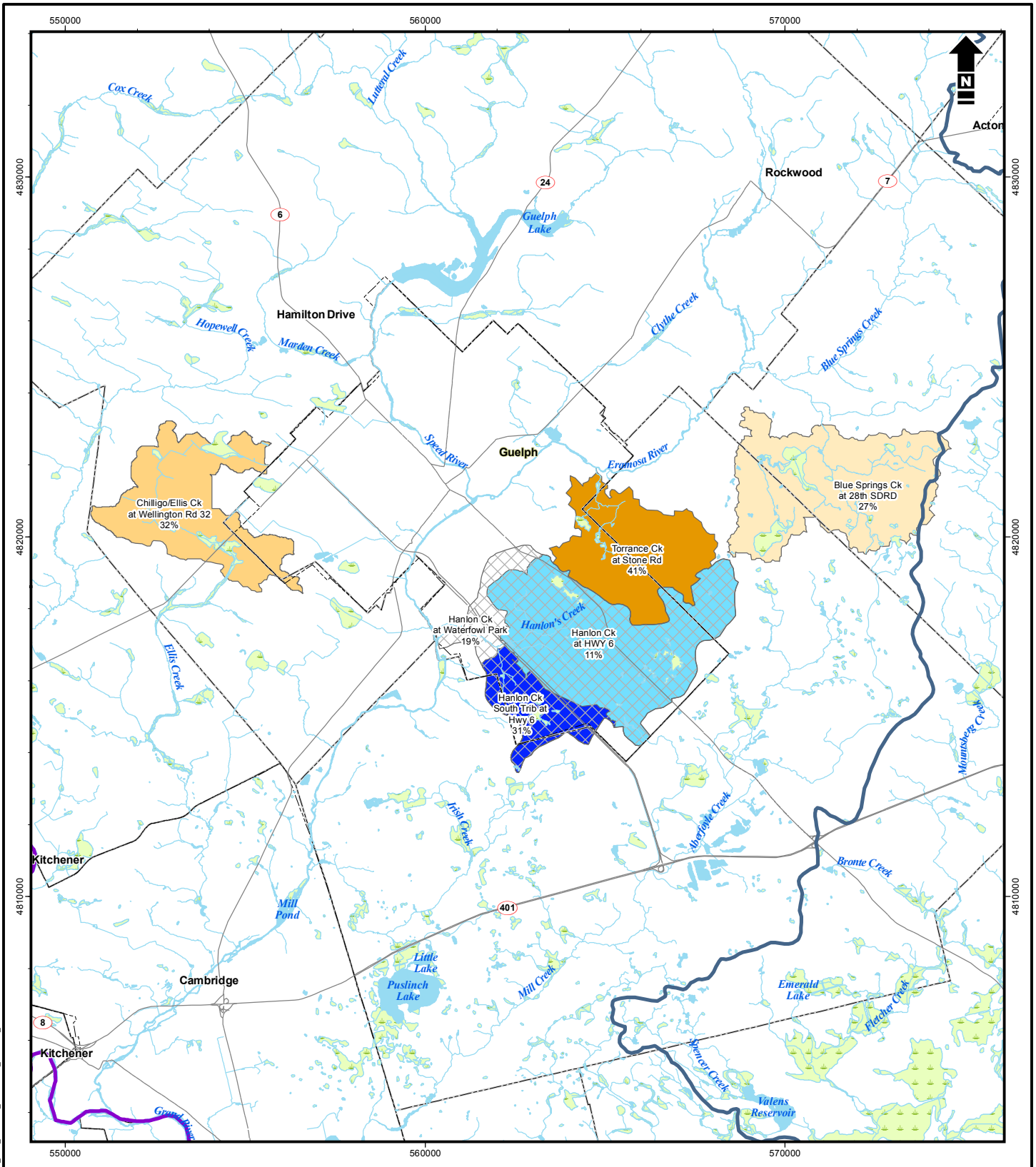
5.5.2.3 Impacts on Provincially Significant Wetlands

Figure 5-23 illustrates the water table reduction predicted under Scenario G(2) as compared to the water table predicted under existing conditions. The increase in municipal pumping to the Existing plus Committed rates is predicted to cause water table reductions in excess of 1 m beneath the following PSWs:

- Marden South Complex in the northwest quadrant
- Ellis Creek Complex in the northwest quadrant
- Guelph Northeast Complex in the northeast quadrant
- Clythe Creek Wetland in the northeast quadrant
- Torrance Creek Swamp in the southeast quadrant
- Eramosa/Blue Springs Creek Wetland in the southeast quadrant

While the Tier Three Groundwater Flow Model has been calibrated against the monitoring data in the deeper aquifer, the model's representation of shallow groundwater flow and wetlands is coarse and based primarily on regional surficial geology mapping. In addition, reductions in shallow water table are strongly influenced by the presence and thickness of the Vinemount Member aquitard, which is uncertain in various areas of the model. As a result of these uncertainties, the model's prediction of water table drawdown near PSWs is uncertain. As a result of the potential for impact to wetlands, Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area would be assigned a Risk Level of *Moderate*.

Due to a lack of predicted impacts on PSWs in Groundwater Vulnerable Areas B, C, and D, a *Low* Risk Level would be assigned in these areas.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Wetland
Water Body
Watercourse
Major Road

Baseflow Reductions (%)

11
19
27
31
32
41

1:150,000
2 0 2
Kilometres
NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Baseflow Reductions (Scenario G(2))

Date:	Project:	Technical:	Reviewer:	Drawn:
16 Jan 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 5-22

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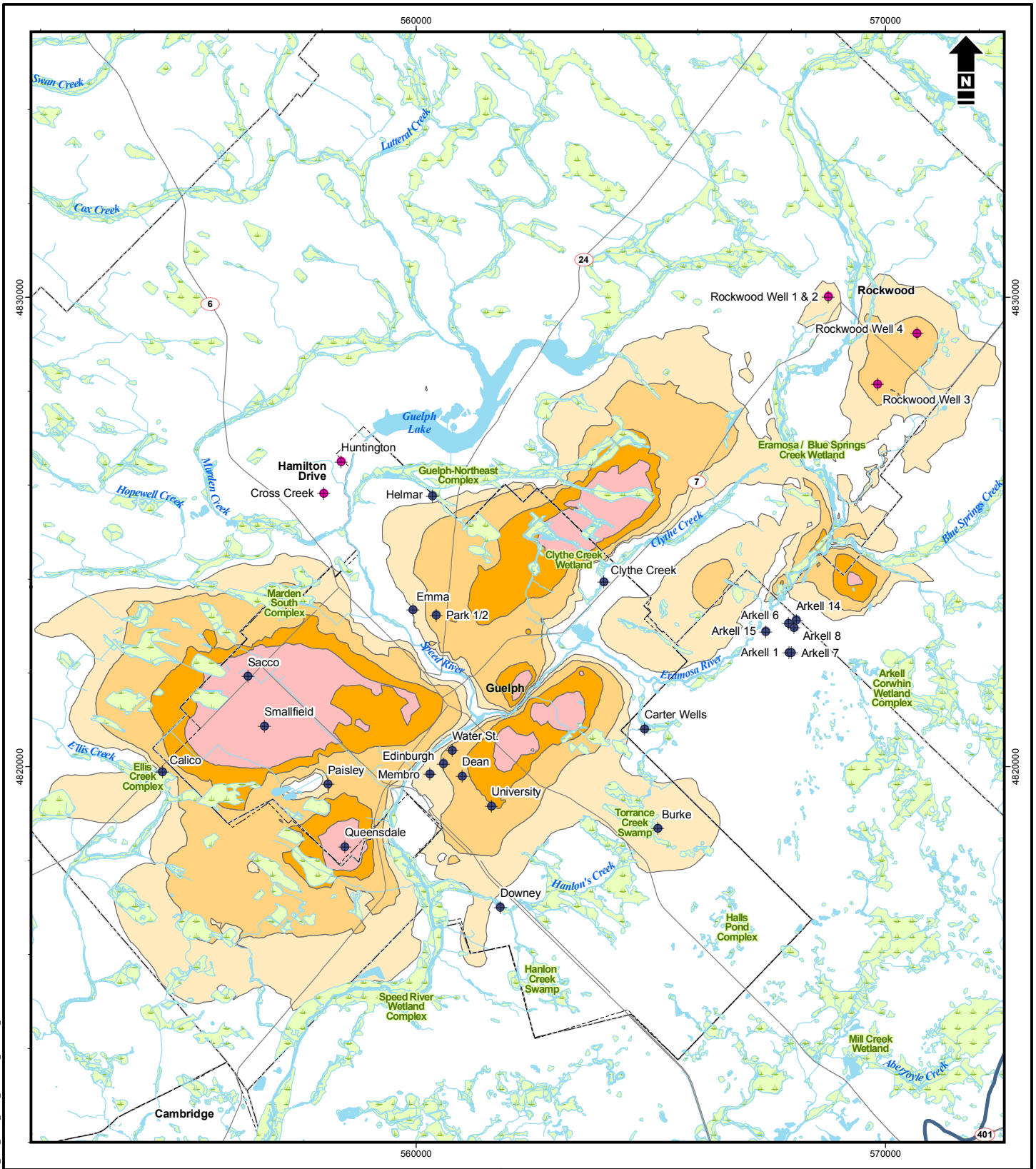

Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Community
Wetland
Water Body
Watercourse
Major Road
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

Drawdown (m)
0.50 - 1.00
1.00 - 2.00
2.00 - 3.00
> 3.00

1:115,000
1 0 1 2
Kilometres
NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Water Table Reduction (Scenario G(2))

Date: 07 Mar 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

Figure 5-23

5.6 Uncertainty - Vulnerable Areas

The Technical Rules (MOECC 2016) require an assessment with respect to the influence of uncertainty on the assignment of a Risk Level to the Vulnerable Local Areas. As described in the Technical Rules (MOECC 2016) and Technical Guidance Memorandum (MOE 2013), the Vulnerable Area should be assigned a Risk Level of *Significant* if the risk scenarios identify the potential that either a well or intake may not be able to pump the Allocated rate, or, in the absence of a Planned quantity of water, a *Moderate* Risk Level if there is an unacceptable impact to other water uses. The rules state that if a Vulnerable Area is assigned a Risk Level of *Moderate* based on the scenarios assessed, the Risk Level should be assigned as *Significant* if an uncertainty analysis characterizes the uncertainty as *High* and a sensitivity analysis suggests that the Risk Level of the Vulnerable Area could be *Significant*.

The Technical Rules also require that the uncertainty analysis be conducted to consider the following factors for the purpose of determining if the uncertainty underlying the risk assignment should be characterized as *High* or *Low*:

1. *The distribution, variability, quality and relevance of the data used to evaluate the scenarios.*

2. *The degree to which the methods and models used to evaluate the scenarios accurately reflects the hydrologic system of the Local Area for both steady-state and transient conditions.*

3. *The quality assurance and control procedures used in evaluating the scenarios.*

As described in the previous sections, Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area (linked through the Glen Collector and the artificial recharge system supplied by the Eramosa Intake) were assigned a Risk Level of *Significant* based on the inability of the Queensdale Well to pump at its Allocated rate. While an uncertainty analysis cannot elevate the Risk Level any higher, the analysis is useful in guiding future efforts to increase the certainty of model predictions. The following subsections provide a discussion of uncertainty relating to the assigned Risk Level along with the factors affecting this uncertainty.

5.6.1 Impacts on Groundwater Discharge to Cold-water Streams - High Uncertainty

Scenario G(2) predicted the impacts of increased pumping at the Allocated rates on groundwater discharge to cold-water streams. This impact was predicted to be *Moderate* for the South Branch of Blue Springs Creek, Upper Chilligo/Ellis Creek, and Hanlon Creek.

The uncertainty with respect to the impact of groundwater discharge on cold-water streams is *High*. For the South Branch of Blue Springs Creek, the following factors contribute to the uncertainty of this Risk Level:

- The groundwater flow model does not reflect many of the local hydrologic and hydrogeologic conditions near the South Branch of Blue Springs Creek and the Arkell-Corwhin PSW Complex.

Although the South Branch is classified as cold water, field observations through most of the creek suggest that it is cool water; only the lower portions of the South Branch may actually be cold water. A more detailed local model that takes into account groundwater and surface water interactions and wetland hydrology may be necessary to better represent hydrologic processes and assess impacts.

- Stantec (2012, 2013, 2015) undertook a long-term pumping test of the Arkell Springs well field. After the first 12 months of pumping, monitoring wells near the South Branch show less response to pumping than was simulated by the model. The model simulates steady-state impacts from pumping on groundwater discharge, and this may partly explain the differences between the model simulation and the pumping test. Calibration of the groundwater model to the pumping test may reduce the uncertainty of the predicted impacts.

For Upper Chilligo/Ellis Creek, the uncertainty of the Risk Level is also *High* with the following factors contributing to this uncertainty:

- Upper Chilligo/Ellis Creek is mapped as cold water in the provincial mapping. However, the GRCA considers the stream to be cool water.

- The groundwater flow model is shown to under-estimate groundwater levels in the northwest quadrant of the City of Guelph. This may be due to gaps in the conceptual model in the area. Hydrogeology in the northwest quadrant is different than through other areas of the City of Guelph. The Vinemount Member aquitard does not exist in some areas and the Gasport Formation aquifer does not include the same high permeable zones that exist in other areas of the City of Guelph.

For Hanlon Creek, the uncertainty of the *Moderate* Risk Level is *Low* due the following factors:

- The City of Guelph has undergone a long-term pumping test as part of the Southwest Quadrant Class EA (Golder 2010). The current groundwater flow model was updated to reflect information collected as part of the EA and calibrated against the pumping test results.

- The Vinemount Member aquitard is mapped continuously through the area, providing a hydraulic barrier between pumping and the shallow groundwater system.

- The City of Guelph has been pumping from the Gasport Formation aquifer for a long time, and a cold-water habitat has been sustained in Hanlon Creek over the period of pumping.

The impacts to cold-water streams cannot result in a Risk Level of *Significant* when considering Allocated rates, as described in the Technical Guidance Memorandum (MOE 2013). Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area were already assigned a *Significant* Risk Level due to the inability of the Queensdale Well to pump at its Allocated rate because of predicted drawdown impacts.

5.6.2 Impacts to Provincially Significant Wetlands - High Uncertainty

Scenario G(2) predicted water table drawdown in excess of 1 m beneath the following PSWs:

- Marden South Complex in the northwest quadrant
- Ellis Creek Complex in the northwest quadrant
- Guelph Northeast Complex in the northeast quadrant
- Clythe Creek Wetland in the northeast quadrant
- Torrance Creek Swamp in the southeast quadrant
- Eramosa/Blue Springs Creek Wetland in the southeast quadrant

The uncertainty of the *Moderate* Risk Level for wetland impacts is *High* due the following factors:

- While the Tier Three Groundwater Flow Model has been calibrated against the monitoring data in the deeper aquifer, the model's representation of shallow groundwater flow and wetlands is relatively coarse and based largely on regional surficial geology mapping. In addition, reductions in the shallow water table are strongly influenced by the presence and thickness of the Vinemount Member aquitard, which is uncertain in various areas of the model. The model's prediction of water table drawdown may be over-estimated by the simplification of overburden hydrogeology and groundwater/surface water interactions.

- The groundwater flow model was shown to under-estimate groundwater levels in the northwest quadrant of the City of Guelph. This may be due to gaps in the conceptual model in the area. Hydrogeology in the northwest quadrant is different than through other areas of the City of Guelph. The Vinemount Member aquitard does not exist in some areas and the Gasport Formation aquifer does not include the same high permeable zones as in other areas of the City of Guelph. Gaps in the conceptual model may result in over-prediction of water table impacts in Scenario G(2).

- The modelling approach employed in this assessment over-simplifies wetland hydrology. Wetlands such as Ellis Creek Complex that are situated in areas of lower-permeability surficial geology may be dominated by surface water contributions as opposed to groundwater discharge. Although the groundwater flow modelling results identify a potential for impact, actual impact to wetlands cannot be estimated very well without considering all aspects of wetland hydrology.

- The City of Guelph has pumped groundwater in the northeast and northwest quadrants for many years and the Marden South, Ellis Creek, Guelph Northeast, and Clythe Creek PSWs remain.

As a result of the above factors, there is a *High* uncertainty associated with the prediction of impact to wetlands. However, for impacts to PSWs, a Risk Level of *Significant* cannot be assigned when considering only Allocated rates. Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area were already assigned a *Significant* Risk Level due to predicted drawdown impacts.

5.6.3 Ability to Pump Allocated Rates - High Uncertainty

The results of scenarios G(1), G(2), H(1), and H(2) indicate that the Queensdale Well will not be able to pump the Allocated rates under average or drought conditions. As a result of the safe additional drawdown being exceeded, a *Significant* Risk Level was assigned to Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area. Conversely, the model predicted drawdown results of scenarios C, D, G, and H indicate that the other municipal wells of the City of Guelph and those of the Township of Guelph/Eramosa (in Rockwood and Hamilton Drive) will be able to pump current and Allocated rates under average and drought conditions with respect to the level in the wells. These results are supported by historical operating experience in the City of Guelph where many of the wells have pumped their Allocated rates over prolonged periods of time. The primary municipal water supply aquifer is protected in most areas by the Vinemount Member aquitard, which reduces the vulnerability of the supply to drought. Well capacities were estimated from long-term operations and maintenance records, which suggest that the Allocated rates are sustainable.

For the majority of the municipal wells, including the Queensdale Well, the uncertainty with respect to the predicted ability to pump Allocated rates is *Low*. The model was based on a refined hydrostratigraphic model representing the groundwater system of the City of Guelph and the Township of Guelph/Eramosa that has been developed over a number of years. The model was shown to be well-calibrated with respect to water levels measured at high-quality observation wells throughout these areas. The model results are also consistent with well capacity estimates based on traditional hydrogeology analytical techniques.

For Arkell Well 1, the uncertainty with respect to the predicted ability to pump Allocated rates is *High*. The maximum simulated drawdown during model scenarios predicted about 0.1 m of available drawdown considering Allocated rates during drought conditions. This well is a shallow overburden well and is highly influenced by recharge. Sensitivity analysis conducted during model calibration (Appendix B) demonstrates the Tier Three model predictions are highly sensitive to recharge. The estimation of recharge through calibrated surface and groundwater models is subject to great uncertainty, especially for local-scale recharge that impacts shallow overburden aquifers. Given this, there is a greater chance that Arkell Well 1 may not be able to pump the Allocated rate during a drought. Given this uncertainty, a *Significant* Risk Level should be assigned to Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area, even if it was not already assigned based on impacts at Queensdale Well.

5.6.4 Impact of Recharge Reductions on Ability to Pump Allocated Rates - Low Uncertainty

Scenario G(3) predicts the steady-state impact of recharge reductions on groundwater levels in the aquifer at the locations of the municipal water supply wells. This scenario assumes that recharge reductions may occur as a result of future land developments that are consistent with the Official Plans. The scenario also assumes no mitigation measures, so recharge reductions are proportional to the increased imperviousness. With respect to the City of Guelph and Rockwood, future land developments generally occur around the periphery of these communities with a minimal increase in imperviousness over the Local Area.

The predicted impacts to water levels at the municipal wells are minimal, ranging from 0.1 to 0.3 m. The Gasport Formation aquifer is protected in most areas by the Vinemount Member aquitard, which reduces the impact of reduced groundwater recharge occurring at locations near the production wells on water levels in the aquifer.

The uncertainty with respect to the impact to water levels is *Low*. The current hydrostratigraphic model provides a generally good understanding of the distribution and characterization of the Vinemount Member aquitard. The model calibration replicates observed vertical gradient across the aquitard and the ability of the aquitard to separate the shallow groundwater system from the deeper water supply aquifer. Finally, the relative amount of imperviousness associated with new land development across the Vulnerable Areas is minimal.

6 WATER QUANTITY THREATS

For each Vulnerable Area identified under clause 15 (2) (d) or (e) of the *Clean Water Act* (Government of Ontario 2017), Drinking Water Threats that are or would be classified as *Moderate* or *Significant*, need to be identified. As outlined in the Technical Rules (MOECC 2016), the definition of a Drinking Water Quantity Threat is any activity that reduces groundwater recharge to an aquifer or any consumptive water demand. These are the activities prescribed to be Drinking Water Threats in paragraphs 19 and 20 of subsection 1.1(1) of O. Reg. 287/07 (General; Government of Ontario 2015). Consumptive demands are activities that extract water from an aquifer or surface water body without returning that water to the same aquifer or surface water body. Since Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area were assigned a Risk Level of *Significant*, all consumptive demands or recharge reductions within these areas are classified as *Significant* Water Quantity Threats.

6.1 Water Quantity Threats - Groundwater Vulnerable Area A

6.1.1 Consumptive Water Demands

Figure 6-1 illustrates the municipal water supply wells, Eramosa River Intake and permitted consumptive water uses within Groundwater Vulnerable Area A. The Eramosa River surface water intake and all of the water supply wells for the City of Guelph (Table 3-1) and the Township of Guelph/Eramosa in

Hamilton Drive (Table 3-2) are consumptive water uses within Groundwater Vulnerable Area A and are therefore classified as *Significant* Water Quantity Threats. Table 6-1 shows the other non-municipal permitted consumptive water uses within Groundwater Vulnerable Area A. These are also classified as *Significant* Water Quantity Threats.

All non-permitted water uses (including those exempt from permitting such as domestic water uses that are taking less than 379,000 L/day) located within Groundwater Vulnerable Area A are also classified as *Significant* Water Quantity Threats. Domestic wells extract very little water as compared to permitted consumptive water users on the scale of the Tier Three Assessment. However they are considered as activities prescribed to be Drinking Water Threats in paragraphs 19 of subsection 1.1(1) of O. Reg. 287/07 (General; Government of Ontario 2015) and thus are identified in this study using information contained within the MOECC water well information system.

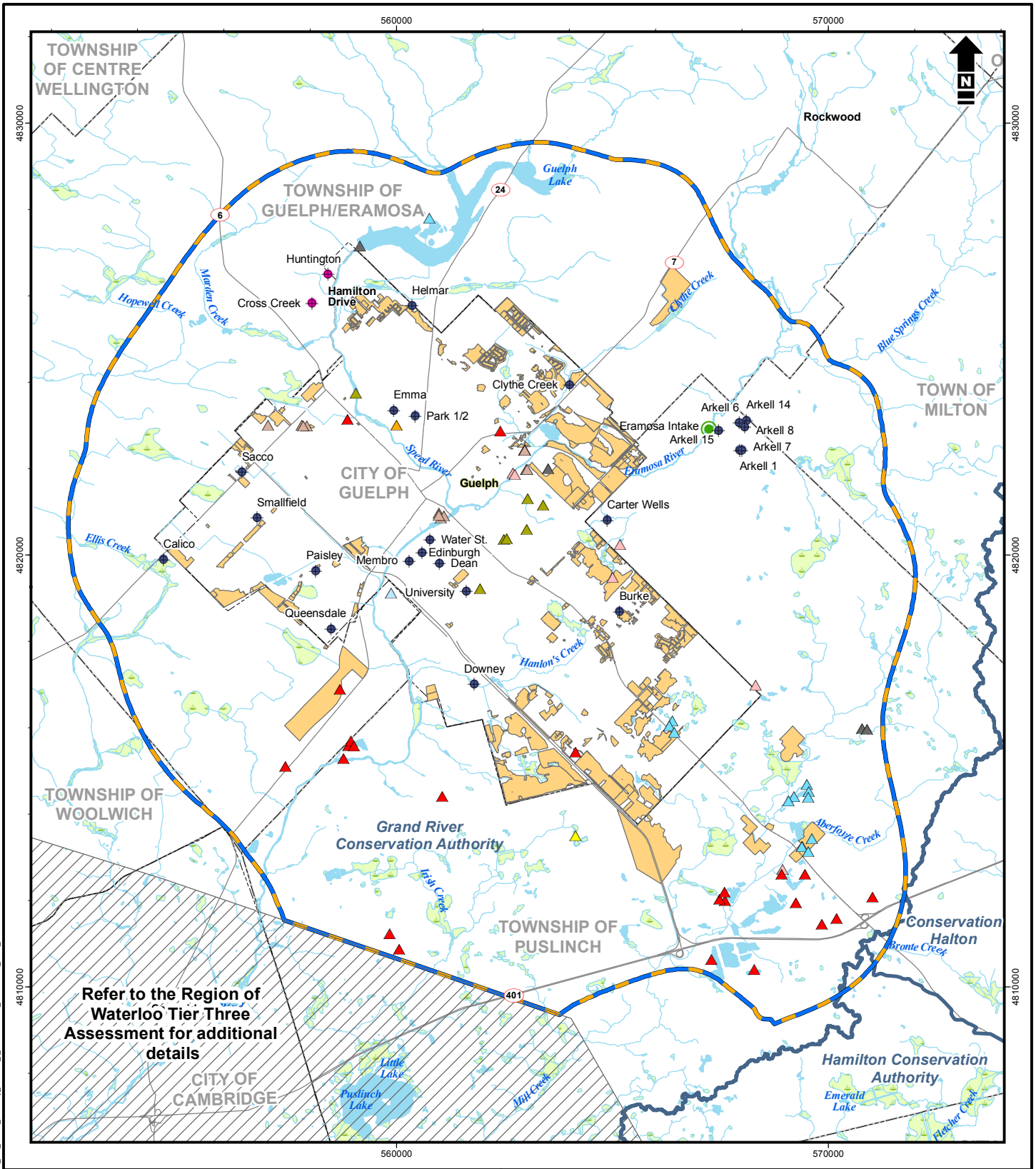
TABLE 6-1 Non-municipal Permitted Consumptive Water Uses - Groundwater Vulnerable Area A

Permit No.	Easting (NAD83)	Northing (NAD83)	Specific Purpose	Maximum Permitted Rate (m^3/day)
01-P-2004	557025	4823001	Groundwater	328
01-P-2245	570784	4815980	Irrigation	60
01-P-2245	570901	4815964	Heat Pumps	69
0147-6K9RKS	562971	4822422	Other - Remediation	23
0147-6K9RKS	562971	4822424	Other - Remediation	13
0147-6K9RKS	563000	4821986	Other - Remediation	7
0147-6K9RKS	563024	4821986	Other - Remediation	7
0147-6K9RKS	562963	4822429	Other - Remediation	10
0147-6K9RKS	562968	4822422	Other - Remediation	13
02-P-2002	559836	4811222	Aggregate Washing	548
02-P-2002	560055	4810875	Aggregate Washing	122
03-P-2003	561056	4814413	Aggregate Washing	490
0882-6FTHMA	566388	4816161	Other - Water Supply	656
0882-6FTHMA	566318	4816054	Other - Water Supply	130
0882-6FTHMA	566425	4815893	Other - Water Supply	65
1065-5VFQ9K	564140	4815443	Brewing and Soft Drinks	553
1204-62XKAF	562403	4822865	Cooling Water	110
1216-6SCL4W	571022	4812087	Food Processing	110
1528-6GTN6M	557917	4822988	Other - Remediation	299
1528-6GTN6M	557809	4823006	Other - Remediation	15
1528-6GTN6M	557836	4822990	Other - Remediation	15
1626-63SRNW	559148	4827151	Dams and Reservoirs	174,240
1787-6C8RLU	562478	4820358	Other - Agricultural	737
1787-6C8RLU	562551	4820377	Other - Agricultural	525
1787-6C8RLU	561928	4819232	Other - Agricultural	1,309
2448-6FUKQ5	567290	4810630	Aggregate Washing	8,183

Permit No.	Easting (NAD83)	Northing (NAD83)	Specific Purpose	Maximum Permitted Rate (m^3/day)
2768-6QXRCC	557427	4815114	Manufacturing	79
3024-6CQJZ5	565174	4820242	Golf Course Irrigation	882
3036-6QPKHE	560000	4823000	Other - Institutional	137
3150-6AYMSU	562699	4821908	Golf Course Irrigation	900
3150-6AYMSU	562739	4821877	Golf Course Irrigation	1,591
3234-74ER7S	568280	4810400	Aggregate Washing	23,568
3331-73RKYV	569499	4814701	Communal	323
3331-73RKYV	569537	4814528	Communal	185
3331-73RKYV	569534	4814390	Communal	132
3331-73RKYV	569080	4814310	Communal	333
3830-6W6JHW	569250	4811950	Aggregate Washing	23,568
4366-6BTRUX	563512	4821997	Heat Pumps	816
5081-6GEPMB	560760	4827800	Other - Water Supply	130
5081-6GEPMB	560520	4828020	Other - Water Supply	130
5170-6X9H33	568312	4816988	Golf Course Irrigation	657
5201-6B7HDA	567608	4811999	Other - Industrial	802
5201-6B7HDA	567476	4812030	Other - Industrial	516
5201-6B7HDA	567598	4812203	Other - Industrial	115
5336-6C8R2N	563036	4821307	Field and Pasture Crops	252
5336-6C8R2N	563010	4820588	Field and Pasture Crops	175
5336-6C8R2N	563398	4821157	Field and Pasture Crops	110
5503-6FUN8K	559052	4823745	Other - Agricultural	75
6560-6DYPGH	570188	4811581	Manufacturing	250
6560-6DYPGH	569847	4811446	Manufacturing	200
6800-72CLQH	558858	4823140	Other - Industrial	1,635
7043-74BL3K	568935	4812721	Bottled Water	3,600
72-P-0103	558770	4815289	Aggregate Washing	1,309
72-P-0103	558886	4815582	Aggregate Washing	4,473
72-P-0103	558939	4815690	Aggregate Washing	273
72-P-0103	559009	4815572	Aggregate Washing	4,910
72-P-0453	568922	4812609	Aggregate Washing	8,183
7240-65YKTN	559873	4819122	Pits and Quarries	13,750
8083-6G3PR7	564140	4813500	Wetlands	666
5626-7WLQ3W	569389	4813250	Communal	785
5626-7WLQ3W	569384	4813245	Communal	785
5626-7WLQ3W	569616	4813435	Communal	137
5626-7WLQ3W	569536	4813137	Communal	67
88-P-2069	558681	4816893	Other - Industrial	655
89-P-2014	569462	4812611	Other - Industrial	73
93-P-2103	565004	4819478	Golf Course Irrigation	540
98-P-2064	569203	4814403	Campgrounds	393

Permit No.	Easting (NAD83)	Northing (NAD83)	Specific Purpose	Maximum Permitted Rate (m^3/day)
99-P-2070	561018	4820862	Groundwater	46
99-P-2070	560982	4820975	Groundwater	46
99-P-2070	561092	4820909	Groundwater	46
99-P-2070	560985	4820923	Groundwater	46

Note:
Permits were current as of the Study Period and obtained from the *Permit to Take Water Database* (MOE 2008)



Tier Three Model Boundary (Study Area)
Grand River Watershed Regulatory Boundary
Groundwater Recharge Reduction Activities
Community
Wetland
Water Body
Watercourse
Major Road
Niagara Escarpment
Groundwater Vulnerable Area A
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)
River Intake

Water Quantity Threat

- Agricultural
- Commercial
- Dewatering
- Industrial
- Institutional
- Miscellaneous
- Recreational
- Remediation
- Water Supply

1:125,000
1 0 1
Kilometres
NAD 1983 UTM Zone 17N

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Water Quantity Threats
Groundwater Vulnerable Area A

Date: 10 Mar 2017	Project: 15072-527	Technical: P. Chin	Reviewer: D. VanVliet	Drawn: M. Urtheil

Figure 6-1

6.1.2 Reductions in Groundwater Recharge

The Technical Rules (MOECC 2016) specify that reductions in groundwater recharge are a potential water quantity threat within the Vulnerable Areas. The Tier Three Scenarios considered the impact of existing and future land development defined by the Official Plans, on groundwater recharge and the resulting impact on water levels in the municipal aquifer at the wells. All reductions in groundwater recharge within Groundwater Vulnerable Area A are also classified as *Significant* Water Quantity Threats and are provided on Figure 6-1.

6.2 Water Quantity Threats - Surface Water Vulnerable Area

6.2.1 Consumptive Water Demands

Figure 6-2 illustrates the municipal and non-municipal permitted consumptive water demands within the Surface Water Vulnerable Area (IPZ-Q). The municipal consumptive water uses in the Surface Water Vulnerable Area are the Arkell wells, Eramosa Intake, and the Township of Guelph/Eramosa municipal wells in Rockwood. All other non-municipal permitted water demands are listed in Table 6-2. These permitted consumptive water uses, along with all non-permitted water uses (e.g., rural domestic water uses that are exempt from permitting if they are taking less than 379,000 L/day, but that lie within the Surface Water Vulnerable Area) are classified as *Significant* Water Quantity Threats.

TABLE 6-2 Non-municipal Permitted Consumptive Water Uses - Surface Water Vulnerable Area

Permit No.	Easting (NAD83)	Northing (NAD83)	Specific Purpose	Maximum Permitted Rate (m^3/day)
00-P-2417	566898	4836647	Other - Agricultural	655
00-P-2417	567174	4837007	Other - Agricultural	655
0510-6LELVD	568983	4831671	Other - Recreational	18,835
2202-6X9QTU	565937	4845420	Aquaculture	1,310
2202-6X9QTU	565845	4845183	Aquaculture	2,620
2202-6X9QTU	566032	4845329	Aquaculture	654
4523-6GEGT5	575238	4839517	Wetlands	43,308
6480-74BKR4	568384	4847833	Bottled Water	1,113
7175-6LCQ2M	574049	4832866	Golf Course Irrigation	238
88-P-2037	567354	4841519	Field and Pasture Crops	655
93-P-2099	569441	4836549	Wildlife Conservation	0
96-P-2059	569295	4842341	Other - Recreational	393
96-P-2059	569333	4842449	Other - Recreational	393

Note:
Permits were current as of the Study Period and obtained from the *Permit to Take Water Database* (MOE 2008)

6.2.2 Reductions in Groundwater Recharge

Similar to Groundwater Vulnerable Area A, all reductions in groundwater recharge in the Surface Water Vulnerable Area are also classified as *Significant* Water Quantity Threats. These threats are provided on Figure 6-2 and consist of future developments in Rockwood and the Town of Erin that are defined in the Official Plan.

6.3 Significant Water Quantity Threat Enumeration

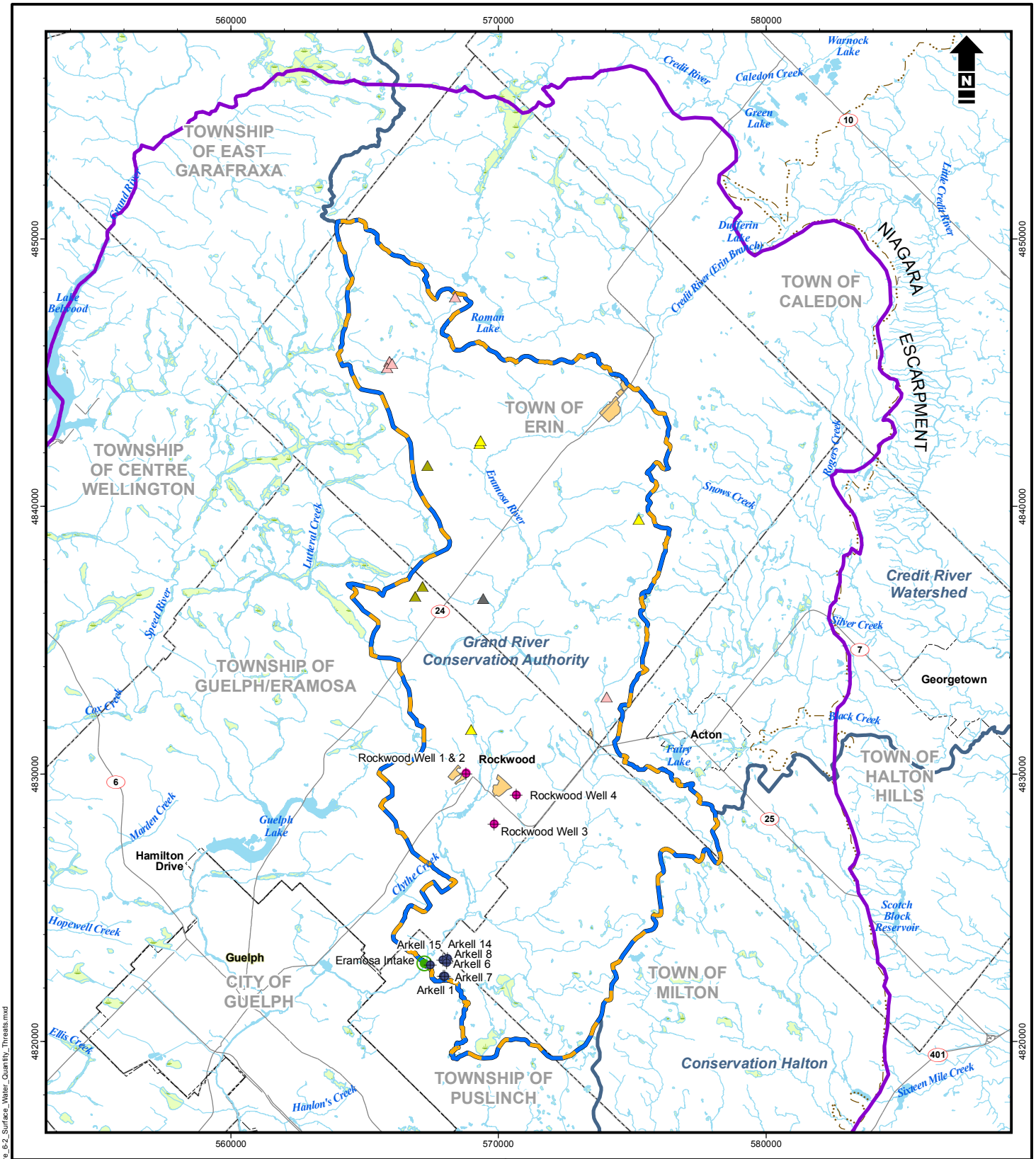
A summary of the number of municipal and non-municipal permitted, and non-permitted *Significant* Water Quantity Threats, lying within various areas (i.e., Vulnerable Areas, Source Protection Areas, and Municipal Areas), is provided in Table 6-3. A total of 116 permitted threats were identified. The *Water Well Information System* (MOE 2012) was used to estimate the number of domestic water wells within the various areas. These are non-permitted takings are exempt from permitting if they are taking less than 379,000 L/day. A total of 7,420 individual non-municipal, non-permitted *Significant* Water Quantity Threats are found within the Study Area and are enumerated in Table 6-3.

Significant Water Quantity Threats represented by areas of reduced groundwater recharge are also summarized in Table 6-3. To avoid the subjective nature of grouping and counting individual polygons of land area, which may or may not be related, these threats are provided as the area of recharge reduction contained within the areas of interest. While these recharge reduction areas range up to 17 km^2 in size, they represent less than 6% of the total area of a Vulnerable Area, less than 0.5% of the total area of a Source Protection Area and less than 15% of the total area of a municipality.

TABLE 6-3 Count of Significant Water Quantity Threats by Threat Group

Threat Group	Vulnerable Area		Source Protection Area		Municipal Area					
	Groundwater Vulnerable Area A (WHPA-Q1/ Q2)	Surface Water Vulnerable Area (IPZ-Q)	Grand River Source Protection Area	Halton Region Source Protection Area	City of Guelph	Township of Guelph/ Eramosa	Township of Puslinch	Town of Erin	Town of Milton	Town of Halton Hills
Municipal	28	11	32	0	16	7	9	0	0	0
Non-municipal Permitted	71	13	83	1	32	9	33	10	0	0
Non-municipal, Non-permitted[1]	5,153	2,671	7,369	51	2,179	1,973	1,659	972	536	101
Total	5,252	2,695	7,484	52	2,227	1,989	1,701	982	536	101
Recharge Reduction[2]	16.33 km^2 (5.3% of Groundwater Vulnerable Area A)	1.04 km^2 (0.4% of Surface Water Vulnerable Area)	17.37 km^2 (0.3% of Grand River Source Protection Area)	0 km^2 (0% of Halton Region Source Protection Area)	12.45 km^2 (14.3% of City of Guelph Area)	2.23 km^2 (0.8% of Township of Guelph/ Eramosa Area)	2.11 km^2 (1.0% of Township of Puslinch Area)	0.58 km^2 (0.2% of Town of Erin Area)	0 km^2 (0% of Town of Milton Area)	0 km^2 (0% of Town of Halton Hills Area)
Total[3]	Total number of *Significant* threats identified within all Vulnerable Areas of the Water Quantity Risk Assessment	7,536[4]	Total number of *Significant* threats identified within all Source Protection Areas of the Water Quantity Risk Assessment	7,536	Total number of *Significant* threats identified within all Municipalities of the Water Quantity Risk Assessment			7,536		

Notes:
[1]Only domestic water wells recorded in the Water Well Information System database (2012) are included. These are exempt from permitting if they are taking less than 379,000 L/day.
[2]Recharge reduction threats are summarized by identifying the total area represented by Recharge Reduction Polygons and as a percentage of the total area of interest
[3]Total number of *Significant* threats does not include individual Recharge Reduction Polygons as those threats have been identified on a per-area basis.
[4]Total number of *Significant* threats identified within all Vulnerable Areas is not equal to the sum of *Significant* threats from each individual Vulnerable Area due to overlapping Vulnerable Areas where some threats lie within both the WHPA-Q1/2 and IPZ-Q.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Surface Water Vulnerable Area
Groundwater Recharge Reduction Activities
Community
Wetland

Water Body
Watercourse
Major Road
Niagara Escarpment
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)
River Intake

Water Quantity Threat
Agricultural
Commercial
Dewatering
Industrial
Institutional
Miscellaneous
Recreational
Remediation
Water Supply

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Surface Water Quantity Threats

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 6-2

7 SIGNIFICANT GROUNDWATER RECHARGE AREAS

7.1 Introduction

The Technical Rules (MOECC 2016) require that SGRAs be delineated for each Source Protection Area. The role of SGRAs is to support the protection of drinking water across the broader landscape. SGRAs delineated using the water budget tools are one of four types of Vulnerable Areas that are used in water quality vulnerability assessments; the other Vulnerable Areas are wellhead protection areas, intake protection zones, and highly vulnerable aquifers.

Recharge is the residual portion of precipitation left after the subtraction of water returned to the atmosphere by evapotranspiration or transferred to stream channels by overland flow and interflow above the groundwater system. The amount of groundwater recharge is influenced by the infiltrability of the ground surface; land use or vegetation; the depth, hydraulic conductivity and soil water storage characteristics of surficial overburden layers; and slope of the topography (if extremely steep). Recharge does not occur in areas of groundwater discharge.

The Technical Rules (MOECC 2016) provide a methodology to delineate SGRAs from the GAWSER and FEFLOW simulation results. This section follows this methodology with several enhancements.

7.2 Methods Used to Delineate Significant Groundwater Recharge Areas

The Technical Rules (MOECC 2016) provide the following instructions for the delineation of SGRAs:

Part V.2 - Delineation of Significant Groundwater Recharge Areas

44. Subject to Rule 45, an area is a significant groundwater recharge area if,

> *(1) The area annually recharges water to the underlying aquifer at a rate that is greater than the rate of recharge across the whole of the related groundwater recharge area by a factor of 1.15 or more.*
>
> *(2) The area annually recharges a volume of water to the underlying aquifer that is 55% or more of the volume determined by subtracting the annual evapotranspiration for the whole of the related groundwater recharge area from the annual precipitation for the whole of the related groundwater recharge area.*

45. Despite Rule 44, an area shall not be delineated as a significant groundwater recharge area unless the area has a hydrological connection to a surface water body or aquifer that is a source of drinking water for a drinking water system.

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

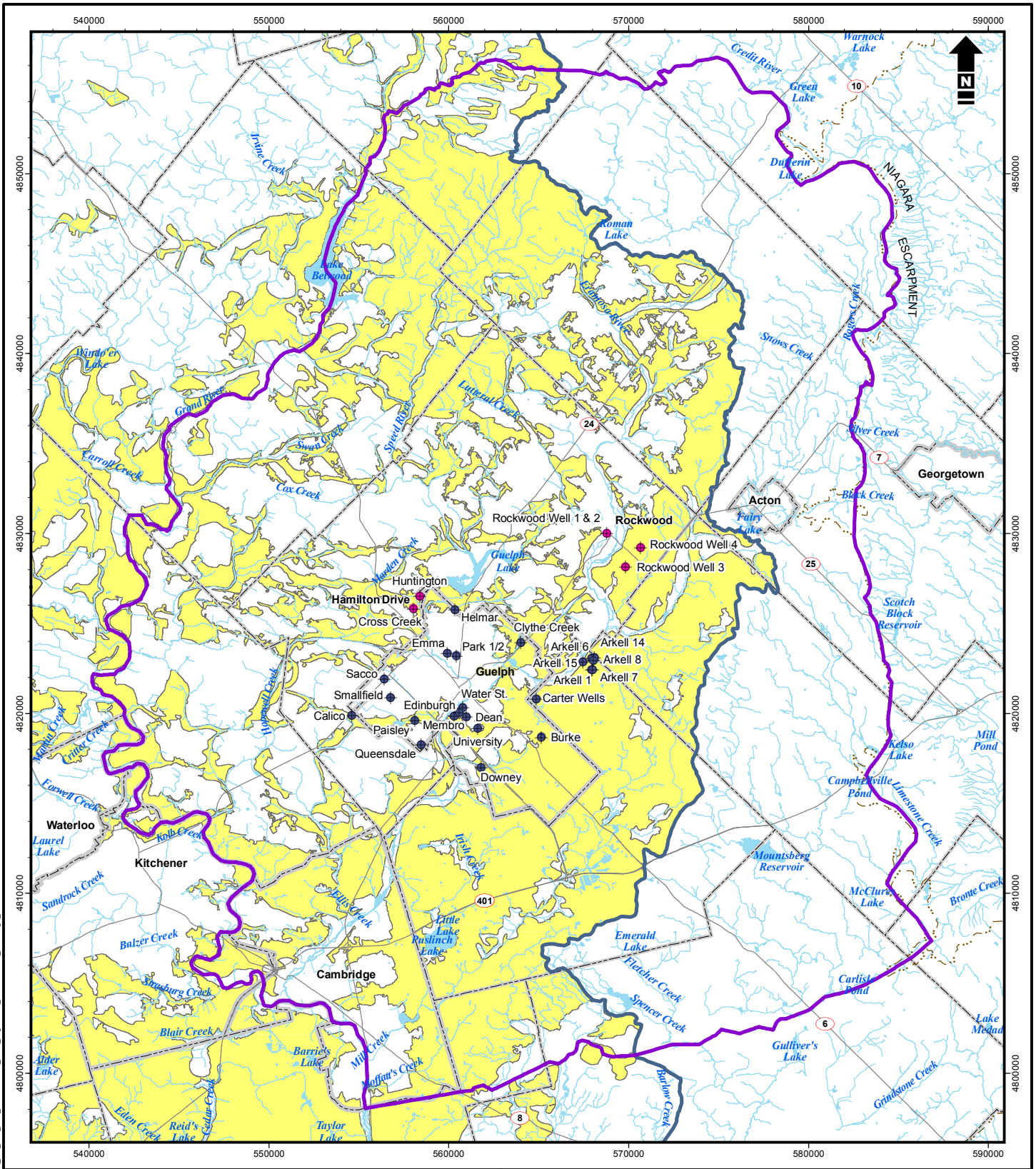
This assessment follows Rule 44(1) to define the thresholds for SGRAs; a review of estimated recharge distribution across the watersheds provide further justification of the threshold value used. The "related groundwater recharge area" identified in Rule 44(1) was defined in the Tier Two Assessment as the entire Grand River Watershed. For this study, the threshold value used to delineate SGRAs within the Grand River Watershed portion of the Study Area was recalculated using the refined recharge estimates from the Tier Three Assessment.

7.3 Significant Groundwater Recharge Area Delineation Results

7.3.1 Tier Two Assessment Significant Groundwater Recharge Areas

SGRAs were delineated in the Tier Two Assessment (AquaResource 2009b) across the Grand River Watershed using the methodology outlined above and are illustrated for the Study Area on Figure 7-1. The average annual recharge across the entire Grand River Watershed was calculated to be 176 mm/year; consequently, the SGRA threshold for all subwatersheds within the watershed was calculated to be 202 mm/year.

The SGRAs cover a large portion of the Study Area Within the Grand River Watershed, but are largely absent in the urban areas and along groundwater discharge areas including lakes, ponds, and wetlands The central part of the Study Area consists of low permeability Port Stanley Till with lower recharge. Areas to the north and south are regions of hummocky moraine (Orangeville, Galt, and Paris moraines) with the majority of the recharge occurring in these areas.



- Tier Three Model Boundary (Study Area)
- Grand River Watershed Boundary
- Significant Groundwater Recharge Area
- Community
- Water Body
- Watercourse
- Major Road
- Niagara Escarpment
- Municipal Well (City of Guelph)
- Municipal Well (Guelph/Eramosa Township)

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Tier Two Assessment Final Significant Groundwater Recharge Areas

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 7-1

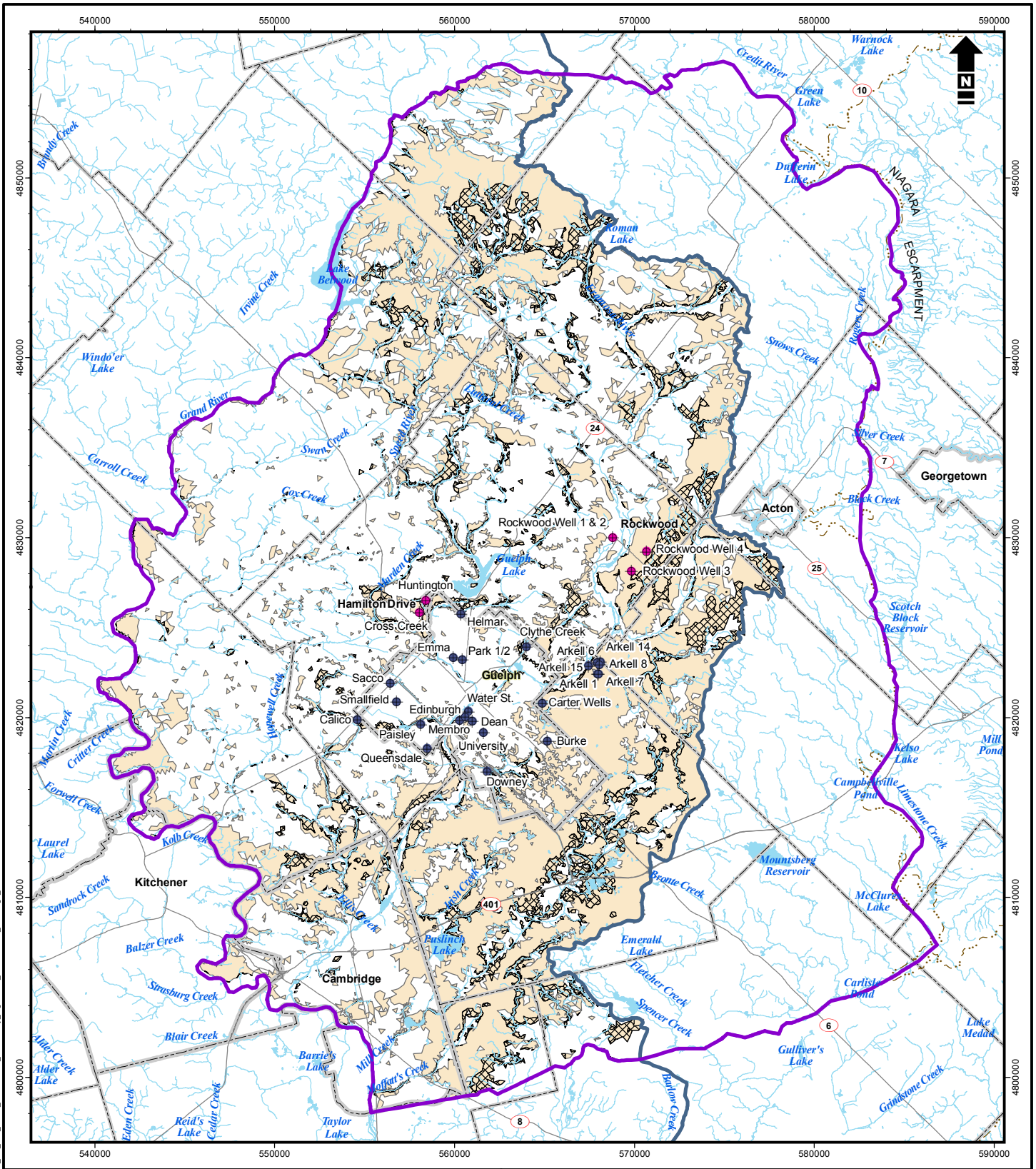
7.3.2 Tier Three Assessment Significant Groundwater Recharge Areas

For the Tier Three Assessment, the SGRA threshold was recalculated using the same methodology as the Tier Two Assessment. The average annual recharge across the portion of the Grand River Watershed lying within the Study Area was calculated to be 174 mm/year; consequently, the SGRA threshold was calculated to be 200 mm/year. This is close to the 202 mm/year threshold calculated for the whole Grand River Watershed used in the Tier Two Assessment and was thus retained for the Tier Three Assessment. Figure 7-2 illustrates the areas within the watershed where recharge was simulated to be greater than 202 mm/year.

Professional judgment was used to remove potential groundwater discharge areas (areas where the model-simulated water table is less than 2 m bgs) from the SGRA mapping; Figure 7-2 provides the spatial distribution of these areas within the watershed. The 2 m threshold was chosen to account for seasonal water level fluctuations not captured by the steady-state groundwater flow model.

Figure 7-3 illustrates the final Tier Three Assessment SGRA mapping for the portion of the Grand River Watershed that lies within the Study Area. Potential groundwater discharge locations as well as isolated areas less than or equal to 4 hectares (40,000 m^2) were removed to simplify the implementation of this mapping in the planning process. Areas that were mapped as sand and gravel by the OGS (2003) were not removed.

As illustrated on Figure 7-3, the SGRAs include large portions of the Orangeville Moraine to the north and Paris and Galt moraines in the south-central portion of the Study Area where coarse-grained sediments are mapped at surface and hummocky topography exists. Within the urban areas, there are few SGRAs as the urban areas have a high percentage of impervious cover associated with roads, buildings, paved areas, etc. The SGRA mapping completed in the Tier Two (Figure 7-1) and Tier Three Assessments (Figure 7-3) are similar as the thresholds were similar (200 mm/year and 202 mm/year). Both assessments identify large portions of the watershed on the moraines outside the urban areas as high recharge areas and well as the low recharge areas associated with the Port Stanley Till.



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Water Table within 2m of Ground Surface
Groundwater Recharge Area
Community
Water Body
Watercourse
Major Road
Niagara Escarpment
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

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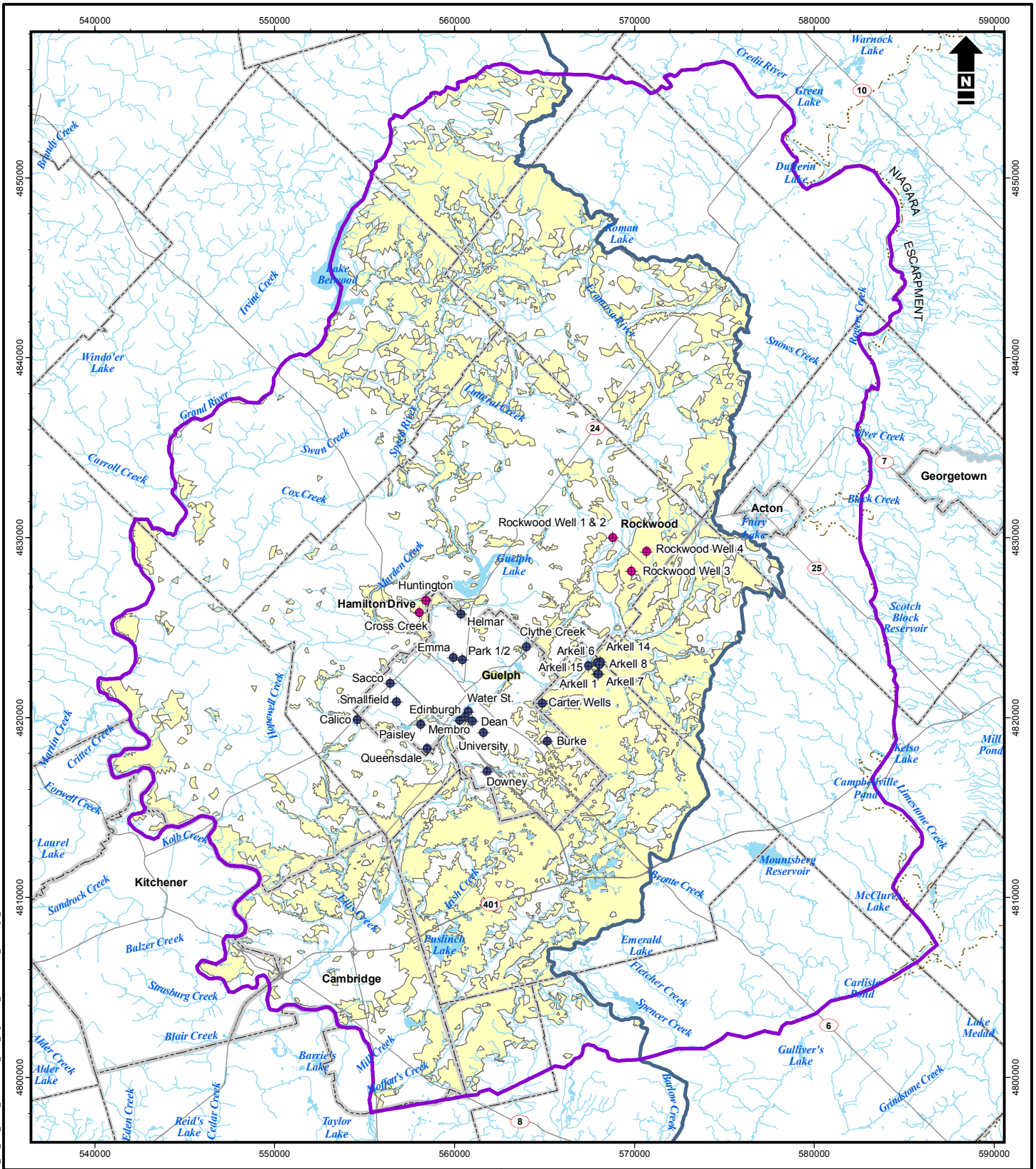
City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Tier Three Assessment Preliminary Significant Groundwater Recharge Areas

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 7-2



Tier Three Model Boundary (Study Area)
Grand River Watershed Boundary
Significant Groundwater Recharge Area
Community
Water Body
Watercourse
Major Road
Niagara Escarpment
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment

Tier Three Assessment Final Significant Groundwater Recharge Areas

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072-527	P. Chin	D. VanVliet	M. Urtheil

Figure 7-3

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8 CONCLUSIONS AND RECOMMENDATIONS

The Province of Ontario introduced the *Clean Water Act* (Bill 43; Government of Ontario 2017) to ensure that all residents have access to safe drinking water. Under the *Clean Water Act*, Source Protection Authorities are required to conduct technical studies to identify existing and potential Water Quality and Quantity Threats to municipal drinking water. Through the development of community-based Source Water Protection Plans, actions will be implemented to reduce or eliminate any *Significant* Drinking Water Threats.

This report describes the Tier Three Assessment completed for the municipal drinking water systems of the City of Guelph, and the Township of Guelph/Eramosa within the province of Ontario, Canada. A Tier Three Assessment is completed to estimate the likelihood a municipality's drinking water wells or surface water intakes will be able to supply their Allocated rates without negatively impacting other water uses.

The municipal wells for the City of Guelph, and Township of Guelph/Eramosa (in Rockwood and Hamilton Drive) are located in the Upper Speed Assessment Area, which was classified as having *Moderate* subwatershed stress levels for groundwater sources in the Tier Two Stress Assessment (AquaResource 2009b) completed by the Lake Erie Source Protection Authority for the Grand River Watershed. This circumstance required these communities to undergo a Tier Three Assessment for their municipal wells. There are no documented issues with respect to the municipal well sources meeting their past or current municipal demands.

The following steps were completed for the Tier Three Assessment following the Technical Rules (MOECC 2016), Technical Bulletin (MOE and MNR 2010), and the Technical Guidance Memorandum (MOE 2013).

1. Develop the conceptual and numerical Tier Three Assessment models. For groundwater, a new 3D conceptual model was developed based on historical information and new boreholes and monitoring wells completed throughout the Study Area (Appendices A and C). A new 3D groundwater flow model was developed based on this conceptual model and calibrated against data available throughout the Study Area (Appendices B, D, and E). The Tier Three Assessment models also included the refinement of the existing GAWSER surface water hydrology model of the Grand River Watershed (Appendix B).

2. Characterize municipal wells and intakes. This Tier Three Assessment required a detailed characterization of the groundwater wells of the City of Guelph and the Township of Guelph/Eramosa (in Rockwood and Hamilton Drive) as well as a surface water intake located on the Eramosa River. The groundwater flow model also includes wells providing drinking water to the Region of Waterloo and other communities.

3. Estimate the Allocated rates. Allocated rates for the City of Guelph's water supply wells were based on estimated capacities and are sufficient to meet the estimated average day demand for 2031. Allocated rates for the municipal wells of the Township of Guelph/Eramosa (in Rockwood and Hamilton Drive) were based on forecasted demands for 2026 and 2020, respectively.

4. Identify and characterize Drinking Water Quantity Threats. Drinking Water Quantity Threats within the Local Area include all consumptive groundwater uses as well as reductions to groundwater recharge. Consumptive groundwater takings include permitted municipal and non-municipal wells.

5. Characterize future land use. Areas of potential future recharge reductions were mapped by comparing existing land use with Official Plans for the City of Guelph, the Township of Guelph/Eramosa, and neighbouring municipalities.

6. Characterize other water uses. Other water uses mapped within the Study Area include cold-water streams and PSWs.

7. Delineate Vulnerable Areas. The Groundwater Quantity Vulnerable Areas (WHPA-Q1 and WHPA-Q2) were delineated using the Tier Three Groundwater Flow Model. The Surface Water Quantity Vulnerable Area (IPZ-Q) is the drainage area contributing to the Eramosa River at the City of Guelph's Eramosa Intake, as well as areas of recharge contributing groundwater discharge to that drainage area.

8. Evaluate risk scenarios. The calibrated groundwater flow model was used to evaluate a series of scenarios taking into account the Allocated rates for each well and intake, average (steady-state) and drought (transient) conditions, and future land use. The scenarios were evaluated in terms of the ability to pump water at each well as well as the impact of increased pumping on groundwater discharge to cold-water streams and PSWs.

9. Assign Risk Levels. Based on the results of the risk scenarios, a *Significant* Risk Level was assigned to Groundwater Vulnerable Area A due to the inability of the Queensdale Well to pump at its Allocated rate under average climate and drought conditions. This risk ranking was also applied to the Surface Water Vulnerable Area as it is linked to the Groundwater Vulnerable Area A through the Glen Collector and the artificial recharge system fed by the Eramosa Intake. Additionally, there was a *High* uncertainty of the ability of Arkell Well 1 to pump at its Allocated rate. A *High* uncertainty was also assigned to the impacts on groundwater discharge to cold-water streams and the impacts to PSWs. Groundwater Vulnerable Areas B, C, and D were assigned a *Low* Risk Level.

10. Identify and characterize Drinking Water Quantity Threats and areas where they are *Significant* and *Moderate*. Drinking Water Quantity Threats within Groundwater Vulnerable Area A and the

associated Surface Water Vulnerable Area include all consumptive demands or recharge reductions and were classified as *Significant.*

8.1 Conclusions

The following conclusions are provided based on the results of the Tier Three Assessment provided in this report.

8.1.1 Vulnerable Areas

The Local Areas in this Tier Three Assessment are represented by the Vulnerable Areas for Groundwater (Figure 5-3), which are derived from the WHPA-Q1/WHPA-Q2, and the Surface Water Vulnerable Area, which is derived from the IPZ-Q (Figure 5-4). These Vulnerable Areas represent the areas where the simulated groundwater drawdown in response to pumping of Allocated rates is 2 m or more (WHPA-Q1), the area where a reduction in recharge would have a measureable impact on this drawdown (WHPA-Q2), as well as the drainage area and associated recharge area that contribute to the Eramosa Intake (IPZ-Q). Groundwater Vulnerable Area A has a diameter of approximately 20 km around the City of Guelph and the Township of Guelph/Eramosa wells in Hamilton Drive and extends southwest toward the City of Cambridge. Another groundwater flow model was developed for the City of Cambridge wells as part of a concurrent Tier Three Assessment for the Region of Waterloo (Matrix and SSPA 2014). Groundwater Vulnerable Area A extends 2 km past the groundwater divide between the City of Guelph and the City of Cambridge Vulnerable Areas as illustrated on Figure 5-3.

8.1.2 Ability to Pump Allocated Rates

The Tier Three Assessment concludes that almost all of the municipal wells of the City of Guelph, and the Township of Guelph/Eramosa in Rockwood and Hamilton Drive will be able to pump current and Allocated pumping rates under average and drought conditions. These results are supported by historical operating experience in the City of Guelph where many of the wells have pumped their Allocated rates over prolonged periods of time. The primary municipal water supply aquifer is protected in most areas by the Vinemount Member aquitard, which reduces the vulnerability of the supply to drought.

The Queensdale Well is the only well that will not be able to pump its Allocated rates during average and drought conditions. Although they are expected to meet their Allocated rates, water levels at Arkell Well 1, Arkell Well 8, Arkell Well 14, Arkell Well 15, Burke Well, Carter Well, Emma Well, and Rockwood Well 3 may be more susceptible to drought conditions as maximum predicted drawdown comes to within 1 m of the safe available additional drawdown amounts.

Even with the recent permitting of all Arkell Spring Ground wells, the City of Guelph's water supplies do not have the capacity to meet the 2031 estimated water demand due to the predicted impacts at Queensdale Well. Furthermore, the City of Guelph will require all wells to be pumped at their Allocated

rates, leaving little redundancy in the system. Redundancy is required to allow for rehabilitation and maintenance of one or more wells, loss of one or more wells due to contamination, or long-term interference from other water users.

8.1.3 Impacts of Recharge Reductions

Recharge reductions, in response to future land developments defined in the Official Plans, have a minimal impact on water levels at the Tier Three municipal pumping wells where water levels decline between 0.1 and 0.3 m. The Gasport Formation aquifer is protected in most areas by the Vinemount Member aquitard, which reduces the impact of reduced groundwater recharge occurring at locations near the production wells on water levels in the aquifer. With respect to the City of Guelph and Rockwood, future land developments generally occur around the periphery of these communities with a minimal increase in imperviousness over the Local Area.

8.1.4 Impacts to Cold-water Streams and Wetlands

The Tier Three Assessment scenarios predicted impacts of increased pumping on groundwater discharge to cold-water streams. This impact was predicted to be *Moderate* for the South Branch of Blue Springs Creek, Upper Chilligo/Ellis Creek and Hanlon Creek.

The uncertainty with respect to the impact of groundwater discharge on cold-water streams is *High*. For the South Branch of Blue Springs Creek, the groundwater flow model does not reflect some of the local hydrologic and hydrogeologic processes near the Creek and the surrounding wetlands. The model also appears to over-estimate the effects of pumping on groundwater levels, as compared to those observed as part of a long-term pumping test (Stantec 2012, 2013, 2015). Finally, there is evidence to suggest that the South Branch of Blue Springs Creek does not provide cold-water habitat; contrary to the province's cold-water stream classification mapping.

With respect to PSWs, the groundwater flow model has not been developed to represent shallow hydrogeology in great detail, and as a result, it may be over-estimating drawdown in shallow groundwater. In addition, the evaluation of actual impacts to wetlands must take into account surface water hydrology and groundwater and surface water interactions at a scale not accounted for in the Tier Three Assessment model.

The Tier Three Assessment scenarios identify a sufficient level of risk that there may be impacts, and additional work should be carried out to reduce the level of uncertainty by refined characterization and modelling around those potentially impacted features.

8.1.5 Risk Level of Vulnerable Areas

There is a potential that pumping may decrease groundwater discharge to wetlands and cold-water streams. The steady-state model results show decreases in groundwater discharge to the South Branch

of Blue Springs Creek, Chilligo/Ellis Creek, and Hanlon Creek that are 10% or more, and there are predicted reductions of shallow groundwater levels greater than 1 m around PSWs in the northwest, northeast, and southeast areas of the City of Guelph. As a result, the Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area would be assigned a *Moderate* Risk Level based solely on impacts to groundwater discharge and PSWs. There is a *High* level of uncertainty with respect to the predicted impacts to cold-water streams and wetlands. However, as the impacts to cold-water streams and PSWs cannot result in a Risk Level of *Significant* when considering only Allocated quantities of water, as described by the Technical Guidance Memorandum (MOE 2013), an uncertainty level of *High* for these other water uses cannot increase the Risk Level past *Moderate*.

While the Risk Assessment scenarios illustrate that most of the Tier Three municipal wells can meet Allocated rates under average and drought conditions, except for the Queensdale Well, there is a *High* level of uncertainty that Arkell Well 1 will be able to. Therefore, even if a *Significant* Risk Level was not assigned to Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area based on predicted drawdown at the Queensdale Well, a *Significant* Risk Level would still apply to these Vulnerable Areas based on a *High* uncertainty at Arkell Well 1. Groundwater Vulnerable Areas B, C, and D were assigned a *Low* Risk Level.

8.2 Recommendations

This report suggests the following key recommendations to reduce the uncertainties of this Tier Three Assessment.

8.2.1 Blue Springs Creek

The City of Guelph has now finished a long-term pumping test for Arkell wells 14 and 15 (Stantec 2012, 2013, 2015). A large amount of hydrogeologic and hydrologic data was collected during this pumping test. Preliminary results show that the Tier Three Assessment model replicates the observed trends quite well; however, the model appears to over-estimate drawdown. Therefore, the steady-state model's predicted impacts to the Blue Springs Creek South Branch may also be over-estimated. An update to the conceptual model in this area will focus on matching hydraulic conductivities, storage parameters, and groundwater-surface water interactions particularly in the Arkell-Corwhin PSW Complex. An integrated groundwater/surface water model (e.g., MIKE SHE) could be introduced to better represent wetland hydrology and groundwater/surface water interactions in that area.

8.2.2 Northwest, Northeast, and Southeast Quadrants

The scenarios identify potential impacts to PSWs in the northwest, northeast, and southeast quadrants of the City of Guelph. The conceptual model incorporated into the Tier Three Assessment model focused on bedrock hydrology and simplified the overburden characterization. This simplification may have resulted in an over-prediction of shallow groundwater impacts from pumping, and as a result, impacts to water levels beneath wetlands may have been over-predicted. Recommended work includes the refinement of the shallow conceptual model beneath those areas with water table drawdown and near PSWs. The University of Guelph has been studying the fractured rock hydrogeology in the area and this new data can be incorporated into an updated conceptual and numerical model.

8.2.3 Risk Management Measures Evaluation Process

As a *Significant* Risk Level was assigned to Groundwater Vulnerable Area A and the associated Surface Water Vulnerable Area, and as all consumptive water uses and areas of groundwater recharge reductions with these Vulnerable Areas are classified as *Significant* Drinking Water Threats, a Risk Management Measures Evaluation Process (RMMEP) is required.

The first step in the RMMEP is a Threats Ranking exercise that evaluates the impact of individual or groups of consumptive water uses, and land use development activities on municipal water supplies. The Threats Ranking will help direct the Source Protection Committee toward possible Risk Management Measures that may be implemented to reduce or eliminate *Significant* Drinking Water Quantity Threats.

Following the Threats Ranking portion, the RMMEP involves the selection and evaluation of Risk Management Measures, using the water budget models developed in the Tier Three Assessment, to determine measures that could be used to reduce the Water Quantity Risk Level within the Local Area(s). The objective of the RMMEP is to help prepare a Threats Management Strategy that provides guidance to the Source Protection Committee to ensure the long-term sustainability of the water resource that supply the municipal drinking water systems.

9 ACKNOWLEDGEMENTS

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

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Paul Martin	Consultant Team - Matrix Solutions Inc.
Sam Bellamy	Consultant Team - Matrix Solutions Inc.

Team Member	Affiliation
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Patricia Meyer	Consultant Team - Matrix Solutions Inc.
John Piersol	Consultant Team - Golder Associates Ltd.
Kevin Mackenzie	Consultant Team - Golder Associates Ltd.
Scott Donald	Consultant Team - Golder Associates Ltd.
Dave Belanger	Project Manager - City of Guelph
James Etienne	Lake Erie Source Protection Region
Martin Keller	Lake Erie Source Protection Region
Kathryn Baker	Ontario Ministry of the Environment and Climate Change
Mike Garraway	Ontario Ministry of Natural Resources
Scott Bates	Ontario Ministry of Natural Resources
Dr. Beth Parker	University of Guelph
Frank Brunton	Ontario Geological Survey
Tony Lotimer	Provincial Peer Review - ARL Groundwater Resources Ltd.
Dr. David Rudolph	Provincial Peer Review - University of Waterloo
Dr. Hugh Whiteley	Provincial Peer Review - University of Guelph

Municipalities local to the Study Area provided technical review for consideration by the project team and the Provincial Peer Review team, and consisted of the following:

Reviewer	Affiliation
Kyle Davis	Risk Management Official - Wellington Source Water Protection
Jim Baxter	R.J. Burnside and Associates Ltd. on behalf of the Township of Guelph/Eramosa
Dwight Smikle	R.J. Burnside and Associates Ltd. on behalf of the Township of Guelph/Eramosa
Stan Denhoed	Harden Environmental Ltd. on behalf of the Township of Puslinch
Ray Blackport	Blackport Hydrogeology on behalf of the Town of Erin
Eric Hodgins	Regional Municipality of Waterloo
Richard Wootton	Regional Municipality of Waterloo

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

10 REFERENCES

AECOM and AquaResource, Division of Matrix Solution Inc. (AECOM and AquaResource). 2014. *Halton Hills Tier Three Water Budget and Local Area Risk Assessment Final Risk Assessment Report*. Report prepared for the Regional Municipality of Halton. Guelph, Ontario. October 2014.

AMEC Environment & Infrastructure (AMEC). 2012. *Stormwater Management Master Plan, City of Guelph*. Report prepared for the City of Guelph. Burlington, Ontario. February 2012.

AquaResource Inc. (AquaResource). 2011a. *Water Budget & Water Quantity Risk Assessment Guide - Drinking Water Source Protection Program*. Report prepared for the Ontario Ministry of Natural Resources and the Ontario Ministry of the Environment. Breslau, Ontario. October 2011.

AquaResource Inc. (AquaResource). 2011b. *Orangeville, Mono and Amaranth Tier Three Water Budget and Local Area Risk Assessment.* Prepared for Credit Valley Conservation. Breslau, Ontario. May 2011.

AquaResource Inc. (AquaResource). 2010. *City of Guelph Source Protection Project, Final Groundwater and Surface Water Vulnerability Report*. Report prepared for the City of Guelph. Breslau, Ontario. March 2010.

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

AquaResource Inc. (AquaResource). 2009b. *Tier 2 Water Quantity Stress Assessment Report, Grand River Watershed*. Report prepared for the Grand River Conservation Authority. Breslau, Ontario. December 2009.

AquaResource Inc. (AquaResource). 2009c. *Integrated Water Budget Report – Tier 2, Credit Valley Source Protection Area*. Report prepared for Credit Valley Conservation Authority. Breslau, Ontario. April 2009. http://www.ctcswp.ca/files/CVC_Integrated_Water_Budget_Report.pdf

AquaResource Inc. (AquaResource). 2007. *Source Water Protection Project – Groundwater Study*. Report prepared for the City of Guelph. Breslau, Ontario. March 2007.

Banks Groundwater Engineering Limited (Banks). 2015. *Meadows of Aberfoyle – 2014 Annual Monitoring Report, Permit to Take Water No. 5626-7WLQ3W*. Report prepared for Wellington Vacant Land Condominium Corporation No. 147. Puslinch, Ontario. January 2015.

Barnett P.J. 1992. “Chapter 21: Quaternary Geology of Ontario.” In: *Geology of Ontario*. Ontario Geological Survey, Special Volume 4, Part 2. Thurston P.C. et al. (Eds.). Toronto, Ontario. Pages 1,011-1,090.

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

R.J. Burnside and Associates Limited (Burnside). 2015a. *Town of Rockwood – Township of Guelph/Eramosa New Rockwood Well 4 Category 3 PTTW Application Amalgamation with PTTWs 4473-8JALSX and 4571-7FRLLE.* Project No.: MSA143680.0000. Memorandum prepared for Ministry of the Environment and Climate Change. Guelph, Ontario. May 28, 2015.

R.J. Burnside and Associates Ltd. (Burnside). 2015b. *Comments on the Draft City of Guelph Tier 3 Water Quantity Report, Project No.: 300036495.0000*. Memorandum prepared for the County of Wellington. Guelph, Ontario. June 16 2015.

R.J. Burnside and Associates Limited (Burnside). 2013. *Technical Memorandum No. 1 Water/Wastewater Infrastructure Phasing, Project No.: MSA143810.0006*. Memorandum prepared for Township of Guelph/Eramosa. Guelph, Ontario. October 24, 2013.

Burnside Environmental, A Division of R. J. Burnside and Associates Limited (Burnside). 2002a. *Town of Rockwood Hydrogeology Study to Examine Groundwater Sources Potentially Under Direct Influence of Surface Water*. Report prepared for the Township of Guelph/Eramosa. Orangeville, Ontario. March 2002.

Burnside Environmental, A Division of R.J. Burnside and Associates Limited (Burnside). 2002b. *Rockwood Environmental Assessment Hydrogeologic Report, Construction and Testing of TW3/02, Proposed Rockwood Well 3, Township of Guelph/Eramosa*. Prepared for Township of Guelph/Eramosa. Orangeville, Ontario. August 2002.

R. J. Burnside and Associates Limited (Burnside). 2001. *Engineers Report for the Township of Guelph-Eramosa, Rockwood Water Supply System*. Report prepared for Township of Guelph/Eramosa. Orangeville, Ontario. January 2001.

CH2MHILL. 2009. *Guelph Wastewater Treatment Master Plan.* Report prepared for the City of Guelph. April 2009.

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

City of Guelph. 2014. *Annual & Summary Report for the Period of Jan. 1, 2013 – Dec. 31, 2013 for: Guelph Drinking Water System [Corporation of the City of Guelph] and Gazer Mooney Subdivision Distribution System [Township of Guelph/Eramosa]*. Water Services Planning, Building, Engineering and Environment. Revision Date February 24, 2014. http://guelph.ca/wp-content/uploads/Annual-Summary-Water-Services-Report-2013.pdf

Conestoga-Rovers and Associates (CRA). 2012. *Test Pumping Investigation for TW2-11*. Nestlé Waters Canada. Guelph, Ontario. December 2012.

Conestoga-Rovers and Associates (CRA). 2011. *2010 Annual Monitoring Report*. Prepared for Nestlé Waters Canada. Guelph, Ontario. January 2011.

Conestoga-Rovers and Associates (CRA). 2004. *Test Pumping Investigation, Supply Well TW3-80*. Nestlé Waters Canada. Aberfoyle, Ontario. December 2004.

Diersch H.-J.G. 2006. *FEFLOW 5.4 – Finite Element Subsurface Flow and Transport Simulation System, User's Manual*. WASY GmbH. Berlin, Germany.

Doherty J. 2013. *Addendum to the PEST Manual.* Watermark Numerical Computing. May 2013. www.pesthomepage.org/getfiles.php?file=addendum.pdf

EarthFX Incorporated (EarthFX). 2009. *Final Report, Simulation of Groundwater Flow in the Vicinity of the Cedarvale Wellfield, Georgetown, Ontario: Model Development and Calibration Report.* Report prepared for Regional Municipality of Halton.

Earth Tech Canada Inc., Lura Consulting, Lotowater Geoscience Consultants Inc., C.N. Watson and Associates Ltd. 2006. *City of Guelph Water Supply Master Plan*. Draft Final Report prepared for the City of Guelph. September 2006.

Gartner Lee Limited. (Gartner Lee). 2004. *Guelph-Eramosa Township Regional Groundwater Characterization and Wellhead Protection Study.* Report prepared for Township of Guelph-Eramosa and Ontario Ministry of the Environment. St. Catherines, Ontario. April 2004.

Gartner Lee Limited. (Gartner Lee). 2003. *Arkell Spring Grounds - Groundwater Supply Investigation*. Report prepared for City of Guelph. St. Catherines, Ontario. August 13, 2003.

Gartner Lee Limited, Jagger Hims Limited, and Braun Consulting Engineers Ltd. 1999. *The City of Guelph Water Supply System Study - Resource Evaluation Summary*. Report prepared for the City of Guelph. Guelph, Ontario. 1999.

Golder Associates Ltd. (Golder). 2010. *City of Guelph Southwest Quadrant Water Supply Class Environmental Assessment – Interim Draft Hydrogeologic Report.* Report prepared for the City of Guelph. August 2010.

Golder Associates Ltd. (Golder). 2009. *Final Report on IUS Groundwater Supply Optimization and Expansion Project: Task D3 – Hydrogeological Assessment of Potential New Well Sites In the Breslau Area*. Report prepared for the Region of Waterloo Water Services Division. Kitchener, Ontario. June 2009.

Golder Associates Ltd. (Golder). 2006a. *Guelph-Puslinch Groundwater Protection Study*. Report prepared for the Grand River Conservation Authority. Cambridge, Ontario. May 2006.

Golder Associates Ltd. (Golder). 2006b. *Wellington County Groundwater Protection Study*. Report prepared for the Grand River Conservation Authority. Guelph, Ontario. September 2006.

Government of Ontario. 2017. *Clean Water Act, 2006*. S.O. 2006, c. 22. Last amendment: 2017, c. 2., Sched. 11, s. 1. Consolidation Period from June 20, 2012, to March 22, 2017 e-laws currency date. https://www.ontario.ca/laws/statute/06c22

Government of Ontario. 2015. *Clean Water Act, 2006, General Regulation*. S.O. 2006, c. 22. Last amendment: O. Reg. 287/07. Consolidation Period from October 31, 2011 to January 1, 2015. e-laws currency date. https://www.ontario.ca/laws/regulation/070287

Grand River Conservation Authority (GRCA). 2013. *Thermal Classification of Municipal Drains*.

Greenhouse J.P. and P.F. Karrow. 1994. "Geological and geophysical studies of buried valleys and their fills near Elora and Rockwood, Ontario." *Canadian Journal of Earth Sciences 31 (12)*:1838-1848.

Harden Environmental Services Ltd. (Harden). 2015. *City of Guelph and Communities of Rockwood and Hamilton Drive Tier 3.* Memorandum prepared for the County of Wellington. Moffat, Ontario. June 12, 2015.

Harden Environmental Services Ltd. (Harden). 2012. *Level I and II Hydrogeological Investigation, Hidden Quarry, Rockwood, Ontario*. Report prepared for James Dick Construction Ltd. Moffat, Ontario. September 2012.

Jagger Hims Limited. 1998a. *Aquifer Performance Evaluation, Volume 1, Northwest Quadrant*. Report prepared for the City of Guelph. St. Catherines, Ontario. November 1998.

Jagger Hims Limited. 1998b. Volume 1, *Aquifer Performance Evaluation, Southwest Quadrant, City of Guelph*. Report prepared for the Corporation of the City of Guelph. St. Catherines, Ontario. November 1998.

Jagger Hims Limited. 1998c. *Aquifer Performance Evaluation, Volume 1, Southeast Quadrant*. Report prepared for the City of Guelph. St. Catherines, Ontario. November 1998.

Jagger Hims Limited. 1995. *Ground Water Resources Study, City of Guelph, Northeast Quadrant, Volume 1*. Report prepared for the City of Guelph. St. Catherines, Ontario. January 1995.

Karrow P. F. 1987. *Quaternary Geology of the Hamilton-Cambridge Area, Southern Ontario*. Ontario Geological Survey Report 255.

Karrow P.F. 1968. *Pleistocene Geology of the Guelph Area, Southern Ontario*. Geological Report 61. Ontario Department of Mines, Toronto.

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

Matrix Solutions Inc. (Matrix) and S.S. Papadopulos and Associates Inc. (SSPA). 2014. *Region of Waterloo Tier Three Water Budget and Local Area Risk Assessment.* Report prepared for the Region of Waterloo. Waterloo, Ontario. September 2014.

McKenzie, D. I. (Ed.). 1990. *Quaternary Environs of Lakes Erie and Ontario*. A field guide prepared for the First Joint Meeting of the Canadian Quaternary Association and the American Quaternary Association. University of Waterloo. June 1990.

Ontario Geological Survey (OGS). 2003. *Surficial Geology of Southern Ontario.* Ontario Geological Survey. Miscellaneous Release Data 128 – Revised.

Ontario Ministry of the Environment. (MOE). 2013. *Memorandum: Assignment of Water Quantity Risk based on the Evaluation of Impacts to Other Water Users*. Memorandum prepared for Source Protection Regions. Toronto, Ontario. December 2, 2013.

Ontario Ministry of the Environment. (MOE). 2012. *Water Well Information System.* Contains information licensed under the Open Government License – Ontario.

Ontario Ministry of the Environment. (MOE). 2008. *Permit to Take Water Database*. Contains information licensed under the Open Government License – Ontario. Accessed in March 2008. https://www.ontario.ca/data/permit-take-water

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

Ontario Ministry of the Environment and Climate Change. (MOECC). 2016. *Technical Rules: Assessment Report, Clean Water Act, 2006*. November 20, 2008. Amended on December 12, 2008 (administrative amendments), November 16, 2009 (EBR Posting Number EBRO10-7573), and December 2, 2013 (Technical Bulletin). Updated on May 19, 2016. https://www.ontario.ca/page/technical-rules-assessment-report

Ontario Ministry of Natural Resources (MNR). 2013. *Provincial stream thermal classification mapping*.

Planning and Engineering Initiatives Ltd. (PEIL), Dougan & Associates, C. Portt & Associates, and P. Chrisholm. 2004. *Hanlon Creek, State of the Watershed Study*. Final Report. Report prepared for the City of Guelph. Guelph, Ontario. September 2004.

Resource Management Strategies Inc. (RMSi). 2009. *Water Conservation and Efficiency Strategy Update* (WC&ES). Final Report. Report prepared for the City of Guelph. Guelph, Ontario. May 2009.

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

SNC-Lavalin Engineers and Constructors Inc. (SNC-Lavalin). 2005. *Hydrogeological Assessment and Pumping Test, Highway 401 and County Road 46, Puslinch, Ontario*. Report prepared for Royal Canin Canada. July 2005.

Stantec Consulting Ltd (Stantec). 2015. *2013-2014 Monitoring Report, Arkell Adaptive Management Plan, City of Guelph*. Report prepared for City of Guelph. Kitchener, Ontario. May 2015.

Stantec Consulting Ltd (Stantec). 2013. *2012 Annual Monitoring Report, Arkell Adaptive Management Plan, City of Guelph*. Report prepared for City of Guelph. Kitchener, Ontario. May 2013.

Stantec Consulting Ltd (Stantec). 2012. *2011 Annual Monitoring Report, Arkell Adaptive Management Plan, City of Guelph*. Report prepared for City of Guelph. Kitchener, Ontario. May 2012.

Totten Sims Hubicki. (TSH). 1997. *Torrance Creek Subwatershed Study – Phase I Characterization Report – Final*. Report prepared for Grand River Conservation Authority. Waterloo, Ontario. October 1997.